Agricultural Risk Management in Africa

A CONTEXTUALIZED MANUAL FOR TERTIARY INSTITUTIONS AND DEVELOPMENT PRACTITIONERS

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Preface

Since 2012, the African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE) has been supporting initiatives to unravel the complex issues surrounding risk management in agriculture and natural resources management. At various workshops and other forums, stakeholders of ANAFE (educators, farmers, students and agribusiness entrepreneurs) have expressed the need to develop adequate capacity on risk management. A recent survey on risk management education revealed that there is very little teaching of agricultural risk management. Worse, it was established that current educators do not have skills in this area and that relevant learning resources were not available. ANAFE was tasked to resolve this situation by providing guidance on curricula, capacity building for educators and the development of learning resources.

As a way of strengthening the capacity of lecturers in developing learning materials, ANAFE through its programme of Strengthening Africa's Strategic Agricultural Capacity for Impact on Development (SASACID) has trained and supported about 40 lecturers to collaboratively develop learning materials in Agricultural Risks Management.

This book is a compilation of chapters on risks management collaboratively developed by African experts on this subject, including lecturers, scientists and development/private sector people from 22 training, research and development institutions and from 12 countries (Cote d'Ivoire, Mali, Niger, Nigeria, Cameroon, Ghana, Botswana, Zambia, Zimbabwe, Mauritius, Kenya and Ethiopia). The authors, met in Abidjan for training on collaborative writing during which they agreed on the main areas of focus, sections, teams and the structure of the chapters. A follow-up write shop held in Nairobi allowed the authors, together with some who were nominated, to jointly develop the chapters. The main introduction to the book that was initiated in Abidjan, during the first workshop under the leadership of some of the authors, was also collaboratively developed and finalized with the input of all the authors.

This book is a pioneer initiative in Africa and which, I am sure, will help lecturers in refining their own learning and teaching resources. It might not address all the issues in agricultural risks management, but it constitutes a valuable reference teaching and learning resource.

Aissetou Dramé-Yayé,

Executive Secretary of ANAFE

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General Introduction

J.A.F. Obiri, B.M.F. Driver and A.D. Yaye

Aim of the Book

The challenges facing the risk management in agriculture are multiple, especially in Africa, where agricultural production systems are increasingly sensitive to risks that are both 'old' (e.g. agro-climatic factors, political environment, economy and demographic changes) and 'new' (e.g. complex biological processes, supply chains, price volatility, emerging pests and diseases, risks of zoonoses, food safety hazards, climate change, environmental footprint of agricultural outputs) (Arce, 2010).

Given the risks that face agriculture, and to strengthen the resilience of smallholder livelihoods in particular, it is critical for all African countries to consolidate the basic science capacity to deliver science-based solutions to current problems facing agriculture. This book provides the agricultural stakeholders (students in agricultural disciplines, agricultural practitioners, policy makers etc.) with contextualised information on risks facing agriculture. It aims at stimulating critical and innovative thinking in future agricultural stakeholders on questions such as:

- What is the existing knowledge on agricultural risk (including indigenous knowledge) in African countries?
- What is the relevance of the information?
- What are the knowledge gaps?
- What are the foresight, initiatives and cutting edge technologies on agricultural risks that need urgent attention in Africa?
- What are the research avenues required, to inform evidence-based policy options and policy formation, on agricultural risks?
- How can the resilience of smallholder farmers in Africa be improved under the current risks facing agriculture?

These issues, among others, confront all stakeholders involved in agriculture in Africa: governments and policy makers, universities and students in agriculture, private and public sectors. Risks facing agriculture need to be better understood and managed. This book is dedicated to disseminating the knowledge of "Agricultural Risk Management" in Africa, with the objective of increasing the capacity to manage risks by providing strategies that are evidence-based, client- driven and country specific.

Significance of this Book

Unlike other text books on agricultural risk management, this book is unique and innovative in its approach as it has contexualised African case studies that have been put together by a wide team of African authors who are active agricultural scholars, practitioners and researchers. Furthermore, the book's uniqueness lies in its multidisciplinary approach to addressing complex issue of agricultural risks. Increasingly, the nature of science itself is changing such that science has to address issues of complexity and uncertainty in current environments. In such situations, multidisplinary teams and authors from different perspectives, fields and countries contribute more effectively to relevant and useful knowledge. The book also recognises and celebrates indigenous knowledge, which contributes significantly to the added-value of the book. Moreover, if Africa wishes to strengthen agribusiness and thus promote agricultural entrepreneurship, it is mandatory that future graduates are able to identify emerging issues facing agricultural risk management, develop strategic mitigation plans and ensure their implementation.

The book has relevant learning outcomes for students, lecturers and other stakeholders in agriculture in that it provides contemporary knowledge on agricultural risks and expounds risk and disaster related concepts. It is hoped the the book will change attitudes of agricultural practitioners such that they will think upfront of risks and disasters and include them in their development plans rather than react to their impacts.

Agriculture and its Importance in Africa

Human civilisation and development have been closely linked with agriculture (Foster and Polinger, 2009 ; Overton, 1998 ; Postgate, 1992). Over the past millennium, agricultural innovations have developed and have directly impacted human life (Frison, 2008 ; Jain, 2010 ; Kagan, 2004). Today agriculture plays a key role in the economy of most countries of the world as it provides large scale employment, high GDP and stimulates trade in other sectors such as agro-based and tourism industries (Diao *et al.*, 2007).

In Africa, agriculture plays an even greater role in the economy as it contributes 75% of the continent's domestic trade and generates 65% of the employment (Yumkella, 2013). The agricultural growth rates in Africa have moderately increased from an average of 2.4% in the 1980s to 3.3% in the 1990s (Fan, 2009). Compared to values elsewhere, these rates are low (FAO, 2014a) and would have been better if not for the continuous vagaries of agricultural risks and its related disasters. Despite the importance of agriculture, most countries in Africa have invested less than 7% of their national budgets in agricultural development as compared to Asia and the developed countries who invest more than 14% of the national budget into agriculture. Only few countries in Africa e.g. Burkina Fuso, Mali, Ethiopia and Malawi have allocated the required 10% threshold of their annual budget allocation to agriculture (Fan, 2009). This is a far cry from what is expected if Africa has to diversify its agricultural potential including combating agricultural risks.

The objective is to create new opportunities for farmers, agribusiness and rural livelihoods to generate revenues in innovative ways by providing safe, sufficient and nutritious food supply whilst conserving the natural biodiversity and genetic resources.

Agricultural Risk Management in Africa - What do We Know?

The subject of agricultural risk is very pertinent and touches on food security, social livelihoods, environmental safety and political temperatures in many countries. Agricultural risk can be seen in three main contexts. It has direct impact on food security, income levels of farmers and market stability. In Africa, unlike most of developed world, the more relevant issue is meeting food security. In addressing the issue of food security, many African farmers and agricultural practitioners face daily challenges and risks. These include changing climatic conditions, crop and livestock diseases, poor agricultural inputs (seeds, pesticides, etc.) and unpredictable market prices. Unlike their counterparts in developed countries, African famers do not have access to advanced farming technologies and prudent instruments like agricultural insurances or government subsidies, to shield themselves from risks. Although there is realisation and new initiatives to address this problem by organisations like IFAD (International Fund for Agricultural Development) and NEPAD (New Partnership for Africa's Development) as well as networks like the Forum for Agricultural Risk Management (FARMD, 2009). These initiatives are still on very minimal scale. As such, agricultural risks are many and their handling is as important as managing communicative health risks such as HIV or ensuring sustainable livelihoods in communities. This book explores agricultural risks and their management issues, sensitises current cutting edge approaches that reduce risks to agricultural practitioners and farmers. It further outlays strategies that assist policy makers in policy formulation and ultimately boosting agricultural investment.

Understanding the Nexus Between Disaster Risk Managment and Agriculture and Its Implications for Innovative Policies and Training

For time immemorial, farmers and agricultural practitioners have always undertaken their agricultural tasks without deep understanding or consideration of the inherent agricultural risks. Agriculture is largely practised with the view that nothing will go wrong with the weather, land, soil or even the markets. Agriculture is an industry that is confronted by risks in the form of climatic variations, emerging pests, diseases and disease vectors, unpredictable price volatility, as well as natural disasters such as cyclones and droughts. An effective risk management strategy is critical for the development of risk management tools for disaster management and disaster risk reduction. For instance, farmers in Budalangi in Western Kenya have continously tilled on flood plains despite the clear dangers of floods (API, 2012). In Ethiopia, pastoralists keep large stock of animals regardless of looming droughts (Glantz, 1988 ; MacMillan, 2011). In Ghana, cocoa is planted with little preparation for future pests attack during the crop's growth or even after harvest (Adomako, 2007; Opoku *et al.,* 2000). All these actions result in agricultural losses (see Box 1) and reduced social livelihoods. In other instances, farmers' actions have resulted in pollution and food security risks (FAO, 2014b). Although these risks and their ensuing disasters are well known, most measures taken to counter them are often done after the risks have been realised or disasters have occurred. Response measures such as evacuation of farming communities from flood plains, providing shelter and relief, and providing agricultural inputs for oncoming seasons are done well after the disasters. In effect, this is a reactive rather than a proactive measure.

What then should we do to reverse these trends? There has to be a shift in the mindsets of agricultural stakeholders and policy makers with regards to how agricultural risks and disasters are perceived. These risks and disasters need to be well thought out before they occur and planning measures put in place well in advance. Proactive and mitigatory measures need to be the normal practice, rather than reactional and emergency measures, as is often the case in most countries.

Changing mindsets cannot occur overnight. There is need for a clear understanding that African agriculture, food security and sustainable livelihoods are closely related to agricultural risks. Indeed, there is a nexus between food security / nutrition, agricultural risks and disasters that has to be embraced by all the people starting from the village farmers to the policy makers. Disasters arising from drought, fire, floods, social conflicts, chemicals and technological risks all have direct exponential impacts on agriculture, food security and social livelihoods. All the people, from villagers to the top bureaucrats, have to realise that the best defence against food insecurity and poor livelihoods is to address agricultural risks. This can be done by ensuring that management of all hazards, risks and their related disasters are included into the development planning, particularly in budgetary accounting. Whether it is budgetary accounting at the village or national levels, funds have to be set aside to address all preventive and mitigatory measures for current and future agricultural risks. By doing so, we will not only enhance resilience towards agricultural risks and reduce livelihood losses but also reverse the yield output to new increased levels.

Box 1. Risks of black pod disease in cocoa — the case of Ghana

Ghana is one of the largest suppliers of cocoa to the world market. Cocoa can be said to be the backbone of the Ghanaian economy, not only in terms of revenue accruing from it, but also the employment avenues it provides and incomes gained by agricultural practitioners. However in recent years, the outbreak of *Phytophthora megakarya,* a serious virulent fungi species that causes black pod disease in all cocoa growing regions in Ghana, resulted in stagnation and dwindling of yield. Yield loss may range from 60 to 100% (Adomako, 2007; Dakwa, 1987; Nyadanu, 2011; Opoku *et al.,* 2007). Cocoa pods infected with black pod disease give low quality beans, which lose market value and fetch low income. A key objective of the government is to control risks associated with this disease.

Plate 1. Spoilt cocoa pods caused by the black pod disease in the eastern region of Ghana

Due to the heavy loses in cocoa harvest (Plate 1) associated with the disease, many farmers are ultimately forced to abandon their cocoa farms. Management of risks posed by black pod disease to the cocoa sector is a major challenge to the Ghana government.

This Ghanaian scenario is likely to be prevalent in other West African countries.

Relationship of Hazards, Risks and Disasters in Agriculture

Hazards, risks and disasters are closely related, especially within the context of agriculture. In the simplest terms, natural disasters are natural events that have catastrophic consequences for living things in the vicinity (Sivakumar, 2005). From an economic perspective, a natural disaster can be viewed as a natural event that causes a perturbation to the functioning of the economic system, with significant negative impact on assets, production factors, output, employment, or consumption (Hallegatte and Przyluski, 2010). The definitions of disaster, hazards and risk are outlined in Box 2.

Disasters and their precursors, which are risks, can be classified into two broad categories: natural and non-natural disasters. This can be further broken into other types of disasters and risks common to agricultural practices as outlined in Figure 1. Natural disasters are largely caused by events such as floods, drought, hurricanes (or hydrometerological disasters), earthquakes and landslides (sometimes referred to as geological disasters). There are serious risks that occurwhen agriculture is carried out in areas prone to these hazards.

Non-natural or anthropogenic disasters and their associated risks are largely caused by social conflicts or technological problems. There are various types of conflicts in societies that include weak policies, ineffective administration or poor resource sharing; which all cause risks for agricultural stakeholders. Among the common risks are those linked with policies and regulation for agricultural production. Regulatory risks often arise when the government adopts policies (e.g. trade agreements, environmental and food safety regulations) that go against the expectation of farmers, thus adversely affecting farmers' income. These policy and regulatory risks are covered in this book.

Box 2. Definitions — Hazard vs. Risk

1. What is a hazard?

This is defined as the inherent property of a system to cause harm or damage. For instance, a flood plain or low lying area susceptible to being covered by water, if a nearby river bank breaks, can be considered a hazard. Such an area is hazardous if human beings settle on it or nearby. It must be noted that a disaster will only be said to have occured if there is a vulnerable human population being affected by an extreme physical environment (Blaike et al 2005). Therefore, a hazard may be viewed as the triggering device for the disaster to occur, and only does so if there is a vulnerable human component involved.

Thus, a disaster then can be considered as a serious disruption of the normal functioning of society, causing widespread human, economic or environmental losses which exceed the capacity of the affected society to cope with given only its own resources" (Benson and Clay, 2004). The disruption can be caused by natural or non-natural hazards which are the cornerstones of risks.

Natural hazards and disasters include floods, drought, hurricanes (hydrometeorological), earthquakes, landslides etc. while non-natural or anthropogenic hazards and disasters include conflict/terrorisms, technology (e.g. greenhouse gases and climate change, pollution, pest infestation, diseases) (see Figure 1). There has to be a hazard before a disaster or harm occurs.

2. What is a risk?

Likewise a risk can only occur if there is a hazard.

A risk is the likelihood of harm or a disaster being realised and therefore a measure of probability of a hazard occurring.

Risk is directly proportional to a hazard and the vulnerability of that hazard to human beings. It is computed as Risk = hazard x vulnerability. For instance, a community inhabiting a mountain slope is exposed to the hazard of the mountain side sliding down towards the community. If the same community has not put structures in place to prevent the slide, (e.g. building contours, gabions, walls) or developed disaster preparedness plans (e.g. escape/exit routes, evacuation plans etc.), then that community is very vulnerable to the hazard. A combination of this vulnerability and the hazard itself renders the community to high risks.

Some of the key technological risks and disasters linked to agriculture arise from climate change, pollution as well as disease spread to crops and animals. Improper use of technology may lead to problems like greenhouse gas emissions (from various sources such as industrial carbon dioxide to methane from livestocks), environmental safety (e.g. poor waste disposal) to wrong usage of agricultural inputs (e.g. herbicides, pesticides, genetically modified organisms etc.). All these are hazards which when in close contact to human beings, and depending on their intensities, increases risks. For example, climate change and climate variability results in poor crop yields, post-harvest problems and thus disasters such as food insecurity and even food safety. In this book, technological risks and their ensuing disasters are extensively dealt with.

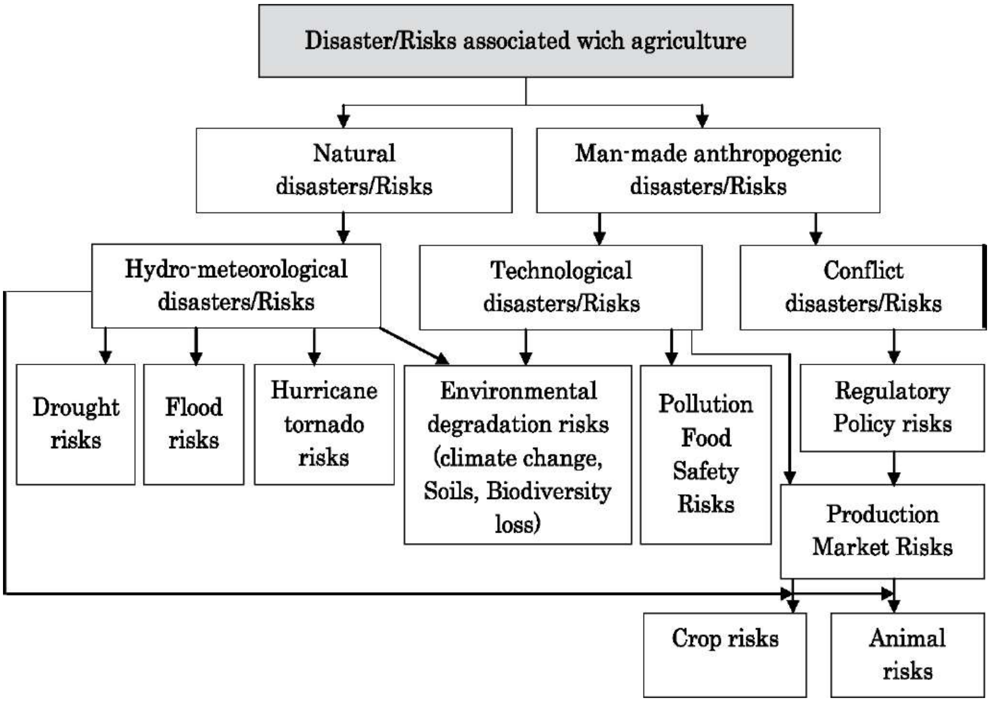

Figure 1. Classification of agricultural disasters and risks

How Does Agriculture Fit into the Disaster Cycle and What are the Enabling Strategies?

Like other issues linked to development, agricultural risks, disasters and their management follow a cyclical pattern that can be explained by the disaster cycle. Understanding this cycle assists in the planning against agricultural risks and disasters as it exhaustively covers the key areas of agricultural disaster risk reduction namely; agricultural disaster/risk prevention, agricultural disaster/ risk preparedness and agricultural disaster response and recovery (Figure 2).

Agricultural Disaster / Risk Prevention

Agricultural disaster / risk prevention involves mitigatory mechanisms that reduce risk and disaster effects mainly through the below measures:

- Data collection and mapping out the agricultural hazards: this involves identifying the hazards and determining their dimension in terms of frequency, duration, magnitude, spatial dispersion etc.;
- Vulnerability assessment: identification of who (population) and what (infrastructure) are vulnerable to the hazard and thus their risk levels;
- Providing information on hazards, vulnerabilities and risks through Early Warning Systems (EWS): the EWS alert stakeholders on all types of risks that may occur (e.g. climate change related factors (e.g. floods, droughts), looming diseases, market fluctuations etc.) and provide sufficient lead time for appropriate measures to be undertaken. These can all be communicated via mass media broadcasts;
- Risk assessments: determining the expected loss from a hazardous event;
- Developing public policies and plans that lessen risks: e.g. strengthening the advisory or extension networks to assist farmers;
- Increasing public education, vulnerability analysis, safety codes, zoning of different agricultural areas or undertaking phytosanitary measures to prevent cross border crop/animal disease spread.

Agricultural Disaster Preparedness

This largely entails planning how to respond to disaster by strengthening the farmers' capacity to provide timely and appropriate response. It may involve risk transfer initiatives like risk pooling by taking agricultural insurance or risk financing. Alternatively, it may involve diversifying the farmers' agricultural practices such as growing crops alongside keeping livestock, poultry or adding value to their products. Furthermore, preparedness may entail creation or strengthening the existing farmers' cooperative societies alongside training and enhancing risk awareness of farmers.

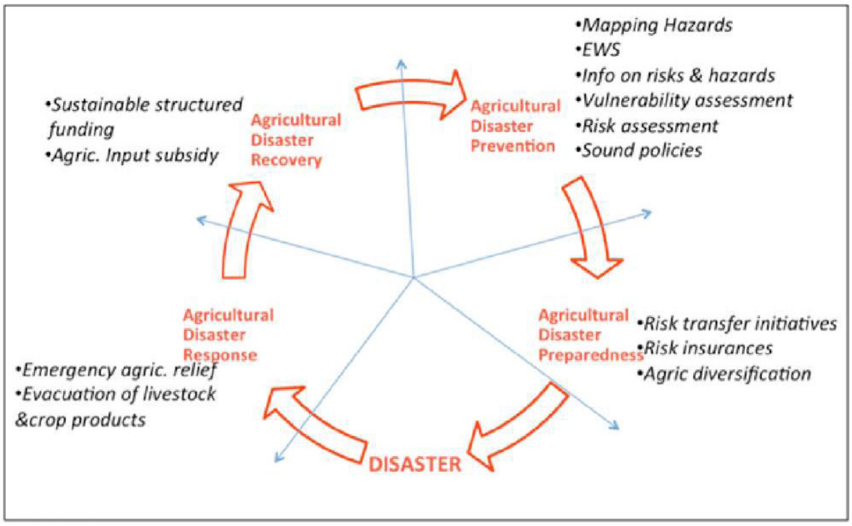

Figure 2. Agricultural risks and the disaster cycle

Agricultural Disaster Response

This part of the disaster cycle aims to minimise the harsh impacts of a disaster immediately after the disaster has occurred. Farmers everywhere get demoralized when their products are destroyed and they are left to face major economic losses. In such instances they can completely give up farming, which may be their only source of income and livelihood, and take up new ventures. Such ventures can be unfamiliar to them and this may even further exacerbate their risks and livelihoods. Consequently, there is need for the government to provide short-term and immediate emergency relief measures to cushion farmers' aggravated problems. Relief may involve measures such as immediate evacuation of surviving livestock in drought-stricken areas to better areas or facilitating farmers to quickly sale such livestock.

Agricultural Disaster Recovery / Reconstruction

This part of the disaster cycle opts to return the farmers to their initial conditions before the disaster occurred. Usually, after the short-term agricultural aid has been given (immediately after a disaster) and donors leave with their news media, farmers can be left 'stranded' in a transitional stage before they get back to normality. This stage can turn into a long-term phase as disaster impacts such as those of drought or flood on agriculture take time to dissipate. Agricultural recovery and reconstruction should involve well-structured plans on funding and other forms of subsidy like agricultural inputs given to farmers to start all over again.

Risk-Related Capacities in Agriculture in Africa

Some African countries, as documented in Box 3, have implemented strategies and devised policies to reduce risks associated with agricultural production so as to strengthen food security.

Box 3. Enabling strategies and policies to mitigate risks in agriculture — case of livestock production in the Republic of Mauritius

Livestock production in the Republic of Mauritius is threatened by existing and emerging animal diseases. Recent outbreaks of highly contagious diseases like the African Swine fever (ASF) and the global threat of avian influenza, have highlighted the risks of disease introduction in the country, and hence the need for intiating a Disease Management Plan for disease control and National Food Safety System (Ministry of Agro Industry and Food Security, 2014). The implementation of the plan is a multi-stakeholder venture, requiring the consolidated efforts of the Veterinary Services, the producer groups (smallholder and industrial producers), technical support and monitoring by the World Organisations for Animal Health (OIE). Furthermore, the adoption of good production and manufacturing practices is necessary for a sustainable development in order to become more resilient.

The vision for the development of the Clean Green and Ethical vision (CGE) and the concepts of Animal Production will contribute to sustainable development of the livestok sub-sector and increase its resilience. The objective of the CGE approach is to provide a competitive edge to agricultural produce by providing a framework in support of innovation, in terms of management practices to meet the expectations of the market, including the domestic and export markets. Sensitisation about and implementation of CGE is highly relevant, in the context of risk management, as it would act as a driving force for innovations in the livestock sector to improve the image, resilience and competitiveness of animal-based food products in the country.

Structure of the Book

This book is divided into five (5) sections that touch on all key issues of risks management in agriculture. Each of the section is made up of chapters that expound on various topical issues within the corresponding section.

The sections include the following:

I. Management of Risks in Natural Resources;

II. Agricultural Practices for Managing Risks;

I. Food and Environmental Safety in Agricultural Risk Management;

II. Management of Risks Associated with use of Agricultural inputs;

V. Managing Risks Associated with Climate Change for Increased Resilience.

This book is accompanied by a sister book that extensively deals with the topic of agribusiness in Africa. While issues related to agricultural risks are covered in this book, the book however excludes risks linked to agriculture markets and pricing as these are covered in the agribusiness book.

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Section 1

Management of Risk in Natural Resources

Section 1: Introduction

This section deals with management of risk in natural resources. The section contains three chapters as folowing: Chapter 1 - resources assessment with special emphasis to plants; chapter 2 - sustainable land management for agricultural risk management and chapter 3 - control and management of pests and diseases within agricultural nurseries.

One practical approach to assessing risk reduction is to predict future population size based on current population structure, growth and fecundity. Demographic studies are essential in simulating species dynamics over time. Since the nature, use and importance of wild resources are so closely related to local ecology, economy and socio-cultural conditions, most studies need to be specifically located. Large-scale field or case studies on exploited natural resources are scarce, yet are essential in understanding the demography of species and identifying the processes or the life stages that regulate or limit population dynamics.

Chapter 1 reviews sustainable management techniques that reduce risks on natural resources in Africa.

Chapter 2: this chapter links sustainable land management with agricultural risk management. It contextualizes these factors through African experiences by combining endogenous ways of risk aversion strategies with contemporary approaches. The chapter incorporates concepts, principles, implementation and evaluation of Sustainable Land Management.

Chapter 3: the chapter highlights the importance of nursery practices in agricultural production and identifies pests and diseases as constraints for producing healthy and good quality seedlings. Control and management strategies for pests and diseases in agricultural nurseries are discussed. Integrated Pest Management (IPM) is presented as a holistic approach for controlling and managing pests and diseases in nursery.

1

Sustainable Natural Resources Management Techniques for Risk Reduction

K. I. Kouassi and N. M. Guedje

Summary

The management of risks is one of the greatest challenges of the 21st century. The ever-growing population, economic and environmental losses due to natural or human-made disasters, provides the need for a systematic approach to the management of risks. It is generally accepted that a multi-disciplinary understanding of disaster risk management is required. This chapter focuses on sustainable natural resources management techniques for risk reduction. One practical approach to assess the risk reduction is to predict future population size based on current population structure, growth and fecundity. Therefore, demographic studies are essential to simulate species dynamics over time. Since the nature, use and importance of wild resources are so closely related to local ecological, economic and socio-cultural conditions, most studies need to be specifically located. Such large-scale field or case studies on exploited natural resources are scarce, but essential to understand the demography of species and therefore, to identify the processes or the life stages that are regulating or limiting the population dynamics. In addition, the chapter presents some African case studies of assessment of clonal and solitary forest plant species, learning objectives, suggested reading materials and some questions for study and discussion.

Resume

Techniques de Gestion des Ressources Naturelles pour la Reduction des Risques

La gestion des risques est l'un des plus grands defis du 2Pme siecle. La population sans cesse croissante, les faibles performances economiques couplees a la degradation de l'environnement, du fait des catastrophes naturelles et anthropiques, montrent la necessity dune approche systematique de la gestion de risques. Il est souvent admis qu'une approche pluridisciplinaire dans la comprehension des risques est necessaire. Ce chapitre met un accent particulier sur les techniques de gestion durable des ressources naturelles pour l'attenuation des risques. Une approche plus pratique pour revaluation de risque est de predire la taille de la population future sur la base de la structure, la croissance et la fecondite de la population actuelle. Ainsi, les etudes demographiques sont indispensables a la simulation de la dynamique devolution des especes dans le temps. Comme la nature, l'utilisation et l'importance des ressources naturelles sont intimement liees aux conditions locales ecologiques, economiques et socioculturelles, la plupart des etudes doivent etre specifiquement localisees. De telles etudes de cas, a grande echelle sur le terrain, sur les ressources naturelles sont rares, mais essentielles a la comprehension de la demographie des especes et done pour identifier le processus implique dans les etapes de la vie qui regulent ou limitent la dynamique de la population. En outre, le chapitre presente quelques etudes de cas en Afrique sur les especes de plantes forestieres clonees ou isolees, les objectifs d'apprentissage, la revue bibliographique proposee, ***et enfin des sujets*** *d'etudes et des points de discussion.*

Introduction

The design of appropriate strategies for multiple-use resources management has become an important subject of increasing international concern as a result of continuing depletion of these resources (Gaoue *et al.*, 2011; Guedje, 2014; Schmidt *et al.*, 2011; von Hagen and Fight, 1999). As tropical forests constitute a diverse ecosystem, providing a great variety of products and services, effective sustainable resource management requires development and implementation of appropriate conservation and management plans, as well as sustainable extraction practices to mitigate against negative impacts and promote positive impacts of harvesting on species or on the ecosystem structure and function (Ticktin, 2004). Among the diversity offorest resources and services, there has been a growing interest on the extraction of Non-Timber Forest Products (NTFPs). Unfortunately, many NTFPs, such as rattan (FAO, 2001), *Prunus africana* and *Warbugia salutaris* are overexploited (Ahmed *et al.*, 2013; Bodeker *et al.*, 2014; Cunningham, 2014; Guedje *et al.*, 2010; Romero *et al.*, 2014 ; Tshisikhawe *et al.*, 2012; Vogel *et al.*, 2012). This probably threatens the survival of some natural populations. It is thus primordial to study the demography of these populations to estimate the risk of local extinction and to develop sustainable exploitation practices.

The irrational exploitation of natural resource could change the demographic parameters of natural populations and, thus influence their dynamics (Caswell, 2001; Kouassi *et al.*, 2014 ; Stearns and Hoekstra, 2000). Under these conditions, the evaluation of the impact of human exploitation on demographic parameters of natural resources becomes a necessity. In general, it is useful to study the demography of the species exploited to optimize the operation of finding the exploitation rate that maximizes production, without causing the extinction of exploited populations. The description of the species demography also compares their life cycle and their demographic strategy. It helps us to understand the impact of human action on species and their life cycle (Schmidt *et al.*, 2011). The study of the evolution of life history is an important area of modern ecology (Adler *et al.*, 2014; Begon *et al.*, 2006; Bontempo e Silva *et al.*, 2015; Crone *et al.*, 2011; Salomon *et al.*, 2013; Stearns, 2000).

A good approach is to compare the life histories of organisms to determine how evolution has acted on the relationships between different features of their life histories and their consequences in terms of spatial structure of population in age and population strategy. Moreover, the study of the evolution and comparison of life cycles of exploited species should also allow adjusting of operation practices for each species. The growth rate of a population is determined by the fate of all individuals in the population (Caswell, 2001). Thus, to understand the dynamics of this population, all demographic processes that occur within a population must be taken into account (Schemske *et al.*, 1994). In plant populations, these processes can be divided into phases of transition in the life cycle, survival, fecundity, recruitment and retrogression (Silvertown *et al.*, 2001). To maintain a population, survival and recruitment of individuals already established are the most important components of the life cycle (Silvertown *et al.*, 1996). The rate of recruitment of individuals positively affects the growth of the population when the probability of survival and fecundity increases with the size of the plants (Silvertown *et al.*, 2001).

However, as highlighted by Hall and Bawa (1993), current ecological theory provides us with fairly robust understanding of population dynamics of single species, while our theoretical understanding of dynamics of communities or ecosystems is not as advanced. Since these systems are more complex, thus much harder to study and to model, most research will need to be specific, focusing on population level dynamics of single species in order to analyse plant demography and to evaluate the effects of harvest on population structure and dynamics of the target species (Peres *et al.*, 2003; Soehartono and Newton, 2001). A highly suitable tool for such demographic studies is matrix projection models, which have been applied for a large number of plant and animal species.

The matrix model approach has been applied earlier to describe the population dynamics of large tropical trees (Emanuel *et al.*, 2005; Hernandez-Apolinar *et al.*, 2006); palms (Souza and Martins 2006; Valverde *et al.*, 2006; Zuidema *et al.*, 2007); perennial grasses (Chu and Adler, 2014; Jacquemyn *et al.*, 2012), as well as NTFPs species such as rattan palm (Kouassi *et al.,* 2008) herbs (Ghimire *et al.,* 2008), trees (Gaoue and Ticktin, 2010; Schmidt *et al.,* 2011; Soehartono and Newton, 2001; Zuidema *et al.,* 2007).

The methodological advantages of matrix models are the flexibility of their mathematical formulation and their capacity to summarise complex demographic information contained in the life cycle diagram into a few summary statistics. These models allow investigators to predict at least the direction of future trends, and help them to set limits on the probable magnitude of futures changes. A disadvantage of matrix models is that they are time-invariant, assuming that the conditions of the studied populations will continue forever, while demography can be influenced by variation in climatic conditions or by the effect of harvest (Zuidema, 2000). Several modifications to the basic matrix models have been developed in order to cope with such problems (Caswell, 2001).

Learning objectives

The objective of this chapter is to analyze and identify the parameters controlling the population dynamics and to establish relationships with the demographic parameters for the development of a predictive model.

Learning outcomes

It is expected that the student shall acquire practical knowledge and, as such, be able to know:

- How to describe the life cycle of a species and the structure of its populations, in terms of stages of development;
- How demographic patterns will determine the population structure of the species, to show the life history of the species.

Concept of Sustainable Management of Natural Resources Demographic Approach to the Study of Plant Genetic Resources

Understanding how plant populations respond to spatio-temporal variations of individuals and the environment is an important goal of ecological plant research. It has been demonstrated that plant populations strongly vary in space and time in response to environmental changes in their habitats (van Groenendaal *et al.,* 1988). Tracking individuals over time allows to accurately estimate the flow of individuals between different categories (alive, dead, stadiums) and their variations (by sex, age group, subpopulations, etc.). It is based on the identification by a single brand, which remains characteristic of the individual to which it was raised (Caswell, 2001). Individuals in a population are born, grow, mature, reproduce and die. Each of these events depends on the environment in which the individual exist and the means available to it in this environment. These rates, which in fact describe the movements of individuals within the life cycle are called critical rate. They completely define the population dynamics. Demographics, based on the study of vital rates of the life cycle, is not only interested in the dynamics, but also, the structure of populations (Caswell, 2001; Ramula and Lehtilaa, 2005). The matrix population models that incorporate clearly the dynamics and structure of populations are particularly used when the life cycle can be described in terms of class size, developmental stages or age classes (Caswell, 2001).

Theory of Life History Traits

Features (any measurable parameter) in the history of life are all characteristics of a species that describe its life cycle (Begon *et al.,* 2006) and vital rates (Stearns and Hoekstra, 2000). Plants have evolved various strategies in the history of life in response to the spatio-temporal variation in abiotic and biotic factors (Ehrlen and Lehtila, 2002). An important part of the life history of a plant species is its longevity (Ehrlen and Lehtila, 2002). The short-lived species populations are generally more sensitive to the environment (Fisher *et al.,* 2002). Due to the longevity of individuals, many plant species from clone can survive long periods, despite strong fluctuations in habitat quality (Souza and Martins, 2006).

Two major types ofpopulation strategies are recognized: strategies biodemographic r and K. The strategy r is characterized by a high rate of multiplication, as well as early sexual maturity. This provides a rapid species colonization of a resource. This type of strategy is characterized by pioneer and opportunistic species. The species development strategy K needs a lot more energy for reproduction and survival of individuals. Species, with a low growth rate (K strategy), takes some time to restore balance in the number of their people after a natural disaster or an accident (Begon *et al.,* 2006; Ricklefs and Miller, 2005). Once the demographic parameters of the populations of a species are established and the dynamics is characterized, it must pass the selection phase of the strategy of conservation of these genetic resources.

Size, Growth, Density and Longevity of Populations

Populations, whose density is subject to wide variations in time, present a risk of extinction. A population composed of individuals of a species with long life cycle will have a lower risk of extinction than that composed of individuals of a species with a short life cycle (Ricklefs and Miller, 2005). The loss of biodiversity due to several factors (biotic and abiotic) greatly disturbs the functioning of the ecosystem. These factors must be taken into consideration in order to provide effective conservation practices to halt the loss of biodiversity. It is clear that the risk of extinction is more important for people with low effective where the rich gene pool resides in the few individuals who compose it.

Vital Rates

The rate of population growth indicated by **X** is determined by the sum of the fate of all individuals in the population (Caswell, 2001): if **X** > 1, the population grows exponentially; if **X** = 1, the population remains stable but if **X** < 1, the population decreases and tends towards extinction. Thus, to understand the dynamics of a population, all demographic processes occurring in this population need to be considered (Schemske *et al.,* 1994). In plant populations, these processes can be divided into phases of transition in the life cycle (Silvertown *et al.,* 2001), which include: survival, recruitment, retrogression and fertility. The survival and growth of already established individuals are the most important components of the life cycle of a population (Silvertown *et al.,* 1996). Plant growth positively affects the growth of the population because the probability of survival and fecundity increases with the size of the plants (Silvertown *et al.,* 2001).

Matrix Models

The matrix models provide a very general framework to study the dynamics of structured populations (Caswell, 2001). This natural approach, which is based on the life cycle of a species, requires discreet vision phenomena that often correspond to the nature of field data available to the biologist. Generally, the matrix models are needed to compare the life cycles of different species to understand the mechanisms and evolutionary factors determining their life cycles causes. They provide an analysis of the growth of structured stages or populations subdivided populations' tool (Caswell, 2001; Ricklefs and Miller, 2005). In plants, the probability of survival, recruitment to the next stage and fertility depend more on size than on age. Thus, the so-called Lefkovitch matrix models of plants are based on classification in stages or size classes (Caswell, 2001). To identify sensitive phases of the life cycle of a plant, the relative influence of demographic rates on the growth rate **(X)** of the population can be assessed by prospective and retrospective analyzes (Caswell, 2001). The prospective approach (elasticity analysis) explores how small changes in demographic rates may affect the growth rate **X** (de Kroon *et al.,* 2000).

Clonal Plant

In this context, we present the first matrix model for two African rattan species: *Eremospatha macrocarpa* (Mann and Wendl.) Wendl. and *Laccosperma secundiflorum* (P. Beauv.) Kuntze (Plate 1.1).

Plate 1.1a: Furniture made with rattan canes in Abidjan (Source: Zoro and Kouakou, 2004);
1.1b: *Eremospatha macrocarpa* (Source: Kouassi, 2009);
1.1 c: *Laccosperma secundiflorum* (Kouassi, 2009)

Parameter Estimation

To estimate the parameters of the models, marking and monitoring of individuals were made. The transition probabilities were calculated from the following equations:

- Probability = (Number of individuals from stage i of t to t +1) / (Number of individuals in the stage i to t); gi: recruitment rates; pi: survival; ri: rate of retrogression; 1 = gi — pi — ri: mortality;
- Fecundity = Number of new seedlings at time t +1 / Number of adults at time t of individuals.

Transition Matrix Construction

For each species, we designed a genet-based matrix population model with the four stages defined above. Since the population was stage classified, a Lefkovitch matrix was used (Caswell, 2001). Transition probabilities were calculated according to the proportion of genets in each stage following the three possible fates of surviving individuals. Fecundity was calculated as the number of newly germinating seedlings and attributed to the adults of the plot considered (Valverde and Silvertown, 1998). For each stage (i), a probability of survival in the same stage (Pi), a probability of growth to the next stage (Gi), a probability of retrogression to the previous stage (Ri), and a fecundity (Fi) were estimated (Figure 1.1).

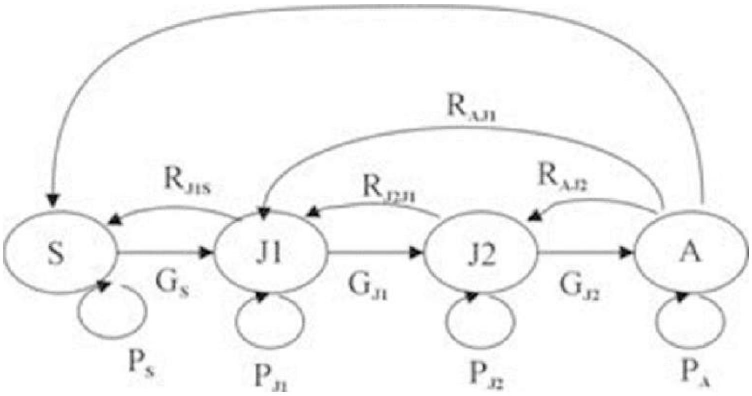

Figure 1.1: Life cycle diagram corresponding to the four-stage matrix model used for *Eremospatha macrocarpa* and *Laccosperma secundiflorum* populations. F i , fecundity in stage i; Gi , probability in stage i of survival and growth to the next stage ; Pi , probability in stage i of survival in the same stage ; Ri, probability in stage i of survival and retrogression to the precedent stage. Seedling = S; Juvenile 1 = J1, Juvenile 2 = J2, and Adult = A.

This leads to the following transition matrix:

$$A=\begin{pmatrix} P_s & R_{j1s} & 0 & F_a \\ G_s & P_{j1} & R_{j1j2} & R_{a1} \\ 0 & G_{j1} & P_{j2} & R_{a2} \\ 0 & 0 & G_{j2} & P_a \end{pmatrix}$$

Initially, a matrix was estimated for each of the three 6-mo periods using the data collected from the N'zodji Forest (Cote d'Ivoire). The 6-mo matrices of each species were compared through a three-way log-linear analysis. The results showed that the 6-mo matrices are not significantly different, thus we were not able to detect any seasonality in the matrices. Consequently, the arithmetic mean of the parameters of the three 6-mo matrices was then calculated to get an average matrix for each species (Caswell, 2001).

Transition Matrix Analyses

The average matrix of each species was used in all analyses. We computed the asymptotic growth rates (1), stable stage distributions and the elasticities of 1 to the matrix parameters (Caswell, 2001). The estimation of the confidence intervals of 1 was based on the approach described by Caswell (2001). The variance of 1 was estimated as the sum of the variances of all matrix parameters weighted by the squared sensitivities of 1 to the parameters. Confidence intervals were then computed, assuming a normal distribution for 1. This allowed testing whether the estimates were significantly different from 1. Moreover, the observed stage distributions were compared to the stable stage distributions predicted by the models using Chi-square tests. The fecundities (number of new seedlings per adult in the plot) of the two species were compared through a GLM repeated- measures model using the three plots as repetitions and the three 6-mo periods as within-subjects factor. The matrices of the two species were compared through a three-way log-linear analysis of variance (Caswell, 2001).

Stage-based matrix models allow estimating age-based parameters, exploiting the idea that, even if the matrix model does not explicitly take age into account, age is implicitly present in the model, since the transition matrix is computed on annual base (or any fixed time step) (Barot *et al.*, 2002). For each stage, we calculated the mean age of residence in the ith stage (Si), the conditional life span of genets remaining in the i mean time to reach the ith stage from the shoot (first stage) (Barot *et al.*,2002).

Sensitivity Analysis

We used elasticity and Life Table Response Experiments (LTRE) to compare the life cycles of the two studied species and to explore the relative importance of the different matrix entries in the population growth rate. The first method consisted of calculating the elasticity of 1 (asymptotic growth rate). Elasticity analyses evaluate the relative contribution of matrix entries to 1 by providing information on how much 1 would change if matrix entries were modified. Elasticities are measures of proportional sensitivity of 1 to proportional change in a (de Kroon *et al.*, 2000). Elasticities have been considered as useful tools to identify vulnerable life cycle stages on which to focus conservation and management strategies. We also used Silvertown's approach (Silvertown *et al.*, 1992) to characterize the life cycle by summing the elasticities of 1 (asymptotic growth rate) to fecundities (F), growth rates (G), and survival rates (L) (Silvertown *et al.*, 1992).

Solitary Plant

Tree bark is an important Non-Timber Forest Product for the production of herbal medicine, food, dyes, spices and incense (Bodeker *et al.*, 2014; Cunningham, 2014; Tshisikhawe *et al.*, 2012). Despite those barks' multiple values, studies of bark production, yields, and sustainable harvest are few (Cunningham, 2014), also population effects of bark extraction have hardly been studied so far (Gaoue and Ticktin, 2010; Guedje, 2014; Schmidt *et al.*, 2011; Ticktin, 2004). To assess the impact of the current bark exploitation on *Garcinia lucida* trees, three transition matrices were constructed for the following harvest practices: (i) debarking only one side of the stem (A), (ii) ring-barking over almost the entire circumference of the stem (A), and (iii) felling the tree at approximately 1-m height above ground level before harvesting bark of the logged tree (A). These matrices are modifications of matrix A for an undisturbed population. Transition probabilities among seedling, sapling, juvenile and adult less than 10 cm DBH stages are equal to those in the matrix A, as bark harvesting does not affect individuals of those stages. Values for other matrix elements were calculated according to the following harvest practices, by combining growth, mortality and fecundity value rates estimated or obtained from both harvest levels and techniques tested at the level of individual tree (Guedje *et al.,* 2007).

RAMAS Stage (Ferson, 1990) was used to calculate the value of 1 for all three harvesting practices and the natural situation. Confidence intervals for 1 were calculated using the first-order approximation proposed by Caswell (1989), which uses the sensitivity and variation of transition matrix elements. Elasticity analyses (de Kroon *et al.,* 2000) were carried out to determine the contribution of vital rates to the value of 1. In their standard form, these analyses consider the impact of changes in matrix elements, not the underlying vital rates, on population growth rate. As bark harvesting directly affects vital rates (growth, reproduction and survival), we choose to conduct elasticity analysis on these vital rates (Caswell, 2001). Harvest simulations analysis for the three common bark harvest practices was conducted by multiplying matrices with population structures. Given these starting values and omitting any density-dependent processes, the matrix model was then used to predict the future number of harvestable trees (>10 cm DBH) in the population for the three harvest practices.

Matrix models used to test the sustainability of current harvest practices of *Garcinia lucida* bark, indicated that population growth rates and patterns of elasticity found were similar to those found for other tropical tree species (Crone *et al.,* 2011; Zuidema *et al.,* 2007; Zuidema, 2000). The mean population growth rates (1) obtained were all above 1, but none were significantly different from one, indicating that the actual exploitation of *G. lucida* bark does not jeopardize the existence of the entire population. However, it rapidly reduced the amount of large harvestable trees to 50 % and 4 % of the initial value, for partial debarking and ring barking/felling, respectively. The projections of harvestable trees were in accordance with the differences in size-class distributions in populations with different harvest pressure (Plate 1.2). Continued existence of harvested populations therefore, does not guarantee that these populations will maintain sufficient trees to make repeated harvests economically viable.

Plate 1.2a: *Garcinia lucida* bark to be sold in South Cameroon, Equatorial Guinea and Gabon (Central Africa); **1.2b:** *Garcinia lucida* stem after bark extraction (Source: Guedje, 2002; Guedje *et al.,* 2002)

Case Studies

The resources for these studies were obtained from the two countries (Cote d'lvoire and Cameroon) that participated in the initiative (Table 1.1). The Case Studies are presented in Boxes 1.1 and 1.2. Table 1.1. lists the studies undertaken by the two authors in Cote d'Ivoire and Cameroon.

Country	Author	Topic
Cote d'lvoire	Kouassi, KI	Uses of matrix models to test the sustainability of demography and life cycle of two rattan species (clon- al plant)
Cameroun	Guedje, NM	NM Uses of matrix models to test the sustainability of current harvest practices of G. lucida bark (solitary plant)

Box 1.1: Uses of Matrix Mode to Test the Sustainability of Demography and Life Cycle of two Rattan Species: *Eremospatha macrocarpa* and *Laccosperma secundiflorum,* in Cote d'lvoire.

The study compared the life-cycle of *E. macrocarpa* (pleonanthic) and *L. secundiflourm* (hapaxanthic) and assessed the impact of human exploitation on their populations. Among the diversities of forest resources and services, there has been a growing interest for the extraction of non-timber forest products (NTFPs). Unfortunately, many NTFPs such as rattan are overexploited (FAO, 2001). It is thus primordial to study the demography of these populations to estimate the risk of local extinction and to develop sustainable exploitation practices.

Matrix population models have been widely used to analyse the demography of palm trees (Rodriguez-Buritica *et al.,* 2005; Souza and Martins, 2006) and to improve the sustainability of natural resources management (Endress *et al.,* 2004; Vormisto, 2002). These models constitute useful tools to analyse the persistence of populations, to describe life-histories, and to compare different populations or species (Caswell, 2001).

Therefore, we present the first matrix model for two African rattan species: *Eremospatha macrocarpa* (Mann and Wendl.) and *Laccosperma secundiflorum* (P. Beauv.) Kuntze. In the continuum between r and K demographic strategies, *E. macrocarpa* seems closer to the r pole than *L. secundiflorum.* This might be linked to the fact that the two species have different flowering types, i.e. pleonanthic for *E. macrocrpa* and hapaxanthic for *L. secundiflorum.*

Eremospatha macrocarpa and *Laccosperma secundiflorum* provide valuable NTFPs. A stage-classified matrix population model was parameterized with field data for the two species (studied in N'zodji forest (Cote d'Ivoire). To do this, transition probabilities (survival in the same stage or recruitment to the next stage) as well as fecundities were assessed. A total of 854 and 1009 genets of *Eremospatha macrocarpa* (pleonanthic) and *Laccosperma secundiflorum* (hapaxanthic) were censused every 6-mo over 18- mo, respectively. The population growth rates of *E. macrocarpa* (1 = 0.979) and *L. secundiflorum* (1 = 0.959) were not significantly different from 1 (Table 1.2). This indicates that the populations were close to equilibrium. However, the difference between the stable stage distributions and the observed distributions indicated temporal variation in vital rates (Figure 1.2). Elasticity analysis showed that growth and fecundity had lower contributions to 1 than the survival rates for the two species (Table 1.3). The elasticity of the growth rate was the highest for adult survival in *E. macrocarpa* and for juvenile 1 survival in *L. secundiflorum.* Reproduction (Table 1.4) took longer time for L. secundiflorum (15.1 year) than for *E. macrocarpa* (9.5 year) to reach the adult stage. On the contrary, the mean remaining lifespan for adult genets was shorter for *L. secundiflorum* (5 year) than for *E. macrocarpa* (21.5 year). Growth and survival strategies of these species were consistent with the patterns found in other tropical clonal palm species. Finally, our results suggested the existence of two trade-offs within reproduction: between vegetative and sexual reproductions and between the size of offspring (by vegetative reproduction) and their number. These trade-offs would explain that, although the two species have different demographic features, the growth rates of their populations are not significantly different from 1.

Table 1.2: Average 6-mo transition matrix for *Eremospatha macrocarpa* and *Laccosperma secundiflorum* computed for three plots and two 6-mo matrices

	Seedling	Juvenile 1	Juvenile 2	Adult
		Eremospatha macrocarpa		
Seedling	0.866	0.062	0.000	0.096
Juvenile 1	0.057	0.804	0.000	0.011
Juvenile 2	0.000	0.017	0.587	0.090
Adult	0.000	0.000	0.397	0.881
		Laccosperma secundiflorum		
Seedling	0.863	0.031	0.000	2.139
Juvenile 1	0.064	0.919	0.190	0.000
Juvenile 2	0.000	0.011	0.619	0.000
Adult	0.000	0.000	0.071	0.750

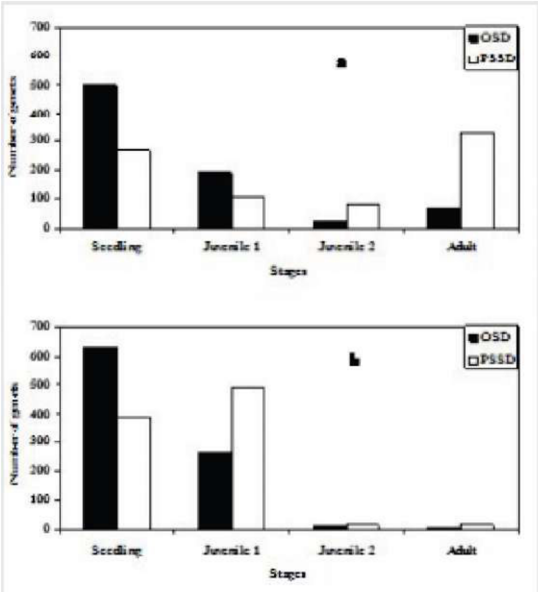

Table 1.3. Elasticity matrices for the four stages average Eremospatha macrocarpa and Laccosperma secundiflorum matrix models

	Seedling	juvenile 1	juvenile 2	Adult
		Eremospatha macrocarpa		
Seedling	0.043	0.001	0.000	0.004
Juvenile 1	0.006	0.031	0.000	0.001
Juvenile 2	0.000	0.005	0.110	0.068
Adult	0.000	0.000	0.073	0.657
		Laccosperma secundiflorum		
Seedling	0.223	0.014	0.000	0.011
Juvenile 1	0.025	0.631	0.004	0.000
Juvenile 2	0.000	0.015	0.027	0.000
Adult	0.000	0.000	0.000	0.038

Table 1.4: Age-based (y) life history parameters corresponding to the four stages average matrix model for Eremospatha macrocarpa and Laccosperma secundiflorum: mean age of residence in the ith stage. Si; conditional remaining life span of genets in the ith stage, Hi; mean time to reach the ith stage from the first stage, oseeldling, i.

	S_1	Ω	seedling i
Eremospatha macrocarpa			
Seedling	4.95	6.56	0.58
Juvenile 1	8.15	06.65	4.47
Juvenile 2	23.78	21.39	9.92
Adult	27.98	21.00	9.23
Laccosperma secundiflorum			
Seedling	5.99	8.33	U.69
Juvenile 1	12.53	10.02	4.22
Juvenile 2	13.85	6.68	12.49
Adult	15.85	2.uu	14.3b

Box 1.2: Uses of Matrix Models to Test the Sustainability of Current Harvest Practices of *Garcinia lucida* Bark

The study aimed at characterising the population dynamics of *G. lucida* in order to identify its processes or life stages, and assess the impact of bark harvesting on *G. lucida* population structure and dynamics in order to provide insight into the future availability of the resource.

Effective sustainable resource management requires development and implementation of appropriate conservation and management plans, as well as sustainable extraction practices to mitigate negative impacts and promote positive impacts of harvesting on species in the community, or on the ecosystem structure and function (Gaoue *et al.,* 2011; Guedje *et al.,* 2007; Guedje, 2014; Mandujano *et al.,* 2015; Schmidt *et al.,* 2011; Ticktin, 2004). This requires, at least, a better understanding of the dynamics of species, communities or ecosystems, as well as quantitative analysis of the impact of extraction on natural resources population (Crone *et al.,* 2011). Therefore, an assessment of these resource harvesting impacts using matrix models are essential to forecast the long- term changes in harvested species population dynamics (Gaoue and Ticktin, 2010; Lopez-Gomez *et al.*, 2015; Mishra et al., 2015). To illustrate such approach, the natural population dynamics of *Garcinia lucida* in the south of Cameroon Atlantic humid forests were analyzed using matrix models.

However, quantitative information related to the entire life cycle of wild resources, their present and future productivity, as well as the risk reduction and the impact of exploitation on their population dynamics are also almost poorly documented. Schmidt *et al.,* (2011) used data from 46 species across 20 families that used matrix models to assess the effects of NTFPs harvest. One-third of these studies (covering 16 spp.) monitored only unharvested populations and simulated harvest effects, whereas about one-fifth (10 spp.) lacked control populations. Nearly half of the species were palms (covering 21 spp.). Trees (12 spp.) and herbs (12 spp.) each represented approximately one-quarter of the species. These authors also found that, for 20 of the 46 species, the impacts of harvest were evaluated from both harvested and control populations. About 75% of these studies have been published since 2005.

The bark of *Garcinia lucida* species is one of the most valued NTFP in Cameroon, Gabon and Equatorial Guinea (Chupezi *et al.,* 2009; Guedje, 2014; Guedje and Fankap 2001; Momo *et al.,* 2011). Size-specific growth and mortality rates of *Garcinia lucida* were determined over 2 years for a sub-sample of marked individuals of varying size. *G. lucida* is a small evergreen dioecious tree species, with the ability of attaining 25—30 cm in diameter at breast height (dbh) and 12—15 m in total height. The bark is used as an additive to palm wine production and in distilling fermented palm wine to produce liquor. The fresh or dried bark and the seeds are widely used for medicinal purposes to prevent food poisoning and to cure stomach and gynaecological pains, as well as to cure snake bites. *Garcinia* life cycle is composed of a set of eight loops representing different developmental stages (Guedje, 2002; Guedje *et al.,* 2003) (Figure 1.3).The population of the species was grouped into eight life cycle stages (S1—S8) based on plant size. The juvenile trees were classified as seedlings (S1: 0—100 cm height), saplings (S2: 100—200 cm height and S3: 200—400 cm height), and juveniles (S4: 2.5—5 cm dbh). Adult trees were classified into adult 1 (S5: 5—10 cm dbh), adult 2 (S6: 10—15 cm dbh), adult 3 (S7: 15—20 cm dbh) and adult 4 (S8: > 20 cm dbh). From this life cycle, a transition matrix model of the form initially described by Lefkovitch (1965) and subsequently modified by Caswell (1989) was used to analyse *G. lucida* population dynamics (Adler *et al.,* 2014; Guedje *et al.,* 2003).

The calculations of the coefficients of the projection matrix for G. lucida populations indicates that the stable stage distribution (SSD) resulting from the model resembled the observed population structure (Figure 1.3), although the relative SSD abundance of large trees was lower, sensitivity analysis was used to measure the importance of any element of the transition matrix to the population growth rate. One of the sensitivity analysis limitations is the impossibility to distinguish the observed transition probabilities from those who exit only in theory. *G. lucida* population growth rate was more sensitive to changes at the level of these unrealistic or hypothetical transition probabilities. At the level of the observed transition probabilities, the population growth was more sensitive to changes in growth than to changes in survival and fecundity throughout the entire life cycle (Guedje *et al.,* 2003). In addition to the unrealistic transitions, the sensitivity value of a matrix element depends also on the actual value of that element, which may be different for fecundity and survival. Small changes in survival rate have much more influence than a similar change in a fertility rate.

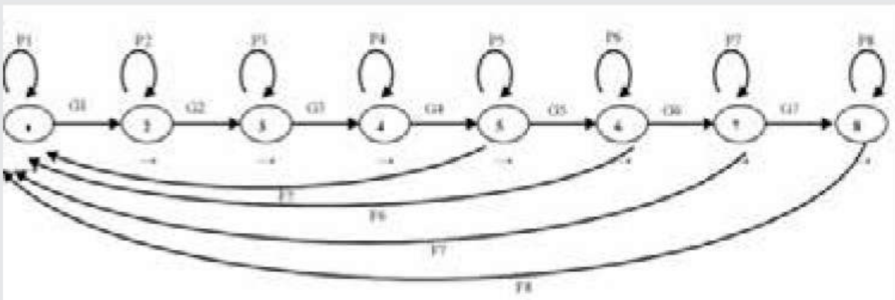

Figure 1.3: Life a cycle of *Garcinia lucida*

As the interpretation of the sensitivities requires some care, elasticity analysis or proportional sensitivity analysis was used to measure the proportional contribution of the matrix elements to the population growth rate (Salomon *et al.,* 2013). The results of such analysis are present in a matrix where each element represents the proportional sensibility of the population growth rate to the associated transition probability. Given that all the elasticities in the matrix sum to 1, matrix elements are summed to obtain a measure of the relative importance of progression or growth (eG), survival or stasis (eL) and fecundity ((eF). In the case of *G. lucida,* growth (0.08) and fecundity (0.02) elements have relatively low contributions to X, suggesting that the harvesting of seeds may have a low impact on *G. lucida* population dynamics (Figure 1.4).

By far, the largest proportion of total elasticity is confined in stasis elements (0.90), with a peak (0.20) in stage 5 (adults between 5 and 10 cm dbh), indicating the importance of individual survival, especially in this stage for the self- maintenance of the population. Stages 6, 7 and 8, containing the largest reproductive individuals (above 10 cm dbh), which are interesting in bark extraction by local population, accounted only for 0.08 of the total elasticity, suggesting that bark exploitation may have at least a low impact on the population dynamics for *G. lucida*. Furthermore, loop analysis showed that size- class 5 — 10 cm dbh has the highest loop elasticities, suggesting that this size class is the most important reproductive stage for population maintenance.

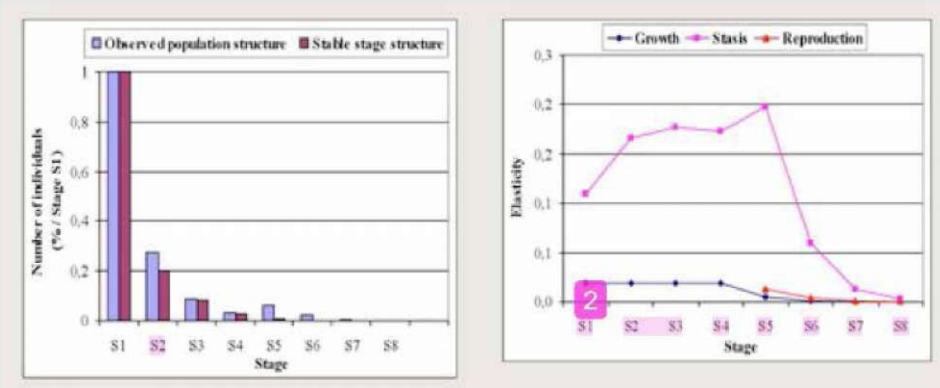

Figure 1.4a: Comparison of SSD and observed distribution (OD); **1.4b:** Elasticity of X changes in reproduction survival and growth for *Garcinia lucida* (Source: Guedje *et al.*, 2007)

The largest contribution of stasis elements to the total elasticity value of G. lucida matrix is typical in long-lived species (Merow *et al.*, 2014; Silvertown *et al.*, 1992). The relatively low contributions of stages 6, 7 and 8 (the largest reproductive individuals which are interested in bark extraction) to the total elasticity value, suggest that there is a good prospect for sustainable extraction of *G. lucida* bark. However, young reproductive individuals in size-class 5 - 10 cm dbh, which proved to be the most important reproductive stage for population maintenance, are also exploited by forest gatherers, especially when the bark of these trees is thick and can be easily detached from the wood. An increased exploitation pressure on trees in this size class is likely to have a considerable risk reduction on the population growth and to compromise the scope for sustainable exploitation of this resource.

Questions

- What are the main processes or life stages that regulated or limited the population dynamics of *G. lucida?*
- Does the actual exploitation rate of *G. lucida* bark jeopardise the existence of the entire population?
- How could be predicted at least the direction of future trends of *the G. lucida* population?
- How could resource managers be empowered to set limits on the probable magnitude of future changes?
- How to include the effects or the role of density-dependence in the population dynamics of species in matrix models?

How to cope with the consequences of environmental changes or climate change in modelling the dynamics of species?

Conclusion

Matrix population models have been widely used to analyse the demography of trees and to implement the management of natural resources. They constitute useful biological models to analyse the persistence of populations, to describe life histories, and to compare different populations or species. For plants, these models are usually stage-classified and require the estimations of the transition probabilities between stages as well as fecundities. The models also allow the calculation of age-based parameters such as the mean ages in different stages. There are two trade-offs which explain that, although the *E. macrocarpa* and *L. secundiflorum* have different demographic features. Their populations are not threatened by the exploitation of ramets by local human populations but that *E. macrocarpa* should be more sensitive to this exploitation. The resulting time-varying and stochastic models describe the demographic consequences of a sequence of environments by the sequence of projection matrices. *Garcinia lucida* must be managed in order to contribute to the long-term exploitation and conservation of tropical forests. Furthermore, the impact of different harvesting and management scenarios should also be assessed using these matrix models.

Questions for Discussion

1. To model the dynamics of a structured population of a plant species, three stages of development in individuals were defined: seedlings, juvenile and adult. The parameters studied through the time steps are: Fecundity (F); Recruitment (G) and Survival (Pi).
   a) Establish the graph of the life cycle of the species;
   b) Write the recurrence equations;
   c) Establish the corresponding matrix;
   d) Give the meaning of the different values of the growth rate (Growth rate > 0; Growth rate = 0; Growth rate < 0).
2. Based on the problem addressed in Box 1.1,
   a) Does the demography of these two rattan species differ?
   b) Are the two rattan populations threatened by human exploitation?
   c) How do the life cycle of *E. macrocarpa* and *L. secundiflorum* compare to other forest palm species, multiple-stemmed or not?
3. Following the issues discussed in Box 1.2,
   a) What are the main processes or life stages that regulated or limited the population dynamics of *G. lucida?*
   b) Does the actual exploitation rate of *G. lucida* bark jeopardize the existence of the entire population?
   c) How could be predicted at least the direction of future trends of the *G. lucida* population and how could resource managers be helped to set limits on the probable magnitude of futures changes?
4. How to include the effects or the role of density-dependence in the population dynamics of species in matrix models?
5. How to cope with the consequences of environmental changes or climate change in modelling the dynamics of species?

Suggested Reading Material

Some successful examples are illustrated by the works of:

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2

Sustainable Land Management For Agricultural Risk Management

D. Gessesse and M. Zerihun

Summary

This chapter discussed Sustainable Land Management (SLM) for agricultural risk aversion with particular focus on Africa. Agriculture, which is the mainstay of Africans, is dominated by smallholder farming and often suffers from multiple constraints and risks. Any attempt that tries to reduce poverty in Africa, needs to overcome constraints and minimize risks. SLM strongly boost the capacity of the smallholders in coping up agricultural risks by harmonizing seemingly conflicting objectives of production, ecological, policy and socio-cultural elements. SLM is based on the concept and principles of 'sustainability' which tries to integrate social responses to environmental and cultural problems. The planning and implementation of SLM needs to look at natural constraints on which farming is operated, institutional, policy and legal frameworks that affect the land use and production. The implementation of SLM needs a comprehensible understanding of the process of environmental degradation, causes and sources of uncertainties and plausible solutions. Process of implementation involves defining the unit of implementation (farm, landscape or watershed), setting the goals, collecting necessary data and information (including biophysical and socioeconomic data), and establishing verifiable indicators and monitoring results. Technology utilization particularly appropriate technology is vital for SLM. Similarly the use of traditional/indigenous knowledge enhances SLM. SLM needs clear and concise indicators and robust system of monitoring in order to measure and examine the processes of changes. This will help to enhance 1) the commitment and capacity of farmers to implement the designed process of SLM, and 2) ensure spatial and temporal sustainability of different farming systems

Resume

Gestion durable des terres pour la reduction des risques en agriculture

Ce chapitre traite de la Gestion Durable des terres pour la reduction des risques, avec un accent particulier sur l'Afrique. L'Agriculture qui est unpilier important de developpe- ment en Afrique est dominee par les petits exploitants et est souvent confronte a de multiples contraintes et risques. Toute tentative visant a reduire la pauvrete en Afrique se doit de vaincre ces contraintes et minimiser les risques. SLM boost fortement les capacites des petits exploitants dans la gestion des risques lies aux activites agricoles, a travers I'harmonisation des objectifs conflictuels de production avec les aspects ecologi- ques, socioculturelles et de politiques. SLM est base sur le concept et le principe de durabilite qui essaie d'integrer les reponses sociales aux problemes environnementaux et culturels. Le planning et la mise en wuvre du SLM exige l'examen des contraintes naturelles qui dictent les pratiques agricoles, les politiques et le cadre legal qui affectent l'utilisation des terres et la production. La mise en wuvre du SLM necessite une compre- hension totale du processus de degradation environnementale, les causes et les sources dincertitudes, ainsi que les solutions plausibles. Le processus de mise en wuvre impli- que la definition de l'unite de d'etude (Sexploitation,

lepaysage et le bassin versant), la definition d'objectifs la collecte d'informations necessaires (y compris donnees biophysi- ques et socioeconomiques), etablir des indicateurs verifiables et assurer le suivi des re- sultats. L'utilisation d'une technologie adaptee est vital au SLM. De fa^on similaire, l'utilisation de connaissances/locales ameliore le SLM. Le SLM repose sur des indica- teurs clairs et concis et un systeme de monitoring solide en vue de mesurer et examiner les processus de changement. Ceci peut aider a ameliorer :1) l'engagement et la capacite des exploitants a mettre en &uvre le processus de SLMcongu et 2) assurer la durabilite spatio-temporelle des differents systemes d'exploitation.

Introduction

Agricultural Risk Management (ARM) aims at minimizing the likelihood of risk occurrences and preparation to withstand the impact if it occurs (Harwood *et al.,* 1999). The types of risks smallholder farmers in Africa are confronted with today are numerous and are weather, biological, market, human health and policy related (Liniger *et al.,* 2011). In the continent, where majority of the population are smallholder farmers and whose livelihoods are based on subsistent farming, the importance of effective ARM is paramount. Minimizing the limiting factors, diversifying alternatives, intensifying production processes and strengthening management options are some of the generic ARM approaches (World Bank, 2005).

There is a growing agreement that improving smallholder agriculture can help solve the problem of poverty in Africa (e.g. Scoones *et al.,* 2005; Salami *et al.*, 2010). Improvement of smallholder agriculture is about creating agricultural systems that are resilient to risks, therefore, ARM is crucial. According to Harwood *et al.* (1999) risk management strategies can 1) reduce risk within the operation, such as product diversification, 2) transfer risk outside the operation, such as production contracting, or 3) build the operation's capacity to bear risk, such as maintaining liquid assets. There are several ARM options, some of which include: risk transfer by insurance (World Bank 2005), household strategies to escape from poverty and hunger (Dixon *et al.,* 2001), as well as sustainable land management (Liniger *et al.*, 2011).

Integrated natural resource management is a scientific and resource management paradigm uniquely suited to managing complex natural resource management challenges in densely settled landscapes where people are highly dependent on local resources for their livelihoods, thus heightening the tension between livelihood and conservation (Laura *et al.,* 2012). Similarly, a well-functioning Sustainable Land Management (SLM) practices can contribute to create a resilient farmer who is able to minimize agricultural risk. Its ultimate target is to create a win-win situation between human needs and environmental conservation. By combining various technologies,

favorable policy frameworks and activities, SLM increases land productivity, improves livelihood and insures ecological security (WOCAT, 2009). There is communality between ARM and SLM, where both attempt to harmonize relationship between land and humans. In both cases, land is a crucial resource with its components, including soils, water, animals and plants.

The role of SLM in strengthening ARM is to lay strong foundation for agriculture by harmonizing the conflicting objectives of productivity, environmental conservation and socio-cultural issues. Here, SLM is particularly important to uplift the productivity of agriculture which is constrained by various biophysical, socio-economic, cultural, policy and institutional factors. The contribution of SLM in ARM is defined by effective implementation of the 5 pillars of SLM (Smyth and Dumanski, 1993), which includes: increase productivity; improve security; create protection functions; insure viability; and insure acceptability.

Among the three ARM practices, namely mitigation, transfer and coping (World Bank, 2011), SLM provides risk mitigation options (i.e. activities that can reduce the likelihood of an adverse event or reduce the severity of actual losses). Within the context of ARM, SLM is specifically minimizing production risks, anticipating the likelihood of occurrence, such as: weather events, pest and disease outbreaks, and livestock morbidity. Therefore, SLM includes actions that promote diversity, adoption of better agronomic practices, use of resistant seeds, as well as implementing viable, adaptable and acceptable technologies.

According to Dixon *et al.* (2001), there are five main strategies to improve farm household livelihoods in Africa, which are: (1) intensification of existing production patterns (2) diversification of production and processing (3) expanding farm or herd size (4) increasing off-farm agricultural and non- agricultural income, and (5) a complete exit from agricultural production within a particular farming system.

There are important research works that address various SLM issues. Some of these works include challenges of SLM and land (World Bank, 2006; FAO, 1999), Strategies for Sustainable Land Management in the East African Highlands (Pender *et al.,* 2006), Framework for the Evaluation of Sustainable Land Management (FESLM) (Smyth and Dumanski, 1993), SLM in practice within the context of Sub-Saharan Africa (Liniger et.al., 2011), practitioners' guide (World Bank, 2008), SLM and climate change adaptation and mitigation (Woodfine 2009), land quality indicators for SLM (FAO, 1997), monitoring and assessment of SLM (Schwilch *et al.,* 2010; Reed *et al.,* 2011), guideline toolkits for SLM implementation (Herweg *et al.,* 1999).

This chapter attempts to link SLM with ARM and contextualizes it with African experiences by combining endogenous ways of risk aversion strategies with contemporary approaches. The SLM has to be relevant to ARM and maintain the required rigour in the level demands. Firstly the subject should be well bounded and contributes value to the knowledge category of Sustainable Natural Resources Management (SNRM). Secondly, the subject should be contextualized as to be able to focus on African agriculture. Thirdly, adhere to education for sustainable development principles; fourthly, emphasize endogenous practices and, fifthly, present comparative case studies.

Learning objective

This chapter is designed as a resource material for SLM in that students will be able to conceptualize SLM, understand implementation procedures and outline indicators for SLM performance evaluation.

Learning outcome

At the completion of this chapter, students will be able to:

1. Define Sustainable Land Management;
2. List Sustainable Land Management implementation procedures;
3. Characterize traditional land management practices;
4. Outline indicators for Sustainable Land Management performance evaluation;
5. Describe the link between Sustainable Land Management;
6. Agricultural Risk Management;

Outline indicators for Sustainable Land Management performance evaluation.

Conceptual Foundation of SLM

More productive and more resilient agriculture requires a major shift in the way land, water, soil nutrients and genetic resources are managed to ensure that these resources are used more efficiently (FAO, 2013).

Principles, Theories and Assumptions

The conceptual foundation of SLM is built on theory of sustainability, principles/guidelines of integrated land-use, and with the assumption that uncertainties characterize the natural and social world (Smith and Dymanski, 1993; Boumi, 1997; Hurni, 2000; Folke *et al.,* 2002). Theories of sustainability attempt to prioritize and integrate social responses to environmental and cultural problems through unifying economic, ecologic and social systems (Jenkins, 2014).Thes e sys tems bring together sustainability of natural and financial capital, biological diversity and ecological integrity and human well- being. According to Smyth and Dumanski (1993) the concept of sustainability is pertinent only against a background of limits to resource availability and use. If no such limits exist, or they are not perceived to exist, then it is common that resources are overexploited; under restraints, however, the concept of sustainability becomes increasingly important, rising as the scarcity of the resource increases.

Integrated land-use makes it possible to minimize conflicts, to make the most efficient trade-offs and to link social and economic development with environmental protection and enhancement. This helps to achieve the objectives of sustainable development (FAO, 1993). Natural resources including soils, minerals, water and biota, that the land comprises, are organized in ecosystems, which provide a variety of services essential to the maintenance of the integrity of life-support systems and the productive capacity of the environment (UNEP, 2014). According to Mehta (2000) ecosystems are increasingly seen to be characterised by variability and unpredictability, with non-equilibrial dynamics often being the norm; rapid and unexpected environmental change can cause hazards, such as: droughts, floods and pollution and affect people's natural environment and their livelihood strategies. Ecological principles of land management relate to time, place, species, disturbance and landscapes (Dale *et al.,* 2000).

Natural and social systems behave in nonlinear ways, exhibit marked thresholds in their dynamics; social-ecological systems act as strongly coupled, complex and evolving integrated systems (Folke *et al.,* 2002). A key challenge of sustainability is to examine the range of plausible future pathways of combined social and environmental systems under conditions of uncertainty, surprise, human choice and complexity (Swarta *et al.,* 2004).

Definition of Sustainable Land Management

Sustainable land management (SLM) is defined as a knowledge-based procedure promoting the adoption of land-use systems that through appropriate management practices, enables land use to maximize the economic and social benefits from the land, while maintaining or enhancing the ecological support functions of land resources (FAO, 2009). SLM seeks to harmonise the often conflicting objectives of intensified economic and social development, while maintaining and enhancing the ecological and global life support functions of land resources (Herweg *et al.,* 1999). SLM combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns based on the following objectives: productivity, stability/resilience, protection, viability, and acceptability/equity (Smyth and Dumanski, 1993). This definition contextualizes all the four functions of land resources, namely productive, physiological, cultural and ecological functions. The productive function of land is to produce goods and services, physiological functions are minimizing toxic substances, cultural functions are about preservation creation and integrity of landscapes, while ecological functions are to ensure maintenance of ecosystem functions and global support functions (Herweg *et al.,* 1999; Table 2.1).

Pillars and Framework of Sustainable Land Management

The pillars of SLM can be categorized as agro-ecological and socio-economic (Bouma, 2002). Accordingly, the first three objectives (Table 2.1) define plausible agro- ecological aspects of SLM: increasing productivity, reducing risks during production and enhancing quality of soil and water. The fourth objective is different: economic feasibility (which also strongly effects social acceptability): largely beyond the control of the land manager. Although a management scheme may be sustainable from an agro-ecological point of view, it can be economically unsustainable because of poor prices for agricultural produce.

The inherent characteristics of SLM integrate the biophysical and socio-economic factors as well as the range of temporal and spatial scales of the phenomena in given agro ecological zones (Dale *et al.,* 2000; Schwilch *et al.,* 2010; Reed *et al.,* 2011). In this regard, universal SLM framework (Figure 2.1) is outlined. The interaction between elements of the framework exhibits: the utilization of natural resources applies pressures and driving forces on the system and changes in the state of the system, and then changes produce impacts, which lead to responses that by a feedback loop interact with the driving forces, the pressures, the state and the impacts (Thomas *et al.,* 2010).

Table 2.1. Basic pillar on which Sustainable Land Management is constructed

Objectives of SLM	Description
Productivity	The return from SLM may extend beyond material yields from agricultural and non-agricultural uses to include benefits from protective and aesthetic aims of land use.
Security	Management methods that promote balance between a land use and prevailing environmental conditions, reduce the risks of production; conversely, methods that destabilize local relationships increase that risk.
Protection	The quantity and quality of soil and water resources must be safeguarded, in equity for future generations. Locally, there may be additional conservation priorities such as the need to maintain genetic diversity or preserve individual plant or animal species.
Viability	If the land uses being considered are locally not viable, the use will not survive.
Acceptability	Land use methods can be expected to fail, in time, if their social impact is unacceptable. The populations most directly affected by social and economic impact are not necessarily the same

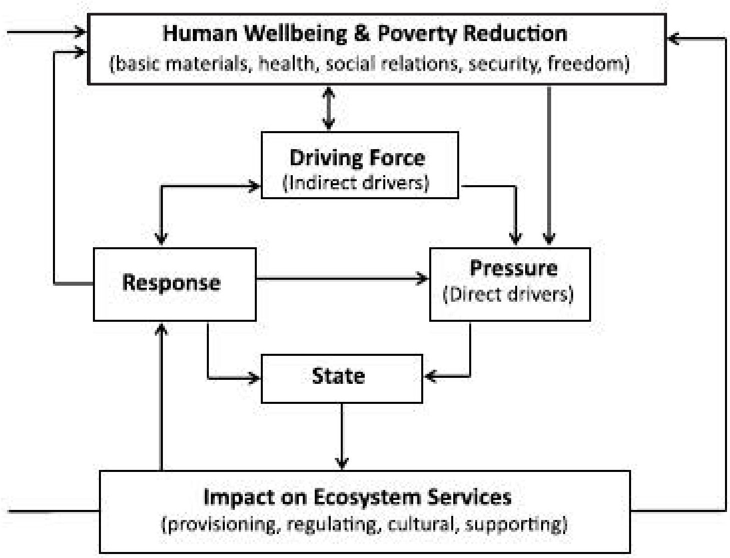

Figure 2.1. Universal SLM frame work link between environmental services and human well-being (Source Thomas et al., 2010)

SLM has great potential for preservation and enhancement of ecosystem services in all land-use systems. The ecosystem services provided through SLM include: provision service, regulating and supporting service, and cultural services (WOCAT, 2009). Provision services benefits for food, fodder, fibre, fuel and freshwater; regulating and supporting services covers mainly soil development and nutrient cycling while cultural/social services keeps cultural and natural landscapes alive and protect cultural heritage.

Sustainable Land Management at Smallholder Farm Level

SLM can be implemented at different scales within the contexts of prevailing agro ecological zones. Smallholder agriculture in Africa is characterized by low agricultural productivity, limited livelihood options, land scarcity, shortage of appropriate agricultural technologies and poor access to market (Pender et al., 2006). Smallholder farmers land management is linked to their biological, physical, economic and cultural environment over which they have limited control (Dixon et al., 2001). Majority of African farmers are smallholders who produce higher percentage of food in the continent where land degradation is prevalent. This type of agriculture practiced in Africa is risk prone (Grrity et al., 2012).

Smallholder farms dominate African agriculture and they are prone to agricultural risk. It is imperative that SLM is practiced at smallholder farms' level to be able to manage agricultural risk. Once each farm is managed sustainably, landscape and beyond level SLM can easily achieved. In order to implement SLM at smallholder farm level it is important to observe the characteristics of smallholder farmers and principles of SLM. Smallholder farmers are characterized by small land size of less than 2 hectares; limited resource endowments, relative to other farmers; practice a mix of commercial and subsistence (crop or livestock) production; and most labor and enterprise come from the farm family (Nagaytes, 2005). These farmers need to attain high and sustained production levels without seriously damaging the environment. To be able to do that, it is important to conserve soil and water, maintain permanent organic soil cover and create crop diversity.

Implementing Sustainable Land Management

Implementing SLM is based on the understanding of processes of resource degradation, identifying causes of unsustainability, and prescribing possible actions (Herweg et al., 1999). Often unsustainability is the result of inappropriate land management and exploitation of resources by land users. To be able to implement SLM, it is necessary to understand what forced land users to engage in unsustainable practices and the prevailing limitations to apply best management options.

About 15 major farming systems are known to operate in Sub-Saharan Africa where over 60% of agricultural population engaged in mixed cereal crops, root crops, maize, highland perennial, forest based and agro-pastoral systems (Dixon et al., 2001). As indicated on Table 2.2, poverty is extensive, particularly in forest based, highland perennial, agro-pastoral and arid systems. These farming systems occupy diverse land characteristics i.e. soil, water, plant and animals; and distributed over different topographic conditions; and agro-climatic zones. In Sub-Saharan Africa, about 70% of the people practice five farming systems, which are: (i) Highland Perennial, (ii) Maize-Mixed, (iii) Cereal Root and Tuber Crops, (iv) Agro- pastoral, and (v) Highland Mixed Farming Systems (Grrity et al., 2012). This part of Africa has unique characteristics, shaped by moisture stress with cropland, irrigated land and range land as the dominant land uses. Here, land degradation is widely distributed (Pender 2009).

Farming Systems	Agric.Popn. % of region	Principal livelihood	Prevalence of poverty
Irrigated	2	Rice, cotton, vegetables, rainfed crops, cattle, poultry	Limited
Tree Crop	6	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work	Limited-moderate
Forest Based	7	Cassava, maize, beans, cocoyams	Extensive
Rice-Tree Crop	2	Rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work	Moderate
Highland Perennial	8	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work	Extensive
Highland Temperate Mixed	7	Wheat, barley, tef, peas, lentils, broadbeans, rape, potatoes, sheep, goats, livestock, poultry, off-farm work	Moderate-extensive

Root Crop	11	Yam, cassava, legumes, off-farm work	Limited-moderate
Cereal-Root Crop Mixed	15	Maize, sorghum, millet, cassava, yams, legumes, cattle	Limited
Maize Mixed	15	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work	Moderate
Large Commercial & Smallholder	4	Maize, pulses, sunflower, cattle, sheep, goats, remittances	Moderate
Agro-Pastoral Millet/Sorghum	8	Sorghum, pearl millet, pulses, sesame, cattle, sheep, goats, poultry, off-farm work	Extensive
Pastoral	7	Cattle, camels, sheep, goats, remittances	Extensive
Sparse (Arid)	1	Irrigated maize, vegetables, date palms, cattle, off-farm work	Extensive
Coastal Artisanal Fishing	3	Marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, off-farm work	Moderate
Urban Based	3	Fruit, vegetables, dairy, cattle, goats, poultry, off-farm work	Moderate

Implementing SLM is a multitask endeavour, ranging from situation analysis to remedial activities followed by performance evaluation incorporating policies, technologies and activities (Herweg et al., 1999; WOCAT, 2011; World Bank, 2008). Within the context of Sub-Saharan Africa agriculture that is known for insufficient productivity and inconsistent yield, from season to season, SLM is expected to deliver increases in agricultural productivity within a short term. The solution for this challenge cannot be contained within a single farmer or a farm plot domain; rather, wider approaches that incorporate communities and landscapes is required.

Often times, SLM implementation at individual farmer level, is challenged by insufficient capacity, which is sometimes due to lack of better options for the farmer. Unsustainable activities are continually practiced by such farmers, despite the fact that associated problems and their cause and effect interactions are known to them. Such instances may mislead development agents to assume that farmers know less and conduct unsustainable practices deliberately. There are three ways to increase land productivity, improve food security and also provide for other goods and services (Liniger et al., 2011), which are (1) expansion/extensification, (2) intensification and (3) diversification of land use.

Declining agricultural productivity (yield/ha) is not the only challenge, as lack of adequate land often limits the production of sufficient produce for the consumption of the family (in case of self-producing farmers) (Dixon et al., 2001). The combination of decrease in yield and shortage of farmland complicates the challenge further. In such instances where compounded productivity decline occurs and options for livelihood is limited, farmers are often forced to look for alternative means of income, often communal resources such as forests, wildlife, etc., are the first to be taken advantage of. In cases where off-farm employment options exist, the livelihood pressure can be eased. Otherwise, the environmental degradation continues in the form of unsustainable extraction, unwise management, and competitive distraction of natural resources that lead to severe environmental consequences, including soil erosion, environmental degradation, loss of biodiversity and decline in water resource. The vulnerability continues with erratic rainfall, unpredictability of the weather condition. Furthermore, the lack of proper diet from shortage of food makes farmers weak, which affects their productivity.

Implementing Sustainable Land Management

Implementing SLM with respect to African smallholder farmer needs to address questions on how SLM can be adapted to crop farmers, whose livelihood is based on limited crops; cattle herders and home gardeners. The questions are: What limitations are to be considered: nutrient, water, land availability/ sufficiency? Are the institutional framework, policy environment, land administration and ownership conditions conducive? What can a single farm household deliver in terms of SLM?

The willingness of farmers to engage in SLM is not only a function of unsustainability; it is about the viability and acceptability of the introduced activities. Implementation of SLM combines the basic principles of land-use planning (FAO, 1993), ecosystem management implementation steps (Brussard, 1998), principles of SLM (Smyth and Dumanski, 1993), SLM practice (WOCAT, 2011), and SLM guidelines (Herweg et al., 1999).

Some of the important questions to be asked in the planning phase of SLM include: what is the present situation? Is change desirable? If so, what needs to be changed? How can the changes be made? Which is the best option? How far is the plan succeeding? (FAO, 1993). Participation of all stakeholders is necessary where the views of local land users provide sound knowledge of locally adapted land management, while external views help to broaden local horizons to be able to develop a common strategy of intervention and action (Herweg et al., 1999).

With respect to agricultural risk, the primary objective of SLM is to avoid or reduce the possibility of risk occurrence through mitigation, transfer, coping and avoidance approaches of ARM (Table 2.3). To be able to create resilient livelihood options for the farmers and maintain the natural resources base, SLM is expected to involve technologies that are appropriate; policies that address economic, social and ecological issues, and actions that can recognize farmer capabilities.

Table 2.3. Links between SLM and ARM

SLM objectives	ARM approaches		
Increase productivity Reduce production risk Prevent resourced degradation Develop economic viability Insure social acceptability	Mitigation	Transfer Coping	Avoidance

Ecological principles of land management suggest the following guidelines (Dale *et al*., 2000). 1) Examine impacts of local decisions in a regional context, and the effects on natural resources, 2) Plan for long-term change and unexpected events 3) Preserve rare landscape elements and associated species, 4) Avoid land-uses that deplete natural resources 5) Retain large contiguous or connected areas that contain critical habitats 6) Minimize the introduction and spread of non- native species 7) Avoid or compensate for the effects of development on ecological processes 8) Implement land-use and land-management practices that are compatible with the natural potential of the area. Concerning natural resources management, three relevant uncertainties concerns ecosystems, livelihood and knowledge.

Steps for SLM implementation include (adapted from Brussard (1998)):

- Define SLM implementation unit. This can be a farm, landscape, or watershed;
- Determine management goals based on the five pillars of SLM, namely: productivity, security, protection, viability, acceptability;
- Collect data on the level of unsustainability, including degradation of soil, water, plant and animal resources;
- Obtain socio-economic data, emphasizing livelihood analysis and social values;
- Determine measurable indicators that take into account the 3 pillars of economic, ecologic and social sustainability;

- Manage adaptively with technologies that are appropriate and activities that are participatory;
- Monitor the performance of the land-use.

To be informed about these issues, proper diagnosis based on reliable data is necessary. Analysis of all relevant stakeholders is important, not only to involve those who are affected, but also because they have first-hand information about the challenges they face more than the external experts. The is important to determine the existing management potential of the people as it helps to identify the gap between what is available and what is needed in terms of resources, technology, institution, policy and in relation to this, what is culturally acceptable or not requires understanding.

Once the situation is analysed with proper data and careful observation of the trends, and by analysing the cause and effect relationship, it is important to draw plan of action that can address the interlinked challenges. Short term fixes to address immediate productivity issues need to be augmented by long term adaptation strategies. Technologies that can fix immediate problems also require careful scrutiny about equally important environmental significance. Multipurpose technologies are more suitable to such cases. Conversely the introductions of such technologies need testing after acceptability and adaptability, however important they can be.

Sometimes, farmers may choose technologies that are financially rewarding but environmentally and socially questionable, hence unsustainable. Such technologies may lead to excessive resource extraction; mono cropping that can be risky and market challenges. In spite of their immediate or log-term risks, such technologies could be pursued basically due to their short term, often economic, rewards. The same can be said with types of crops produced. The dilemma with such crop/ technologies is that they are preferred engagement by the farmers.

Externally imposed remedial measures can be less effective unless they are well integrated to the local settings. Thus, any external technological intervention should take the local environmental, social, and economic situations into consideration. Likewise, awareness is one of the major components to bring about change. However, awareness about SLM should be accompanied with appropriate and equally attractive technologies in order to bring about the des ired change. The role of policies and their implementation is also an important component. However, unless they are supported by viable incentive mechanisms they may not achieve much. It is important to augment the action plans implementation schedule with interim milestones that can be used to track changes. This is followed by development of criteria towards meeting the set out goals.

SLM do not end in the farm fields alone, enhancing productivity may not be enough however well achieved. Unless the products get deserved value, SLM is not achieved. Post-harvest loss reduction, value adding, proper valuation and marketing are equally important for the success of SLM. SLM cannot be achieved within limited time project cycle as well. Progressive improvement is required and good practices need scaling up to reach wider spatial expanse to address transboundary issues.

Strategies for Sustainable Land Management

Various strategies exist to achieve SLM (Table 2.4). For instance, a vision for improved land and water management in rural landscapes (World Bank 2006) listed the following strategies:

- Increased planning and implementation of land and water management at the watershed scale;
- Widespread awareness of the importance of both productive and environmental services of land and natural resource management;
- Better targeting of farm inputs via precision farming and increased use of conservation and no-till and direct seeding farming methods;
- Increased use of integrated crop protection methods and a significant reduction in pesticide use;
- Integrated land and water management and optimization of farm nutrient balances through nutrient bookkeeping;

- Major investments for manure storage and management in intensive livestock operations;
- Protection of riparian zones via vegetative filter strips, rehabilitated wetlands, and zero tolerance for nutrient leakages into local streams;
- More efficient water use in irrigation and the recycling of waste water.

Best land management practices address and harmonises the three aspects of SLM; i.e. improves productivity, enhance people's livelihood and preserve the ecosystems.

Table 2.4. Strategies and practices to improve land productivity and yields (Source Liniger et al., 2011).

Principles	Aim	Strategies	SLM practices
Water use efficiency and productivity	Increase plant water availability in rainfed agriculture	minimise run-off; maximise rainfall infiltration and storage in the soil	soil cover, composting, contour cultivation, conservation agriculture, life barriers, soil / stone bunds, terracing, fanya juu, etc.
		reduce non-productive evaporation harvest & concentrate rainfall through runoff to crop area or for other use	good plant cover, intercropping, mulching, windbreaks, agroforestry, etc planting pits, semi-circular bunds, microbasins, contour bunds, stone lines, vegetative strips, trash lines, runoff and floodwater farming, small dams, etc.
Plants & their Soil Fertility	Increase plant water availability in Irrigated agriculture	minimise water losses from irrigation system efficient and effective application of water	lining of canals, deep and narrow instead of shallow and broad canals, good maintenance, pipes, etc. watering can irrigation, drip irrigation, micro sprinklers, low pressure irrigation system, improved furrow irrigation, supplemental irrigation, deficit irrigation, etc.
		recharge aquifer / groundwater; water collection to enable off-season irrigation	small dams, farm ponds, subsurface tanks, percolation dams and tanks, diversion and recharging structures, etc.
	Increase plant water uptake	increase productive transpiration	afforestation, agroforestry, optimum crop rotation, intercropping, improved crop varieties, planting date, etc.; vigorous plant and root development through soil fertility and organic matter management, disease and pest control, weed management, etc.
Soil Fertility	Improved nutrient availability and uptake	Reduce nutrient mining and losses	composting and manuring (e.g. corralling) integrated fertility management (organic combined with inorganic), microfertilization, green manuring, rotations including legumes, improved fallows with leguminous trees and bushes, enrichment planting of grazing land, rotational grazing, etc.
		improve soil nutrient holding capacity and plant nutrient uptake capacity use best suited planting material and optimise management	minimum to no till, improve soil biotic activity, increase soil organic matter, mulching, manage avoid burning (residue management), etc; adapted varieties, etc.
Plants & their management	Maximise yields	use best suited planting material and optimise management	choice of species, varieties, provenances, etc.; short season varieties, drought tolerant varieties, pest and disease resistant varieties, etc.; planting dates, plant geometry, fertility and water management, etc.
Micro-climate	Create favourable growing conditions	Create favourable growing conditions	windbreaks, agroforestry, hedges, living barriers, parklands, good soil cover, dense canopy, etc.
		optimise temperature and radiation reduce mechanical damage of plants	agroforestry, vegetative and non vegetative mulch, etc. windbreaks, barriers, vegetative and non vegetative mulch, etc.

In the use of SLM for ARM, there is no generic one-for-all strategy and approach. Strategies can vary depending on ecological, social, cultural and economical factors. For instance, in agro ecologically, less favoured areas, farmers can use a variety of risk minimization strategies based on biological sources of nutrients, adapted crop varieties or species, and integrated land and water management (World Bank, 2006) (Table 2.5).

Table 2.5. Generic practices for effective nutrient management and sustainable cropping (Source: World Bank, 2006)

Practices	Description
Minimize soil erosion and leaching	The most effective way to reduce soil erosion and leaching is to maximize soil cover via the use of cover crops and mulches and by integrating perennials in vegetative strips along the contours to further stabilize the soil.
Recycle organic nutrients	One method is to return all crop residues to the field of origin. In many cases, however, crop residues are fed to livestock. Ideally the livestock should be fed the residues in the field so that the manure goes directly onto the soil. If the residues are removed and fed to livestock elsewhere, the manure should be returned to the field as soon as possible.
Enhance biological sources of nutrients	Nitrogen-fixing trees, shrubs, and herbaceous and crop species can fix nitrogen from the atmosphere and make it available to subsequent crops via biological or associative nitrogen fixation.
Compensate for nutrient loss	Add nutrients first as green or animal manure and, if necessary, top off with inorganic fertilizers. Where soil nutrients have been severely depleted, it is often necessary to restore the minimum levels required for adequate plant growth and yield.
Select and use adapted and efficient species	Some leguminous tree and crop species are able to fix nitrogen at very low levels of available soil phosphorus. Leguminous crops that combine some grain yield with high levels of root and leaf biomass, and thus a low nitrogen harvest, offer a useful compromise in meeting farmers' food security concerns and improving soil fertility.
Optimize fertilizer-rainfall interactions	Rainfall markedly affects fertilizer use efficiency, yet there is almost no guidance as how farmers should adjust fertilizer use to seasonal rainfall.

Unless common ground rules are put in place, individual farmers' relentless drive to increase yield and income can compromise common environmental goods. As sustainability principle demand, systemic approach, based on unit of landscape or environmental system, is important. System level practices are important because at a system level, the input and output are contained within the defined space and time (the cause and effect of a given SLM action can be bounded within such a scale). Therefore, SLM technologies, policies and activities have spatial context at a farm, landscape, watershed or regional scale.

Technologies for Sustainable Land Management

There are several technologies for SLM implementation (Table 2.6). Some are specific to a given land component (e.g. soil conservation technologies), some are management techniques (e.g. grazing management) while others are multipurpose in nature (e.g. agroforestry). Technologies vary in performance depending on topography and agro ecological zones. Steep slopes require soil conservation structures, while dry lands require water management.

Table 2.6. Sustainable Land Management technologies, practices and approaches (adapted from FAO, 2008).

Approaches	Techniques	Description
Crop production management	Soil fertility improvement through better land husbandry	Land husbandry addresses the totality of the farm household livelihood system with the aim of improving both the productivity and sustainability of its natural resource based land use activities
	Conservation Agriculture	Restore, sustain and enhance agricultural production through the integrated management of locally available soil, water, and biological resources, combined as required with cost-effective use of external inputs.
	Integrated plant and pest management	More comprehensive efforts that combine investigations into various production related problems and includes a variety of focus areas ranging from integrated pest management (IPM) to integrated plant nutrient management (IPNM).
Pastoral and livestock management	Integrated crop-livestock farming system	community-based approaches and have led to improved cycling of nutrients between rangelands and crop land, and between ruminant livestock and the soils
	Opportunistic management	in response to uncertainties over rainfall and feed availability in arid and semi-arid environments.
Agroforestry and Forestry	Agroforestry and Soil Fertility Improvement	involving the growing of woody perennials (trees, shrubs, palms, bamboos etc) on the same plot of land used for agricultural crops and/or livestock in ways that permit significant economic and ecological interactions between the woody and non-woody components
	Afforestation and reforestation	involves planting trees for shelterbelts, windbreaks, and woodlots to increase fuel wood, timber and fodder
Freshwater Fisheries	Freshwater fisheries	include fish production in rivers, lakes and reservoirs which require participatory and co-management arrangements related to land and water for reducing over fishing and environmental degradation (e.g. sedimentation, contamination due to agricultural run-off) and ensure sustainable fish supplies.
Water and	Small-scale	Involves the combination of new and indigenous technologies for small-
Irrigation Management	Irrigation and Water Harvesting	scale irrigation (e.g. buried porous ceramic pots, pipe drip irrigation) as well as mechanisms to enhance rainfall capture (e.g. v-shaped micro-catchments).
Community Based Natural Resources Management	Community-based land or watershed planning and management	Participatory approaches to identify local priorities and develop community level action plans for tackling land degradation and low agricultural productivity, through improved ecosystem resource management (soils, water, vegetation, forestry, wildlife etc) within locally recognized landscape or watershed units
Farmers Learning Networks	Farmer Field School Approach For Integrated Soil Management	is based on the concepts and principles of people centred learning It uses innovative and participatory methods to create a learning environment, including learning networks, in which the land users have the opportunity to learn for themselves about particular crop production problems, and ways to address them, through their own observation, discussion and participation in practical Learning-by-doing field exercises.

Traditional vs. Contemporary Land Management Practices

After centuries of cultural and biological evolution, traditional farmers have developed and inherited complex farming systems, adapted to risk-prone situations (Singh and Sueja 2006). The prevailing land management practices, in the majority of African landscapes are neither endogenous nor exotic. They evolved over the common traditional agricultural practices, which include, shifting cultivation, nomadic pastoralism, continuous cultivation and mixed subsistence farming (Kazimirski, 1998). The change is largely attributed to increase of population density, decline of land productivity, change of ownership regimes and institutional setups.

The prevailing condition, today, forced smallholder farmers to opt for increasing yield and income per given area, using selected crops and technologies at the cost of diversity. Such mono-crop practices made farmers vulnerable to biological, weather and market risks. Often, each farmer makes his own agricultural decisions based on available land characteristics, household assets, management options and market conditions. Such unilateral farm level decision can have off- site impacts that may harm the wider agricultural landscape. A common example is the impact of upstream farming activities on downstream environment.

Shortage of agricultural products and increased deforestation has justified yield boosting promises through mono crop cultivation. Crops that are introduced and technologies accompanying them are often in conflict with the African settings. The cultural, economic, environmental and management options were not well understood before the introduction of the technologies. Some soil conservation practices, however good intentioned, are less accepted due to their design flows and the problems they pose.

The conditions responsible for traditional land management have gradually weathered away in the face of increasing population density, because they were land intensive. Farmers are now forced to increase productivity per surface area and per crop. This was not the case earlier when diversified farming style was promoted as long as sufficient production was maintained. The home gardens/ diversified agriculture have given way to monocrop. The native agricultural crops are overtaken by introduced varieties; so are indigenous trees. Shifting cultivation, which was aimed at regenerating soil nutrients by resting the land from cultivation, was seriously challenged by forced shortage of fallow periods. Nomadic pastoralism thrived in unsuitable places for rain-fed agriculture. Grasses which are non usable for human consumption are converted to high value food, like milk and meat. Seasonal movement of animals in search of pasture and water has been challenged by increasing boundaries and evolving private ownership of the previously communal land.

The conditions under which traditional /indigenous land management practices used to operate have changed. Land became scarce due to population density. Free grazing was restricted due to change in land tenure. Labour supply is strained as a result of changed social interactions while subsistent farming was changed to market oriented engagement. Consequently, in many places, traditional practices failed to be viable options.

Traditional agriculture has several important features to be copied from for contemporary SLM processes, especially in the context of ARM. The principal features of traditional agriculture are risk aversion, diversity, mimicking of nature, low input, and permanent vegetation cover (Table 2.7). The merits of traditional agriculture are already recognized and some of the features are promoted in contemporary smallholder agriculture. Unlike in previous times where small holders are self-sufficient at community level through exchange of labour, risk and bartering, today, they are strongly tied with the “outside” world through market, political and social integrations. Markets determine the production and farmers buy what is lacking in their livelihoods, including food. Market bring price which is determined by supply and demand, more often shaped by access to market and market forces and value adding capability.

Table 2.7. Common characteristics of traditional agriculture (Source Kazimirski 1998).

Characteristics	Description
Focus	Mainly risk aversion by balancing productivity and diversity
Conditions	Communal property of land and low population density
Elements	Risk aversion, diversity, permanent vegetation cover, low input
Types	Crop farming, grazing, subsistent mixed farming
Knowledge transfer	Experimental learning, from older person to younger
Scale	Localized in space and sustained through time

Sustainable Land Management Indicators

Although SLM is widely promoted to prevent and mitigate land degradation and desertification, it's monitoring and assessment has received little attention (Schwilch *et al*, 2010).

SLM indicators are about understanding changes: changes with regards to land productivity in a negative or positive direction. The justification for implementing SLM is the widespread unsustainable use of natural resources, and its negative impacts such as, land degradation. Thus, the performance the effectiveness of SLM in bringing about the desired outcome needs to be measured. In this regard, measurement scales should not only reflect relative values, but also, absolute figures. Setting a threshold above the productivity functions of a given land is necessary. Similarly, it is important to visualize the threshold below which the ecosystem functions would collapse.

To be able to understand changes brought about by implementing SLM and be able to outline indicators, criteria accompanied by measurement scales and logical stepwise queries are important. First, it is important to perceive change occurring and its positive or negative direction. Second, there is a need to understand what is changing in the process. Is it the productivity that is affected? Third, what is the scale of change? How big or small is it? Fourth, what is the rate of change, is it rapid or slow? Fifth, what processes of change are in motion? Sixth, why have these processes of change been set in motion? For each of these sequential lines of enquiry, the data to be recorded varies in depth and breadth, as well as in time.

Conceptualizing, listing, analysing and synthesizing SLM indicators have academic, research and development implications. Academics tend to match the right and relevant indicators with the intended outcome; i.e. conceptualize each indicator, list them and analyse their performance and role in attainment of SLM by understanding the process. The research part of it refines cause and effect relationships, defines threshold beyond which desirable outcomes emerge, and examine the benefit of diversity and level and balance of inputs and scenarios of certain model of human environment interactions.

Land quality and land use suitability are at the core of SLM indicators. The levels of quality implicitly indicate how sustainable the resources are. Suitability is about matching land with its intended use. In the perspective of sustainability, which is the fact of spatial and temporal scale, land quality measures require to adhere to scale issues.

Rather than managing multiple resources independently, an ecosystem-based approach focuses on the collective management of all resources, maintaining ecological integrity, while allowing resource extraction (Leech et al., 2009). Assessment of agro-ecological potential of the land is important to capture the agro-ecological factors that are relevant in the socio-economic and political context (Bouma, 2002).

According to Gallopin (1997), the functions of indicators are: (1) to assess conditions and changes; (2) compare across place and situations; (3) assess conditions and trends in relation to goals and targets; (4) provide early warning information; and (5) anticipate future conditions and trends. Indicators measure change in relation to a reference point which is a threshold. Threshold is a boundary level of a variable, which is regarded as an expertise to represent the point at which significant changes occur. When an indicator passes a given threshold, then the system is considered to be unsustainable or on the way to unsustainability. Issues arise as to the identification of a threshold level (be it qualitative or quantitative), whether passing a threshold level for one indicator is sufficient to signify unsustainability, or whether several indicators need to have passed their threshold levels before the system is unsustainable (Woodhouse *et al.*, 2000).

Indicators should provide relevant and robust measures, clear and straightforward to interpret; consistent with systems-based information; based on accepted standards, recommendations and best practices; constructed from well-established data sources (SDSN, 2014). Indicators are also scale/level dependent, constructed differently at plot, farm, watershed, region or agro ecological zones. It is useful to identify two sets of indicators: those identified by external experts, such as: the project

researchers; and, those internally identified by the different stakeholders in the systems (Woodhouse *et al.*, 2000). For indicators, a fundamental issue is time to know what has changed with regards to the biophysical environment, people's perceptions, changes in management and livelihood strategies, policies and institutions and how these have affected each other.

The following criteria were identified by Muller (1996) for assessment of agricultural systems: efficiency, resilience and biodiversity, rules for natural resources management, basic life support functions, and satisfaction of basic needs. Gomez et al., (1996) constructed farm-level indicators including yield, profit, frequency of crop failure, soil depth, organic carbon and permanent ground cover. Farm-level indicators have several important purposes, particularly developing farmer's capacity towards more sustainable land-use. According to Howlett (1996), the purposes of farm-level indicators are:

- To develop capacity and commitment of farmers towards more sustainable land-use, and to allow farmers to evaluate their own practices;
- For the simple diagnosis of problems and improvements to farming practices, and development of appropriate research and extension activities;
- To enhance (or improve) the relationship between the researcher, farmer and extension agent, and through this, encourage farmer participation, the incorporation of indigenous knowledge, and ultimately to an increase in the adoption of improved technologies;
- To assess and monitor the spatial and temporal sustainability of different farming systems, and to use this for the evaluation, prediction, planning and management of these systems by farmers, researchers, extension agents and planners.

Steps to develop SLM indicators (Woodhouse *et al.*, 2000) are:

- Identification of an initial set of «external» indicators based on literature review;
- Identification of an initial set of internal (community) indicators through interviews and participatory methods with key stakeholders;
- Development of a combined set of indicators for field testing and monitoring;
- Analysis and selection of final set of indicators which are practical, meaningful and measurable.

At its core, SLM is land capability classification and land suitability analysis for a given land-use. These incorporate two complementary factors: quality measure criteria and methods of measurement. Moreover, the managementaspect encompasses the process involved and procedures to be followed. After implementation of the activities, it is important to measure the resulting success and challenges.

The principles of sustainable land management evaluation (Smyth and Dumanski 1993) include:

- Sustainability evaluation for defined kinds of land-use;
- Sustainability evaluation related to specific land sites;
- Sustainability evaluation as a multi-disciplinary activity;
- Evaluation made, in terms relevant to the physical, economic and social contexts of the areas concerned;

- Sustainability relates to a defined time frame;
- The processes and practices of any existing present land-use should be fully understood and its present suitability established before change based on sustainability evaluation is recommended;
- Evaluation based on scientifically valid procedures and data and on a choice of criteria and indicators of sustainability, which reflect understanding of causes, as well as of symptoms.

Land quality refers to the condition of land, relative to the requirements of land-use, including agricultural production, forestry, conservation, and environmental management. Core land quality indicators (Dumanski and Pieri 2000) include: soil quality, land degradation, and agro-biodiversity. Other land quality indicators include: water quality, forestland quality, rangeland quality, and land contamination/pollution.

Integrated methodological framework for land degradation and SLM Monitoring and Assessment (Reed et al., 2006) allows to:

- Identify system boundaries, stakeholders and their goals;
- Describe socio-cultural, economic, technological, political and environmental context and drivers of change;
- Determine current land degradation status, future land degradation risk and existing SLM using indicators;
- Identify, evaluate and document existing SLM options;
- Prioritize SLM options with stakeholders;
- Trial and monitor SLM options in field;
- Up-scale/aggregate biophysical and economic effects of SLM from field to region/nation to further prioritise options;
- Finalize selection of indicators (in collaboration with users) to represent relevant system components for ongoing monitoring by land managers;
- Disseminate SLM strategies and indicators for extension as well as national and international policy;
- Apply SLM strategies, monitor degradation and progress to sustainability goals, up-scaling or aggregating to district and national levels;
- Adjust strategies to ensure goals are met.

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3

Control and Management of Pests and Diseases In Agricultural Nursery

J.C. Onyekwelu, F.S. Agbidye and I.A. Okunlola

Summary

Nursery management is very important in obtaining the right kind of seedlings, in the right quantity and at the right time, which are fundamental for successful agricultural production. Raising seedlings in the nursery is essential for the survival and early establishment of some agricultural and forest plant species. However, numerous pest and diseases attack seedlings in the nursery, thus posing great risks to their survival and obtaining healthy and high quality planting materials. Sometimes, the threat to seedlings by pests and diseases can be enormous, consequently it is imperative to prevent, control or manage them, depending on their severity and economic importance. Prevention and therapy are the simplest strategies for control and management of pest and diseases, with prevention being the most preferred method. Prevention strategies are applied before infection while therapy or curative methods are applied after the plants have been infected This chapter discusses principles for producing healthy seedlings, measures for maintaining good hygiene in the nursery as well as measures for control and management of pests and diseases with the aim of avoiding/minimising the risks/damage associated with them. The control measures discussed includes: cultural, biological chemical, mechanical methods, resistant crop varieties and Integrated Pest Management (IPM). The effectiveness of these measures varies depending on the nature of pest and disease, stage and severity of attack, duration of attack and environmental conditions. In addition, the chapter presented some African case studies of pest and disease attacks and their control measures; learning objectives; suggested reading materials and some questions for study and discussion.

Resume

Controle et gestion des pestes et maladies de plantes en pepiniere

La gestion d'une pepiniere est cruciale dans I'obtention de plantules adaptees, en quantite adequate et au moment opportun pour une production agricole. La production de plantules en pepiniere est essentielle pour la survie et l'etablissement premature d'especes agricoles et forestieres. Cependant, beaucoup d'attaques par des insectes nuisibles et des maladies sur les plantules en pepinieres sont frequentes. Ceci entraine des risques sur leur survie et l'obtention de plantules de qualite. Parfois les menaces sur les plantules par les insectes nuisibles et maladies peuvent etre tres importantes. Par consequent, il est imperatif de prevenir, les controler et gerer sur la base de la severite et de l'importance economique. La prevention et la therapie sont des strategies de controle et de gestion d'insectes nuisibles et de maladies, ou la prevention est la methode la plus preferee. Les strategies de prevention sont appliquees, avant l'infection, tandis que, la therapie ou les methodes curatives sont utilisees apres que la plante ait ete infectee. Ce chapitre aborde les principes de production de plantules saines, la prise de mesures pour le maintien de bonnes conditions d'hygiene dans la pepiniere, aussi bien que les mesures de controle et de gestion dinsectes nuisibles et maladies, avec l'objectif d'eviter / minimiser les risques et dommages associes. Les mesures de controle discutees concernent

: les methodes culturales, biologiques, chimiques et mecaniques, des varietes de plantes resistantes et la Gestion Integree des Pestes (IPM). L'efficacite de ces mesures varie en fonction de la nature des insectes nuisibles et des maladies, le niveau et la severite des attaques, la duree des attaques et des conditions environnementales. En outre, le chapitre presente des etudes de cas en Afrique sur les attaques d'insectes nuisibles et de maladies, ainsi que les mesures de controle, les objectifs d'apprentisasge, la bibliographie a consulter et les questions devant faire l'objet d'etude et de discussion.

Introduction

Obtaining the right kind of plant seedlings, in the right quantity and at the right time is fundamental for successful agricultural production. One of the major constraints faced by farmers in intensifying and diversifying land-use in agricultural production is lack of access to adequate germplasm, (i.e. planting materials such as seeds and seedlings) (Bohringer *et al*., 2003; Place and Dewees, 1999). Plant seedlings are usually raised in the nursery before transplanting to the field. For some agricultural and forest plant species (e.g. oil palm, cocoa, coffee, cotton, pinus spp, eucalyptus spp, etc.), it is essential that the seedlings are first raised in the nursery to enhance their survival and early establishment when transplanted to the field.

Nursery crop production is the art and science of raising seedlings (young plants: trees, shrubs, vines agricultural crops, etc.). Nursery is an important sector in agricultural production all over the world. With the increasing demand for agricultural products, the need for good agricultural practices and higher agricultural productivity, the importance of nursery will continue to increase. Also, the demand for large quantity and high quality seedlings will continue to increase, which can only be obtained from nurseries. Seedlings can be produced to feed large-scale planting programmes, local and temporary need or to be sold for commercial purposes. Since nursery practices may influence the success or failure in planting programmes, the role of nursery in agricultural production cannot be over-emphasised (Onyekwelu et al., 2011). Thus, a high degree of control over nursery conditions to ensure that they are reasonably constant and uniform is essential. Every year, hundreds of millions of seedlings are produced in the nursery, which generates billions of dollars in revenue and employs tens of thousands of workers (USDA, 2009). Millions of seedlings were produced in a central nursery to feed the pulpwood afforestation project with *Gmelina arborea* in Nigeria between 1980 and 1990 (Ogunlade et al., 1990). A total of 657 farmer nurseries in Tanzania, Zambia and Malawi produced 934,782 agroforestry seedlings during 1998/1999 growing season and by the following growing season, 956 nurseries in Zambia and Malawi alone produced 1,767,602 (Table 3.1), indicating a 252.4% increase in the number of seedlings produced in Zambia and Malawi compared with the previous growing season.

Table 3.1: Total number of farmer nurseries recorded by ICRAF and partners and total nursery output in three study areas of southern Africa over two growing seasons (1998-2000)

Growing season	1998/1999		1999/2000	
Study area	Number of nurseries recorded"	Total number of seedlings produced	Number of nurseries recorded[a]	Total number of seedlings produced
Shinyanga, Tanzania	150	234,379	288	N/A
Eastern Province, Zambia	204	121,244	339	167,498
Southern Region, Malawi	303	579,159	617	1,600,104
total	657	934,782	1244	1,767,602

Source : Bohringer et al., 2003

[a] Note that numbers indicated are the ones ICRAF and partners were able to record; total actual numbers of nurseries established by farmers in each location are expected to be higher.

The availability of strong and healthy nursery stock is the aim of all nursery managers. However, numerous pest and diseases are known to attack seedlings in the nursery, thus posing great risk to their survival and obtaining healthy and high quality planting materials. A pest is any biotic (biological) stress factor that interferes with the healthy development of seedling and causes a sustained departure from the normal physiological or morphological condition that characterizes a healthy seedling. A plant disease is a disturbance that interferes with the normal structure, function, physiology or economic value of a plant, it is deviation from the normal physiological functioning of a plant which is usually manifested externally as symptoms. Pest and disease can be micro-organisms (e.g. fungi, bacteria, virus, etc.), weeds, and animals (e.g. insect, nematode, rodent, etc.). Various pest and diseases have been recorded in plant nurseries, some of which are major impediments to production of healthy seedlings. The threat to seedlings can be enormous due increase in their population, emergence of new pests and disease species, severity and duration of attacks (Hurley *et al.,* 2007; Nyeko, 2005; Roux *et al.,* 2005). The increase in pest and disease attacks is partly due to high seedling densities, improper nursery practices (Sharma, 1990), changes in climatic conditions, etc. Thus, plants are continually challenged by pest and disease agents that may enter the nursery via: infected plants; infested soil, equipment, clothing; windblown fungal spores, aerosols containing bacteria, insects transmitting viruses and phytoplasmas, etc. (Douglas, 2009). It is therefore imperative to prevent, control or manage pest and diseases in the nursery, depending upon their severity and economic importance.

There are many strategies and techniques for pest and disease management, the simplest of which consist of two principles: prevention and therapy (Maloy, 2005). Prevention includes disease management strategies applied before infection (i.e. plant is protected from disease), while therapy or curative action are measures applied after the plant has been infected (i.e., plant is treated for the disease) (Maloy, 2005). Some pests and diseases are difficult to control once established in a nursery, thus prevention is the most preferred form of control and management as well as the best way to reduce pest management costs. It is widely accepted that the best method of preventing and/or reducing prevalence of pests and diseases is by increasing sanitation across the nursery (Adkins *et al.,* 2009; Roux *et al.,* 2005).

Although damages by pest and disease cannot be completely avoided, the risks posed by them can be prevented or minimized. The first step in diagnosing pest and disease problem is recognizing that the problem exist. The manager must routinely monitor the nursery and learn what healthy seedlings look like under all conditions (Mangini, 2012). Once this healthy standard is established, the manager can spot abnormalities. Also, routine monitoring facilitates early detection of the problem, when it is relatively simple and inexpensive to treat and before extensive damage occurs.

Over the years, various control and management measures have been adopted to reduce the risks associated with pests and diseases in the nursery. These measures range from cultural, biological chemical, mechanical methods, resistant crop varieties, etc. Their effectiveness varies depending on the nature of pest and disease, stage and severity of attack, duration of attack and environmental conditions. In an attempt to address the concerns associated with the use of the various control measures, researcher have proposed alternative procedures for plant protection, using a minimum of broad-spectrum chemical insecticides in combination with selective chemicals, biological agents, and cultural practices. This holistic approach, termed Integrated Pest Management (IPM), is evolving and is being widely implemented. The use of IPM system should be based on sound knowledge of the biology, behaviour and population dynamics of pests and diseases and should operate under favourable socio-economic conditions (James *et al.,* 2010; Padi and Owusu, 2014).

Learning objectives

The general objective of this chapter is to discuss measures for controlling and managing pests and diseases in agricultural nursery with the aim of avoiding/ minimising the risks/damage associated with them. The specific objectives include:

- Discuss principles for producing healthy and good quality seedlings;
- Examine the measures for maintaining good hygiene in the nursery;
- Review some pests and diseases associated with plant nurseries;
- Review the management practices used to control and manage pests and diseases in nurseries;
- Discuss the principles and workings of Integrated Pest Management (IPM) system. as a holistic method for managing pest and disease problems in the nursery.

Learning outcomes

It is expected that the student shall acquire practical knowledge and as such be able to know/acquire:

- Principles for producing healthy and good quality seedlings in the nursery;
- How to prevent/minimize pest and disease infestation in the nursery through hygiene measures;
- Good knowledge of some pests and diseases associated with nursery plants;
- Have a good understanding of the various methods (biological, cultural and mechanical, physical, use of resistant varieties) of pest and disease control;
- Have a good understanding of the principles and workings of Integrated Pest Management (IPM).

Concept of Agricultural Nursery, Nursery Pest and Diseases, their Control and Management Measures

Concept and Definition of Agricultural Nursery

The 2012 global food insecurity report revealed that about 870 million people (representing 12.5% of the global population) do not have enough food to eat (FAO, 2012). The vast majority of the global hungry populations live in developing countries, especially in sub-Saharan Africa where the prevalence of undernourishment is now estimated at 14.9%. In sub-Saharan Africa the incidence of hunger increased from 170 million people between 1990 and 1992 to 234 million between 2010 and 2012 (Hunger Notes, 2012). As the need to produce more food to feed the growing population increases, so will the importance of agriculture. In view of the importance of agriculture in the socioeconomic development of a nation, in feeding the high global population and the importance of managing agricultural resources on sustained basis, adequate supplies of high quality planting materials are required. One major difficulty encountered in agricultural production is shortage of quality seedling. The provision of qualitative and quantitative food can only be achieved from healthy plants, which are produced from vigorous and healthy seedlings raised in the nursery. Consequently, the need for nursery is basic in agricultural production.

Nursery is defined as a place where young plants (trees, shrubs, vines, agricultural crops, etc.) are grown to usable size through intensive care and management, with the aim of producing high-quality plant materials for transplanting to the field or for commercial purpose. In the nursery, young seedlings are tended to develop in such a way that they will be able to endure hard field conditions. Nursery seedlings survive better than those from seeds sown directly in the field or through natural regeneration. Nurseries are broadly classified according to:

- Type of plants grown: fruit plant nursery, vegetable nursery, ornamental plant nursery, medicinal and aromatic plant nurseries, forest tree nursery, etc.;
- Type of sale: retail nursery and wholesale nursery;
- Type of ownership: private nursery, public nursery and community nursery.

Importance of Nursery in Agricultural Production

When plant seeds self-sow (fall), germinate and grow in their natural environment, only a limited number usually survive even where there are optimal conditions for seed germination and seedlings growth. Seeds sown directly in the field over a large extent of land are not usually given adequate tending operations (e.g. watering, fertilisation, weeding, pruning, etc.) necessary for good establishment and growth. As a result of the intensive care and tending operations given to seedlings in the nursery, the nursery provides the optimal conditions for seedlings to grow into healthy and strong plants thereby increasing not only the number of plants produced but also their vigour and chances of survival in the field. Consequently, the importance of nursery in agricultural production cannot be over emphasised. Some specific importance of nursery in agricultural production includes:

- Seedlings of most plant species fail in competition with other plants. Thus, the seedlings are raised together, free of competition, until they are sturdy enough for planting out;
- The right growing conditions for healthy, vigorous seedlings are provided in the nursery. Soil preparation and tending operations in nursery are intensive, ensuring high survival rate and early seedlings establishment in the field;
- Some plant species grow very slowly and if the seeds are sown directly in the field, the seedlings are suppressed by weeds and are ultimately killed. Therefore, the seedlings are raised in the nursery and planted out, when they are not liable to damage by weeds;
- Some plant species do not seed every year. These species can only be raised by sowing all available seeds in nursery to be transplanted when required;
- For introduction of exotic species, the seedlings are usually raised in the nursery where they can be closely monitored for provenance and species evaluation trials;
- Production of uniform-sized planting stocks (seedlings) is only possible in the nursery;
- Protection of seedlings against animals, diseases, insects, rodents, etc. are provided in the nursery. This enables selection of vigorous and disease-free seedlings for planting;
- Nursery operations can be planned such that seedlings are available at the beginning of planting season. This saves time, money and efforts of the farmers to raise seedlings.

Techniques/Principles for Producing Healthy and Good Quality Seedlings in the Nursery

The way seedlings are handled in a nursery determines their survival after planting. Field survival, establishment and productivity of planted seedlings are related to the quality of the seedlings used. Good quality seedlings are more likely to survive, establish early with higher productivity than poor quality ones. It is often better to produce a few seedlings of high quality than many of poor quality. Thus, improving seedling quality will lead to high survival, growth and productivity. The nursery manager should aim at producing uniform and good quality seedlings that will survive and grow well under the prevailing climatic conditions when transplanted to the field. Targeting seedling production to the anticipated planting site is an important step in producing strong healthy seedlings. Seedling quality is governed by the genetic make-up of the parent trees, physical growth of the seedlings, tending operations, etc. To obtain healthy and good quality seedlings, the following measures are recommended (CTA, 2007; Onyekwelu *et al*, 2012):

- Proper attention should be given to quality issues when procuring and storing seed for planting, only good quality seeds should be used. This is because seed is the basic input into any planting programme;
- Where possible, use resistant varieties when raising seedlings;
- Seedlings in the nursery bed should not be overcrowded to minimize competition for resources. Overcrowded seedlings tend to be spindly and are easily susceptible to wind throw when transplanted to the field;
- Frequently check the health of the seedlings;
- Ensure sufficient nutrition to create strong and healthy seedlings;

- Weeding should be done regularly to prevent weeds from competing with seedlings for moisture, nutrients and light;
- Watering should be undertaken twice daily (especially during hot dry days) to protect seedlings from wilting. Avoid watering when the sun is high to prevent root burn;
- Control insects and diseases like damping-off, etc., which could destroy seedlings. Damping-off is mainly caused by overcrowding the seedlings;
- Control pests and disease from the start when their population is still small; spray the seedlings with appropriate pesticide in case of pest problems;
- Fence off the nursery to prevent damage of seedlings by animals;
- Seedlings should be hardened-off by gradually by reducing the shade and frequency of watering. This allows them to get used to field conditions before transplanting.

Constraints to Nursery Production: Pests and Diseases

Pests and diseases are common in agricultural production. To a farmer, all organisms that reduce crop yield are considered pests and/or diseases. Fungi, bacteria and viruses are disease causing organisms, which could interrupt or modify the vital functions of growing plants. Most crop pests are insects, mites and nematodes. In Africa, mammals (e.g. elephants, monkeys, etc.), and birds (e.g. sparrows, starlings and crows) can also damage crops. One major constraint farmers face in intensifying and diversifying agricultural production is the increasing incidence and attacks from pest and diseases. Most agricultural plants are damaged, weakened, or killed by insect pests, which could result in reduced yields, lowered quality, and damaged plants or plant products that cannot be sold (Beard et al., 2008). In some cases, the attack is so severe that the whole ecosystem is jeopardized, which could be attributed to increase in pests and diseases population, emergence of new pests and disease species, the severity, duration of attacks, etc. (Day *et al.,* 2003; Hurley *et al.,* 2007; Mendel *et al.,* 2004; Roux *et al.,* 2005). For example, damages to oil palm trees by vascular wilt in some African countries; outbreaks of *Cinara cuppressivora* on cypress in eastern and central Africa; *Sirex noctilio* attacks on pines in South Africa have been reported (Box 3.1; Day *et al.,* 2003; Hurley *et al.,* 2007). Infestations by two insect species *(Leptocybe invasa* and an *Aphis* species) and birds were observed on seedlings in nurseries in Uganda (Nyeko and Nakabonge, 2008). Unless controlled, attacks from pest and diseases can lead to significant loses in farmers' income. Widespread crop damage by fusarium head blight of wheat and barley cost farmers about USD 1 billion in lower yield and poor grain quality (Cook *et al.,* 1995). Such a short-fall in income for farmers has major economic and social effects on the communities dependent on this income. The apparent increase in pest and disease attack in the nursery is partly due to high seedling densities, improper nursery practices (Sharma, 1990), in addition to change in climatic conditions, etc.

It is important to assess the immediate or potential danger to nursery crops posed by pests and diseases. Failure to assess these threats could result in ignoring serious pests and diseases or over-reacting to minor ones.

Box 3.1: Damages to Oil Palm trees by Vascular Wilt

The oil palm, *Elaeis guineensis* Jacq., is the most important and highest oil yielding crop in the world. The fruit pulp yields crude palm oil (CPO) while the kernel produces palm kernel oil (PKO). Africa is the second highest palm oil produces after Asia (Bolivar and Cuellar-Mejia, 2003). The vascular wilt caused by *Fusarium oxysporum* f. sp. elaeidis is the most damaging disease of oil palm in Africa, causing up to 70% mortality (Flood, 2006; Tengoua and Bakoume, 2008). By 1986, vascular wilt affected about 600,000 hectares of palm plantations in Africa (Renard and Ravise, 1986). Losses at nursery level could be up to 40,000 seedlings while the disease can occur from the first year after planting in young oil palm trees (Cochard *et al.,* 2005). Under favourable conditions (susceptible planting material, in an area predisposed to the disease), up to 50% of the trees may be affected (Renard and De Franqueville, 1989). Under unfavorable conditions (uninfected soil with resistant plant material), cumulative losses is less than 1% of trees per year for first generation plantations. Yield losses due to vascular wilt range between 25% and over 70% (Renard and Ravise, 1986; Tengoua and Bakoume 2008). In DR Congo and Cameroon, vascular wilt was reported to be responsible for 25% and 42% mortality, respectively, in oil palm plantations (Tengoua and Bakoume, 2005; Tengoua and Bakoume, 2008).

Principles and Practices for Nursery Pest and Disease Management

The goal of plant disease and pest management is to ensure that crops are healthy enough to yield to their full genetic potential within the physical limits imposed by the uncontrolled variables of climate, weather, and soils (Cook *et al*., 1995). A strong and healthy plant will have less pest and disease problems. Insufficient nutrition makes a plant more vulnerable to pest and disease attack. Management is the process of limiting damage from pests and diseases to a level at or below an acceptable economic or aesthetic threshold (Cook *et al*., 1995). This process does not require total elimination or eradication of the pest or disease problem. It is advisable to start management with cheaper and less destructive methods of cultural or biological control and treat chemicals as an option of last resort. Once infested, damage by pests and diseases may never be completely avoided. Aiming at complete eradication, especially with chemicals can damage natural enemies of the pest; cost more money than is obtained from extra crop yield; pollute the environment; damage human health; and create resistance of the pest or disease against the chemical used.

Knowledge of the biology of particular tree and insect or pathogen may suggest one or more appropriate pest management principles (Stanosz *et al*., 2003). These principles can be considered "strategies," or general approaches to minimizing the effects of damaging agents on agricultural plants. Stanosz *et al*. (2003) highlighted six strategies that are employed in pest and disease management, which includes attempts to control pests and diseases of nursery seedlings and landscape trees. The strategies are:

- ***Avoidance:*** utilisation of locations, conditions, or practices that do not favour, or even suppress, development of disease and/or pest infestations;
- ***Resistance***: utilisation of plants with inherent, genetically controlled characteristics that minimize the impacts of pests and diseases, or use of practices to increase the ability of plants to defend themselves;
- ***Exclusion***: prevention of the introduction of a pest and disease to an area where it is not already present. There are 3 cardinal points in exclusion: (i) interception (ii) elimination, and (iii) prohibition;
- ***Protection***: placement of a barrier or other material (usually chemical) that interferes with interaction of the pest and/or disease with the plant;
- ***Eradication***: removal or destruction of pest and disease life stages to reduce or eliminate the population;
- Therapy: treatment to cure already diseased or infested trees (may involve employment of one or more of the other strategies listed above).

A variety of methods such as physical, chemical, cultural, or biological, etc. may be applied in managing pests and diseases (Stanosz *et al*., 2003). Selection of particular method depends not only on availability, cost, and effectiveness, but also on compatibility of the method with nursery management objectives, environmental impacts, and societal constraints.

Major / Key Pests and Diseases in Agricultural Nursery

Numerous pests and diseases have been documented in agricultural nursery. Some major nursery pests and diseases include: damping-off (Box 3.2), insect defoliators (especially the variegated grasshopper, *Zonocerus variegatus*), large African cricket (*Brachyptrupes membranaceus*), some coleopteran defoliators, capsid, mealybug etc. (Box 3.3; Plate 3.1a — d; Akanbi, 1983; Akanbi and Ashiru, 2002). The nymphs (Plate 3.1c) and the adults of these insects do cause serious damages to leaves and sometimes stems of seedlings in the nursery. Damage done by nymphs and adults of *Zonocerus variegatus* is enormous; sometimes an entire nursery can be defoliated if care is not taken. Nymphs and adults of *Brachyptrupes membranaceus* are notorious in cutting down seedlings and dragging them into their holes in the soil.

Box 3.2 : Damping-off disease of seedlings

Damping-off is a serious disease of seedlings in the nursery, with the potential of causing up to 60% seedlings destruction (Nandil *et al.,* 2013). The disease is the most cosmopolitan nursery disease and affects a wide variety agricultural crops around the world (Landis, 2013). Fungi *(Fusarium* spp, *Rhizoctonia* spp) and Oomycetes *(Phytophthora* spp, *Pythium* spp) are the most common causes of damping-off (James, 2012). There are two types of damping-off: (i) pre-emergence and (ii) post-emergence damping-off. In pre-emergence damping-off, the pathogens attack and cause the death of developing seedlings such that they do not emerge from the soil even if the seeds have germinated. In post—emergence damping-off, the pathogens attack seedling at the soil level, leaving a wound at the collar region of the seedling, which usually turns brownish. The tissues at this point of attack are destroyed by the enzymes produced by the pathogens. This situation leads to prevention of the flow of water and mineral salts to the upper portions of the seedlings. The attacked seedling then falls-off or collapses and eventually dies. In saplings or older seedlings, the situation is called collar rot and the destruction of the plant tissue is slower because of lignification of the plant tissues. In collar rot, the plants usually do not collapse but there is a reduction in the upward flow of mineral salts and water which reduces the growth of the plant. Unsatisfactory nursery practices, such as continuous cropping, have undoubtedly played a major role in development of damping-off and other soil-borne diseases in nurseries. Seasonal effects such as dampness during the wet season, overcrowding, overwatering, poor ventilation of seedlings are also known to promote damping-off disease.

Damping-off is reported to be common in nurseries in Kenya, especially in nurseries where forest soil was used as planting medium (Roux *et al*., 2005). In south Africa, the yield of cowpea (Vigna unguiculata (L.) Walp) was low due to pre- and post-emergent damping-off disease (Adandonon *et al*., 2001). Damping-off is a major nursery disease of Eucalyptus spp, Pinus spp, Rubber, etc. seedlings. The disease can easily be controlled by good phytosanitary practices because the spores of the pathogens are spread by water, soil, or growing media rather than through the air (Landis, 2013). Growing seedlings in a well-ventilated, cool greenhouse will produce far fewer Damping-off problems. Damping-off fungi need high humidity, so seedlings should be thinned promptly to prevent overcrowding, avoid overwatering (especially on cool sunless days when water doesn't evaporate quickly) and ensure good ventilation and air circulation.

Plate 3.1a: Post-emergence damping-off disease attack on cowpea seedlings; 3.1b : Mealybug attack on *Ceiba petandra* seedlings; 3.1c : Nymph of Large African cricket (*Brachytrupes membranaceus*) ; 3.1d : Oil palm seedling blight

Control of these insect defoliators can be achieved by first and foremost removing the nesting sites and destroying the eggs/nymphs of these insects prior to planting the seedlings. Controlled burning of bushes around nursery boundaries should be done to ensure destruction of the eggs and nymphs of these insects. Adults of the insects can be hand-picked and destroyed by nursery attendants on daily basis. Where attack is much, a mild application of systemic insecticides like Dimethoate (Rogor) at 2-5 g (a.i.) can be applied.

Box 3.3: Pest and disease problems limiting cocoa production in West Africa - Capsid

Cocoa *(Theobroma cacao* L.) is one of the most important export crop from West African. Up to 60% of global cocoa production is from Africa. Over the years, production has continued to decline in the three major cocoa producing countries of Cote d'Ivoire, Ghana and Nigeria (Freud *et al.,* 1996). Paramount among the causes of this decline is the ravages by cocoa capsids and other diseases like swollen shoot and cocoa black pod. Capsids, also known as mirids (Heteroptera: Miridae), are the most economically important insect pests of cocoa in West Africa (Padi and Owusu, 2014). Average annual yield loss due to capsid and mealybug attacks is estimated at between 25% and 30%, though yield loss may be as high as 75% if cocoa farms attacked by capsids and left unattended for a period of over three years (Padi and Owusu, 2014). Four genera of cocoa mirid *(Sahlbergella, Distantiella, Bryocoropsis* and *Odoniiella)* are endemic to West and Central Africa. The most widespread and generally economically important mirid in Africa is *Sahlbergella singularis* Hagl. The species attacks cocoa from Sierra Leone in West Africa to Central African Republic in the east. Routine hand collection has given between 1000 and 2000 capsids per hectare and a mean of 6 capsids per 10 trees represent a high and damaging population level (Owusu-Manu, 1995). Extensive feeding by capsids on branches results in tree canopy degradation. Where the damage covers a large area of exposed cocoa, death is easily seen during the dry season, a condition referred to as "capsid blast". If crowns of persistently attacked trees are extensively reduced by die-back, the condition is known as "stag headed". Flowering and pod setting are severely affected by previous season's attack. In extreme cases, whole trees become unproductive and die. Seedlings may fail to become established and, if they are not killed, capsid attack delays their maturity by several years. Feeding by cocoa mirids is characterized by dark markings known as «lesions», on both pods and shoots, which result from the collapse of plant tissue caused by the toxic saliva. Secondary damage characterised by canker and die-back occurs when the feeding lesions are invaded by parasitic fungi like *Calonectria rigidiuscula* Berk and *Fusarium decemcellulare,* resulting in the death of the shoots and branches. Light and humidity are the main climatic factors that influences the abundance of cocoa capsids.

Control and Management Strategies of Pests and Diseases in the Nursery

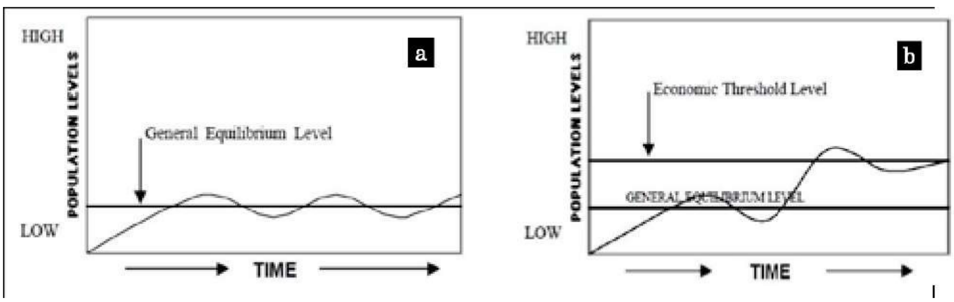
The key to effective plant health management is prevention (Douglas, 2009). Healthy, vigorously growing plants is less prone to pests and diseases attack than weak or stressed ones. It is much easier to prevent a pest problem than to control, thus, early detection make any outbreak much easier to manage.

Nursery sanitation is key to prevent and/or reduce outbreak of pests and diseases. Sanitation is best accomplished by promoting good hygiene procedures, removing leaf litter and trash, grasses and weeds, eliminating standing water from the nursery area and washing seedling containers with solution of chlorine bleach and water after each season (Josiah and Allen-Reid, 1990). Hygiene management practices should be introduced before infection and followed assiduously in nurseries to reduce pressure from diseases enhanced by poor sanitation (Adkins et al., 2009). However, when there is an attack, it must be managed and controlled with the aim of avoiding or minimising damages. Early recognition, treatment, and continued monitoring are key to preventing pest outbreak from getting out of control and making significant damage to nursery crops.

Pest and disease management requires the recognition and understanding of their habits, life cycles, and control measures. The first step in controlling pests and diseases is to properly identify them and recognize the problems they cause. The decision on pests and disease control is related to levels or thresholds of infestation, which is dependent on insect populations (Beard *et al*., 2008; Stanosz *et al*., 2003; Figure 3.1 a-d). When pest populations increase to damaging numbers at the economic or damage threshold, control measures must be initiated or increased crop losses will occur. If control measures are not taken and the pest population continues to increase, the quantity and quality of the crop will be substantially reduced. This point is referred to as the economic injury level (Beard et al., 2008). Application of an appropriate pest management practice at the action threshold (arrow) should prevent development of unacceptable damage.

1. Pest populations normally fluctuate above and below a *general equilibrium level* that represents the average population size. Profits may be slightly affected when pest populations are present at this level.
2. *Economic or action threshold level* is the pest population density at which control measures are necessary to prevent an increasing pest population from reaching the economic injury level.
3. *Economic injury or damage threshold* is defined as the lowest pest population density that will cause economic crop damage.

The steps for disease prevention, control and management can be divided into three: diagnosis, assessment and implementation of control strategies (Douglas, 2009).



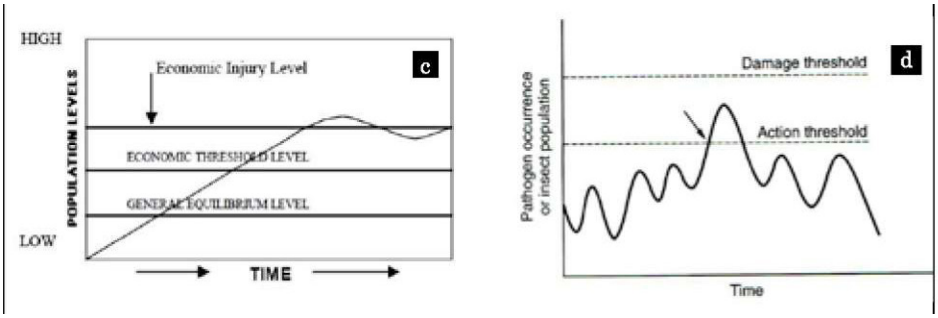


Plate 3.1a: Post-emergence damping-off disease attack on cowpea seedlings; 3.1b : Mealybug attack on Ceiba petandra seedlings; 3.1c : Nymph of Large Afri¬can cricket (Brachytrupes membranaceus) ; 3.1d : Oil palm seedling blight

Diagnosis: This involves knowing what is to be controlled. Accurate diagnosis is critical for successful pest and disease control. If the nursery manager has a basic knowledge of symptoms and a habit of careful observation, most disease problems can be diagnosed (Mangini, 2012). The success of pest and disease control measures depends on how accurately and how early the diseases are diagnosed. Early diagnosis followed by appropriate action is required to avoid large crop losses. Different pests or diseases cause similar symptoms on plants, and an accurate diagnosis is required to choose the best control measures (Bissonnette, 2008). Plants should be collected for diagnosis as soon as disease symptoms are noted. Diagnosis can be done following three steps:

1. The first step is recognizing that the pest and disease problem exists (Mangini, 2012). To do this, the manager must monitor the nursery and learn what healthy seedlings look like under all conditions, which will enable him to identify abnormalities when they occur;
2. The second step is proper identification of the problem (Bissonnette, 2008). This is often the most difficult, but the most important step. The manager should ensure that the pests and diseases are accurately identified, failure which the problem could have severe consequences;
3. The third step is to determine the cause of the pest and disease attack (Mangini, 2012) using a systematic approach. The key to this approach is to consider the most probable causes first; then, as each pest is ruled out, one moves logically to the less likely causes. Before any potential causes can be evaluated, it is necessary to do a thorough examination of both individual seedlings and the nursery in general.

Assessment. It is usually not sufficient to determine whether a pest or disease is present or absent; the critical information required is the amount present. Pest and disease assessment involves determining how widespread or severe the problem is. Often, pest and disease have to exceed a certain threshold before it reduces the yield of a crop. Small amounts have little effect on yield and the disease may not be worth controlling. Pest and disease problem assessment involves determining (i) the nature of the problem: type of disease, i.e., root vs. foliar, systemic vs. localised and (ii) level of disease: loss threshold, i.e., amount of disease, number of plants infected. The amount of disease is measured as the proportion of the crop population (counted as individual plants or branches or leaves etc.) that is infected (disease incidence) or the proportion of the area of a plant or plant organ (e.g. leaf area) that is affected (disease severity). In some cases, the proportion of leaves or branches infected may provide a measure of disease severity.

Implementation of control strategies. Over the years several methods have been used to control and manage pests and diseases problems in agricultural nurseries. Some of these methods include: cultural, biological, chemical, mechanical methods, use of resistant varieties, etc.

1. *Biological control:* Biological control of pests and diseases is the reduction of the amount of inoculum or the disease producing activity of the pest/ pathogen accomplished through one or more organisms other than man (Cook and Baker, 1983). It involves the use of living organisms,

generally predaceous insects or non-pathogenic fungi or bacteria, to manage pest populations. Predatory insects lower the pest population directly by feeding on the pest (e.g. ladybugs that feed on adelgids). Some fungi and bacteria produce toxins or antibiotics that inhibit growth of pathogenic organisms. Other beneficial microorganisms produce chemicals that increase seedling growth and thus reduce pest damage. Biological control of plant pests and diseases stems from the desire to decrease use of pesticides in agricultural, forest and urban environments (Axelrood, 1990). It is very important to gain an understanding of the pest and disease prior to developing a biological control. Biological control is most effective when applied as a preventative measure, so it should be applied early in the production cycle of each crop.

Biological control has advantages over chemical control. Firstly, a biological control organism may grow and reproduce on the seedling; the population of a single application may protect the plant throughout the period of susceptibility. This contrasts with the need to spray certain pesticides several times to obtain good disease control. Secondly, most biological agents pose little or no threat to workers or the environment, they can safely be applied several times if necessary.

2. *Chemical control:* Pesticides are the predominant chemicals used to control pests in nurseries due to their effectiveness in killing pests. Pesticides can be classified into several categories depending on their target: soil fumigants, fungicides, nematicides, and insecticides. Chemical control involves the application of pesticides to soil, seeds, or seedlings to reduce pest damage. Sometimes, the location of pests in soil and in plants makes it difficult to control the disease and the application of pesticides is expensive for large areas (Renard and Ravise, 1986). The application of chemical to the crop may not only kill the target pests and disease but may also kill beneficial arthropods, harm humans, repel birds and have serious detrimental effects on the environment. Thus, the use of pesticides that are selective for the target pest species with minimal effects on non-target species, humans and the environment is desirable for pest management. This can be accomplished through registration process, which entails tests to ensure that the chemical is environmentally safe, not harmful to operators or crop handlers, and the produce safe for human and livestock consumption. If well-planned and if used judiciously, chemical control are valuable in pest management. An advantage of using insecticides in many crop ecosystems is that more than one major insect can be controlled with a single application (Beard et al., 2008). A major problem with chemical control is the rapid development of pathogen races or pest populations that are resistant to pesticides. When that happens, their continued use will have little effect and can aggravate the situation by killing other organisms that contribute to natural biological control of pathogens and other pests.
3. *Cultural control:* Cultural control of nursery pest refers to the routine nursery operations that help reduce losses to pests. It is the reduction of insect populations using agricultural practices as well as making environments unfavorable for pests (Beard *et al.*, 2008). Cultural control is the first and often the most effective defense method against pest and disease attack. This control method can limit pest populations or damage directly, by removing or suppressing the pest, or indirectly by altering its environment or food supply through soil and water management, practices affecting seedling, sanitation and growing resistant seedlings. Scheduling cultural practices during the most vulnerable time of an insect's life cycle is a very effective control measure. The insect's favorable environment is altered to kill the pests or reduce their reproduction. Some cultural control methods are: crop rotation, crop planting location, tillage, sanitation, prevention of pest immigration, timing of planting and harvesting, resistant varieties, removal of old and infested crops, destruction of pupae and larvae, removal of plant debris, weed control, etc. (Beard et al., 2008; Caldwell *et al.*, 2013)
4. *Mechanical control:* It is often difficult to distinguish mechanical control methods from cultural methods. According to Beard *et al.* (2008) mechanical control is the reduction of pest populations by means of devices that affect them directly or alter their physical environment radically. However, mechanical controls involve special physical measures rather than normal agricultural practices.

They tend to require considerable time and labour and often are impractical on a large scale. Hand picking and trapping are familiar mechanical methods of insect control. Screens, barriers, sticky bands, and shading devices are also mechanical methods or devices. Hopper- dozers and drags are types of specialized control equipment for collecting or smashing insects.

5. *Use of resistant crops varieties*: Another major step toward sustainable agriculture is to produce crop varieties resistant to pest and disease attacks (Cook *et al*., 1995). The use of resistant plants is one of the most effective and practical means of pest and disease control to lower risks of pest and disease damage. Selecting a plant variety with resistance or tolerance to pests and diseases will enable farmers avoid or reduce the use of chemicals and other management tactics (Caldwell et al., 2013). Local crop varieties are believed to be better at resisting local pest and diseases than introduced varieties. Thus, the knowledge of farmers about the characteristics of traditional and local crop varieties is relevant in selecting resistant crop varieties. Agricultural plant varieties are rarely resistant to all pests and diseases in a specific area, so identifying the pests that are most damaging and finding suitable, resistant varieties are important steps in pest control (Caldwell et al., 2013). Resistance to pests and disease is based on plant genetics and the molecular interactions between host plant and the pest (Pedley and Martin, 2003). Based on pest-host plant interaction, three types of resistant mechanisms have been recorgnised: antibiosis, antixenosis, and tolerance (Caldwell et al., 2013). Depending on the complexity of the interaction, plant resistance may either break down rapidly or be long-lived. Successful breeding for pest and disease resistance has occurred in many different crop types, including vegetables, fruits, field crops, and ornamentals.

Integrated Pest Management (IPM) Systems in Agricultural Nursery

In the past, scientists from different disciplines such as, entomology, plant pathology, soils, forestry, chemistry, etc., often approached pest and disease problems with minimal communication with their colleagues in other fields. Sometimes methods proposed to deal with one pest were in conflict with those used to manage another, or had other undesirable effect on the plant community, including beneficial organisms. For example, use of broad spectrum insecticides to kill defoliating insects also can diminish populations of parasites, parasitoids, predators that help hold pest populations in check. Thus, it has been realized that it is not only feasible, but necessary to integrate pest and disease control strategies and practices, and in so doing consider simultaneously the effects on a multitude of other factors, including other organisms, other plant management activities, and all benefits produced by the plant ecosystem (Stanosz *et al.,* 2003). Traditionally, there are two basic approaches to nursery plant health: (i) *preventive actions,* which include use of balanced fertilizers, use of resistant species or cultivars, timely hardening of plants, nursery cleanliness, training of staff, etc. and (ii) *curative actions,* which include the use of pesticides, heat, biological control or physical measures (e.g. cutting out of diseased parts), etc. (Stanosz *et al.,* 2003). The Integrated Pest Management (IPM) system evolved from these two approaches, combining 'preventive' measures with 'curative' methods, and using chemical, biological and cultural control (Stanosz *et al.,* 2003) and draws from experts in different disciplines. The IPM can be defined as a sustainable approach to control and management of pests and diseases that combines biological, cultural and chemical tools in a way that minimizes economic, health and environmental risks (James *et al.,* 2010; Kiss and Meerman, 1991; Radcliffe *et al.,* 2009). Hoover *et al.* (2011) defined IPM as pest population management system that utilizes all suitable techniques (biorational, chemical, cultural, fertilisation, irrigation, monitoring with sex pheromone traps, resistant plant varieties, etc.) and information to reduce or manipulate pest populations that are maintained at tolerable levels while providing protection against hazards to humans, domestic animals, and earth's environment. Thus, the IPM is a holistic approach to control and management of pests and diseases, which involves the combination of various crop protection options to avoid pest infestations from reaching economically damaging levels (James *et al.,* 2010) while at the same time minimizing damages to humans and the environment. It uses natural predators, pest-resistant plants and other methods to preserve a healthy environment in an effort to decrease reliance on harmful pesticides (Radcliffe *et al.,* 2009).The goal of IPM is not to eradicate every pest and disease, but rather to manage serious infections to a level that reduces crop damage and the cost of pest and disease control.

Thus, the IPM involves rotating crops to disrupt pest life cycles, selecting varieties resistant to pests and diseases, using strategic cultivation to disrupt the development of pests, eradicating plants which harbour insect pests or disease, monitoring crops to determine pest and beneficial insect activities, encouraging and protecting beneficial insects, applying pesticides only when pests approach economic injury level using selective or 'soft' pesticides which target pests only. It requires dedication to scouting, monitoring, identifying pests, choosing the best options available for control and evaluating (Chappell *et al.,* 2011). IPM is based on an understanding of host and pest biology, knowledge of ecological principles, and integration of methodologies from several disciplines (Dent, 1995), it is environmentally safe, socially acceptable, economically feasible, and compatible with other non-disruptive pest control methods. The IPM systems are designed to be effective, practical, economical, and protective of human health and the environment. The system consists of two basic elements: decision and action processes. The decision process establishes the basis for any subsequent actions to be taken. Tactics directed against the pest or diseases are referred to as direct control or suppression tactics (e.g. various types of biological, mechanical or chemical methods). The decision process is often the most time consuming and complex aspect of IPM, which requires careful consideration of the pest, its host, resource management objectives as well as ecological, economic and social consequences of the various tactics available. The action process may consist of one or more ecologically, economically and socially acceptable tactics designed to reduce pest populations to non-damaging levels.

Although damage done by pests and diseases can never be completely avoided, IPM is a useful tool in combating the menace posed by the use of chemicals (pesticides, fungicides, nematocides), by optimisation of pest/pathogen control in an economically and ecologically sound manner, through the coordinated use of multiple tactics to assure stable crop production while minimizing hazards to humans, animals, plants and the environment. There has been several IPM initiatives in Africa, one of which is the West African regional Integrated Production and Pest Management (IPPM) programme. The IPPM began in 1996, and was aimed at improving farming skills and raising smallholder farmers' awareness on alternatives to toxic chemicals. The programme targeted working with 116,000 farmers in four West African countries (Benin, Burkina Faso, Mali and Senegal), resulting in improved yields and incomes and making substantial progress in reducing the use of chemical pesticides (Settle and Garba, 2009). To grow healthy crops, IPPM promoted soil improvement and alternatives to chemical pesticides such as the use of beneficial insects, adapted varieties, natural pesticides and cropping practices (Crop Site, 2010). The ICIPE's (International Centre of Insect Physiology and Ecology) Integrated Pest Management research and development programme for stern and pod borer control in maize, sorghum and cowpea delivered a simple 'IPM package' and led to considerable yield improvements for subsistence farmers in Western Kenya (Meerman, 1991). These IPM strategies are resulting in a more precise approach to disease and pest control, reducing risk in agricultural production, increasing agricultural productivity and are within the spirit of sustainable agriculture.

Conclusion

Pest and diseases attack plant seedlings in the nursery, thus posing great risks to their survival and obtaining healthy planting materials. The attack could be enormous, which makes their prevention, control and management an imperative. The goal of pest and disease management is to ensure that crops are healthy enough to yield their full potentials within the limits imposed by the climate, weather and soils. A strong and healthy plant will have less pest and disease problems. Preventive and curative actions are the traditional approaches to nursery plant health. The first step to control and manage pests and diseases in the nursery is to understand their habits and life cycles; recognize the problems they cause and identify their control measures. The steps to pest and disease control and management are diagnosis, assessment and implementation of strategies. Over the years, several methods, such as cultural, biological, chemical, mechanical methods, use of resistant varieties, etc., have been used to control and manage pests and diseases in nurseries. It is not only feasible but necessary to integrate pest and disease control strategies and simultaneously consider their effects on factors like other organisms, other plant and all benefits produced by the ecosystem. The Integrated Pest Management (IPM) system is a holistic approach to control and management of pests and diseases. It involves the combination of various crop protection options to avoid pest infestations from reaching economically damaging levels while at the same time minimizing damages to humans and the environment. The IPM systems, which are designed to be practical and effective, are environmentally safe, socially acceptable, economically feasible, and compatible with other non- disruptive pest control methods.

Questions for Discussion

1. Discuss the concept of Integrated Pest Management (IPM) as a useful tool in the control of nursery pests and diseases.
2. What are the risks associated with the use of pesticides in the control of nursery pests and diseases? How can these risks be avoided or minimised using non-pesticide pest control measures?
3. Discuss the three pest population threshold levels used to decide the necessity of otherwise for pests and disease control. At what threshold level is control imminent?
4. Highlight the general principles to be employed in producing healthy seedlings in agricultural nurseries
5. Identify a pest or disease attack in a named nursery in your locality, highlighting the level of damage and the measure(s) adopted in its control.

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Section 2

Agricultural Practices for Managing Risks and Uncertainities

Section 2: Introduction

Risk in agriculture is the potential deviation between expected and real outcomes. While this deviation may be positive or negative, a negative outcome has greater importance from a practical point of view and is usually the focus of decision- makers. In this section, risk management in agriculture is considered as the range of techniques and tools which can be applied in order to avoid or minimize losses and to utilize opportunities.

Farmers face a number of risks which are often interconnected. Five types of risks are considered in agriculture which, according to their sources, include: production, marketing, financial, legal/regulatory and human risks. Production risks are anything that directly affect the quantity and quality of crop yields and livestock production. This section largely dwells on *production risks* and *their management* so as to avoid or minimize losses of production yield. Some of production risks according to sources are: weather (drought, flood, freezes, hail, wind, excessive rainfall or heat), pests (insects and diseases), resource bases, production management (planting, harvesting, food safety), technologies, and infrastructure (on-farm and off-farm) malfunction or breakage.

Some of techniques and tools that can be used for managing production risks include: crop insurance, enterprise and crop diversification, investing in new technologies, producing surpluses, especially if they can be stored, maintaining farm infrastructure and equipment, and protected cultivation (greenhouses and tunnels).

This section also focuses on crops and livestock production practices that manage risks. Crops and livestock production practices are further subdivided in two major categories: husbandry and breeding. As the basis of crops and forages production, soil fertility/ productivity management vis-a-vis risk resilience is also included in this section.

The section constitutes the following five chapters: chapter 4 - managing risks associated with soil degradation for sustainable crop production in Africa; chapter 5 -agronomic practices for managing risks; chapter 6 - crop breeding for agricultural risk management; chapter 7 - livestock production in Africa for increased resilience, and chapter 8: animal breeding for managing risks.

4

Managing Risks Associated With Soil Degradation For Sustainable Crop Production In Africa

B. Ahamadou, P. O. Kisinyo, P. A. Opala, G.A. Damot, I.I. Mudita and D. Nyadanu

Summary

Soil degradation is increasingly being viewed as a critical problem affecting agricultural productivity and human welfare in Africa. Overcoming soil degradation is therefore the key entry point for achieving food security, reducing poverty and preserving the environment for smallholder farms in sub-Saharan Africa. Furthermore, understanding the properties of soils is important not only for the optimum use they can be put to, but also for best management requirements for their efficient and productive use. In most African countries, enhanced, sustainable and self-sufficient agricultural production largely relies on soil conservation, development planning and management.

This chapter describes the major soil degradation issues in Africa and their management practices. It identifies the key issues associated with managing the fertility, quality and health of African soils used for agricultural purposes. In addition, the chapter specifically highlights and discusses the processes, factors, and causes of soil degradation, as well as the proposed strategies and technological options to reversing the degradation trends. In this respect, solutions to the challenges faced by farmers in addressing key soil degradation attributes and their management, and how these affect or can be used to improve the fertility, quality, health and resilience of soil are comprehensively discussed. Furthermore, the chapter contains illustrative case studies of soil degradation from Kenya and Mali. The chapter is of significant interest to students, lecturers and researchers in agronomy, soil, crop and environmental sciences, as well as to stakeholders involved in issues related to land use and agricultural risk management.

Resume

Gestion des risques lies a la degradation des sols et production agricole durable en Afrique

La degradation des sols est de plus en plus vue comme un important probleme qui affecte la productivity agricole et le bien-etre des populations Africaines. Juguler la degradation des sols est donc le point d'ancrage principal dans l'atteinte de la securite alimentaire, la reduction de la pauvrete et la preservation de l'environnement pour les petits exploitants en Afrique subsaharienne.

En outre, la connaissance des proprietes des sols, est primordiale, non seulement pour leur utilisation optimale, mais aussi, pour respecter les bonnes pratiques en vue de leur utilisation efficiente pour la production. Dans la plupart des pays africains, l'amelioration, la durabilite et l'autosuffisance de la production agricole repose, principalement, sur la conservation des sols, la planification du developpement et la gestion.

Ce chapitre aborde les questions majeures de degradation des sols en Afrique et leur gestion. Il met l'accent sur les points cles lies a la gestion de la fertilite des sols. La qualite, la sante des sols africains utilises pour la production agricole. En outre le chapitre met un accent particulier et discute les processus, les facteurs, et les causes de degradation des sols, ainsi que les strategies proposes / identifies et les options technologiques

permettant de renverser les tendances de degradation des sols. Dans ces conditons, les solutions face aux defis auxquels les paysans sont confrontes dans la resolution de ces problemes cles de degradation et leur gestion, et comment ceci peut affecter, ou etre utilises pour ameliorer la fertilite, la qualite, la sante et la resilience sont amplement discutes. Enfin, le chapitre contient des etudes de cas illustres sur la degradation des sols au Kenya at au Mali. Le chapitre represente un interet certain pour les etudiants, les conferenciers et les chercheurs dans le domaine de l'agronomie, des sols, les sciences environnementales, aussi bien qu'aux acteurs impliques dans les questions liees a l'utilisation des terres et a la gestion des risques en agriculture.

Introduction

The major soil constraints affecting crop production in Africa include low soil moisture, land degradation, and soil fertility depletion. In traditional farming system, shifting cultivation maintained soil fertility whereby farmers used a piece of land for a period after which it was allowed to remain fallow and the vegetation restored soil fertility. Due to increase in human population, this is no longer practicable and land is continuously cultivated. Therefore to maintain soil fertility under continuous cultivation, many soil-fertility management options have been developed generally focusing on the use organic and inorganic nutrient inputs. Although both materials work well in specific circumstances, they pose major limitations for most smallholder farmers in Africa (Sanchez *et al.*, 1997).

Recurrent fertiliser use is the obvious way to overcome soil-fertility depletion, and indeed it has been responsible for a large part of the sustained increases in *per capita* food production that have occurred in Asia, Latin America, and the temperate region, as well as in the commercial farm sector in Africa (Buol and Stokes, 1997). Although, most smallholder farmers in Africa appreciate the value of fertilisers, they are seldom able to apply them at the recommended rates and at the appropriate time because of high cost, lack of credit, delivery delays, and low and variable returns (Okalebo *et al.,* 2006). Such constraints are largely due to the lack of an enabling policy environment in rural areas caused by the deficient road and market infrastructure, typical in most African countries. The price of fertilisers in rural areas of Africa is usually at least twice the international price (Bumb and Baanante, 1996). Transport costs are about seven times higher in Africa than in the USA. Transport and other costs (import duties, demurrage, taxes) more than double the international price by fertilisers reach the farmer in Malawi (Donovan, 1996).

Use of organic material is a logical alternative to expensive fertilisers in Africa to replenish soil fertility (Reijntjes *et al.,* 1992). The main advantages of this approach are (i) the replacement of scarce or non-existent capital for labour and (ii) the fact that cattle manures or green manures contain all essential nutrients plus carbon (C), the source of energy for soil biota that regulates nutrient cycling. However, organic materials have low nutrient content in comparison with inorganic fertilisers. For example, animal manures and plant material contain only 1 to 4% N compared 20 to 46% N in common inorganic fertilisers. Organic materials also have are very low levels of soil P (Palm, 1995; Palm *et al.,* 1997) and therefore cannot meet the P requirements of most crops. An additional challenge is the wide variability in the nutrient content of some organic inputs such as animal manures (Murwira *et al.,* 1995). Production of organic resources, be they green manures, litter fall and plant biomass for transfer, composts, or animal manures, for soil fertility management requires fertile soils. However, in nutrient-depleted soils common on smallholder farms, it is difficult to grow enough forage to feed cattle and produce sufficient quantities of manure.

It is important to distinguish between nutrient inputs and nutrient cycling (Sanchez and Palm, 1996). At the field scale, nutrient inputs are additions from outside the system, such as N2 fixed from the air by legumes or inorganic fertilisers. Cattle manures are considered inputs if the manure was produced from forage grown outside the field. Nutrient cycling refers to the transfer of nutrients already in the field from one component to another, e.g. (i) the return of maize stover back to the soil, (ii) cattle manure and urine deposited by animals while grazing crop residues, and (iii) the transfer of nutrients from trees to the soil through prunnings, leaf drop, or root decomposition in agroforestry systems. Nutrient cycling is extremely important, but nutrient-depleted soils need inputs from outside the field. Given the limitations of the extremes of either using pure organic inputs or pure inorganic inputs, the integrated soil fertility management (ISFM) strategy, which emphasizes the combined use of organic and inorganic nutrient sources has been proposed.

Learning objectives

The objectives of this chapter are to:

1. Analyse risks and challenges associated with soil fertility management in Africa;
2. Explain the extent and degree of soil degradation processes, factors and causes in Africa;
3. Equip the learners with the available options for soil fertiility replenishment in Africa;
4. Describe the best soil fertility management practices for sustainable crop production.

Learning outcomes

After completing the chapter, the reader should be able to:

1. Identify risks and challenges associated with soil fertility and problem soils management in Africa;
2. Describe the extent and degree of soil degradation processes, factors and causes in Africa;
3. Describe options available for soil fertiility and problem soils management in Africa;
4. Apply the best soil fertility management practices for sustainable crop production in Africa.

Soil Degradation and Agriculture in Africa

The global land area is 13.2 billion ha of which, 12% (1.6 billion ha) is currently in use for cultivation of agricultural crops, 28% (3.7 billion ha) is under forest, and 35% (4.6 billion ha) comprises grasslands and woodland ecosystems (FAO, 2011). These researchers stated that demographic pressures, climate change, and the increased competition for land and water are likely to increase vulnerability to food insecurity, particularly in Africa and Asia. They further mentioned that land productivity is generally low on rain fed croplands, because of inherent low soil fertility, severe nutrient depletion, poor soil structure and inappropriate soil management practices. This is particularly the case in Sub-Saharan Africa, where yields of staple cereals such as maize are often below 1 t/ha and most of countries in this region are particularly vulnerable to threats of natural resource degradation and poverty due to various factors including a high population growth rate and increasing population pressure, urbanisation, reliance on agriculture that is vulnerable to environmental change, fragile natural resources and ecosystems, high rates of erosion and other soil degradation, unsustainable soil management practices, and both low yields and high post-harvest yield losses.

About 16% of Africa's land is considered high quality, 13% as medium quality, 16% of low potential, whereas 55% of the land is unsuitable for cultivated agriculture but supports nomadic grazing (Bationo, 2004). Soil degradation, caused by land misuse and soil mismanagement, has plagued humanity since the dawn of settled agriculture (Lichtfouse *et al.*, 2009). Many once thriving civilisations collapsed due to erosion, salinisation, nutrient depletion and other soil degradation processes. Declining soil fertility is also driven by socio-economic factors, which include macro-economic policies, unfavourable exchange rates, poor producer prices, high inflation, poor infrastructure and lack of markets. These multiple causes of low soil fertility are strongly inter-related including the interaction between biophysical and socio-economic factors and hence, tackling soil fertility issues requires a long-term perspective and holistic approach for achieving food security, reducing poverty and preserving the environment in Africa. The major soil constraints affecting crop production in Africa include low soil moisture, land degradation, and soil fertility depletion.

Major Soil Degradation Risks and their Management in Africa

Problem Soils in Africa: Major Types, Risks and Constraints

Problem soils are substantial in occurrence in Africa. Being sandy or infertile is only one of the very common conditions that influences people's livelihood making it difficult to make a living (Rojanasoonthon and Kheoraunrom, 2003). There are also many other soil related conditions such as saline soil, shallow soil, gravelly soil, hard pan soil, lateritic or plinthitic soil, acid sulphate soil, and many others. According to these authors, many of these problem soils are the result of substantial use of the land without any rehabilitation processes being put in place. Soils become, depleted, degraded, eroded or washed away. This problem is spreading as time goes by, particularly with increasing population pressure or more mouths to feed. The situation is getting more serious, particularly when other conditions such as water crisis and related problems are escalating.

The global arable land area is estimated to be 1.351 billion ha, 38% of which has been degraded at variable intensities and of this the share of degraded territories in Africa is estimated to 65% (Osman, 2014). This researcher further indicated that saline and alkaline soils occur in 3,105,000 km^2 (2.4% of the land surface), and soil acidity affects 18,420,100 km^2 (14.1% of the total land). Of the affected area, 55.6% was reported as damaged by water erosion, 27.9% by wind erosion, 12.2% by chemical, and 4.2% by physical degradation (Braimoh and Vlek, 2008). In fact, land degradation is one of the most serious threats to food production in Africa where the population is trapped in a vicious poverty cycle between land degradation, and the lack of resources or knowledge to generate adequate income and opportunities to overcome the degradation and it is urgent to invest to combat land degradation to revert this vicious circle (Bationo, 2004). According to this author, Alfisols, Oxisols and Ultisols dominate sub-Saharan Africa zones and many factors such as soil type, farmer's practices, crop residues and mineral fertilisersmanagement influence crop yields. In addition, he stated that the Sahel zone of West Africa is particularly covered with sandy acidic soils with low buffering capacities and an acidity which is probably a consequence of parent sands derived from acid continental terminal deposits, strong paleoclimate and contemporaneous leaching and base-cycling processes. In such an African context, soil fertility management and sustainable farming practices are issues of particular concern for farmers, researchers, decision-makers and other land users across the continent. Agricultural productivity in Africa is far behind that of the other regions of the world increasing food insecurity mainly due to some biophysical and socioeconomic factors and constraints. These factors of risks and constraints to a sustainable agricultural production in Africa include some problem soils among which land degradation and soil erosion, heavy cracking clays, gypsiferous soils, calcareous soils, acid soils, sandy soils, salt-affected soils, waterlogged soils, polluted or contaminated soils etc., as illustrated in Table 4.1. Soil water management, tillage, cropping systems, as well as nutrient management, availability and uptake by plants pose special problems in most of these soil types and hence significantly reduce their productivity and crop yields.

Table 4.1: Summary of soil problems: causes and management options

Major soil problems and their impact on plant growth	Causes	Management options
Crusting		
1. Layer of denser, cemented soil between 2 - 5mm thick 2. Poor plant emergence Compaction	1. Raindrop impact, 2. Poor structural stability 3. Low organic carbon 4. Dispersive clay	1. Maintain good ground cover through pasture phase and stubble retention: improve organic C levels 2. Broadcast gypsum
Compaction		

1. Deep wheel ruts or hoof marks 2. Poor plant emergence and growth	1. Heavy machinery and livestock movement on wet	1. Controlled traffic farming 2. Keep livestock off excessively wet soils
Poor structural stability		
1. Slaking or dispersive soil. 2. Increased surface soil when cultivated 3. Requires more cultivation to achieve a good seedbed	1. Low organic carbon 2. Dispersive clay	1. Increase organic matter levels through good pasture phase and stubble retention 2. Gypsum may be applied
Salinity		
1. Poor and uneven plant growth in sensitive plants. 2. White crystals appear on the soil surface. Clay soils appear loose and crumbly, spongy when cultivated.	1. Increase in soluble salts . in soil 2. Water courses which are naturally saline 3. Rising water tables. 4. Cyclic salt from the ocean deposited by rain or wind	1. Reduce use of saline water for irrigation. 2. Plant salt tolerant species to maintain ground cover and increase water use
Acidity		
1. Poor plant establishment and persistence in sensitive plants 2. Yellowing or necrotic tips on leaves 3. Short or stunted root growth 4. Increased levels of Aland Mn available to the plant.	1. Removal of agricultural products 2. Use of ammonium fertilisers. 3. Soil type and parent material 4. Leaching of nitrates	1. Lime 2. Reduction in use of ammonium fertilisers 3. Tolerant cultivars.
Sodicity		
1. Clay disperses when wetted 2. Loss of soil structure when wet, producing a soupy consistency 3. Sets like concrete as it dries	1. High sodium levels. 2. Rising sodium levels.	1, Gypsum, which displaces the sodium, allowing it to be leached (pH Ca> 6) 2. Lime or lime/gypsum mix may be used when sodicity is combined with acidity (pH Ca<4.8) 3. Stop irrigating with water high in sodium.
Poor drainage/aeration		
1. Lower areas in paddocks where water may lie for long periods. stab 2. Light colored soil (yellow' drain with flecks of grey/red. 3. Plants may exhibit yellowing due to limited nitrogen and oxygen	1. Compaction, surface crusting, poor structural stability and ploughpans. 2. Duplex soils which poorly.	1, Aeration can be improved by increasing organic carbon to achieve better structural stability 2. Good pasture phase and stubble retention can improve organic carbon
Ploughpans		
1. Poor plant growth. Plants display roots which deflect sideways along the compacted layer.	1. Heavy machinery and livestock movement on wet soil 2. Continual cultivation particularly when soil is wet	1. Keep livestock off excessively wet soils. 2. Deep tillage, but ploughpans will re-form over time with continued cultivation

Adapted from: MacKinnon et al., 2003

According to Osman (2014), five types of land/soil degradation can be distinguished:

- Soil erosion by water (loss of topsoil, terrain deformation/mass movement, off-site effects, reservoir sedimentation, flooding, coral reef and seaweed destruction);
- Soil erosion by wind (loss of topsoil, terrain deformation, overblowing). Physical deterioration (compaction, sealing, and crusting, water logging, lowering of water table, subsidence of organic soils, other physical activities such as mining and urbanisation);
- Chemical deterioration (loss of nutrients and/or organic matters, salinisation, acidification, pollution, acid sulphate soils, eutrification);
- and Degradation of biological activity.

Although a focus is made on soil erosion and some specific aspects of this classification as follows, it needs to be kept in mind that all processes of natural resource degradation are closely interconnected (Figures 4.1 and 4.2). These relations are particularly important when discussing mitigation practices that are not only supposed to be ecologically sound, but at the same time economically viable and socially acceptable. For example, soil conservation always integrates management of other resources, such as water and plants, and, therefore, soil conservation must be an integral part of an overall land management strategy at the household and community level.

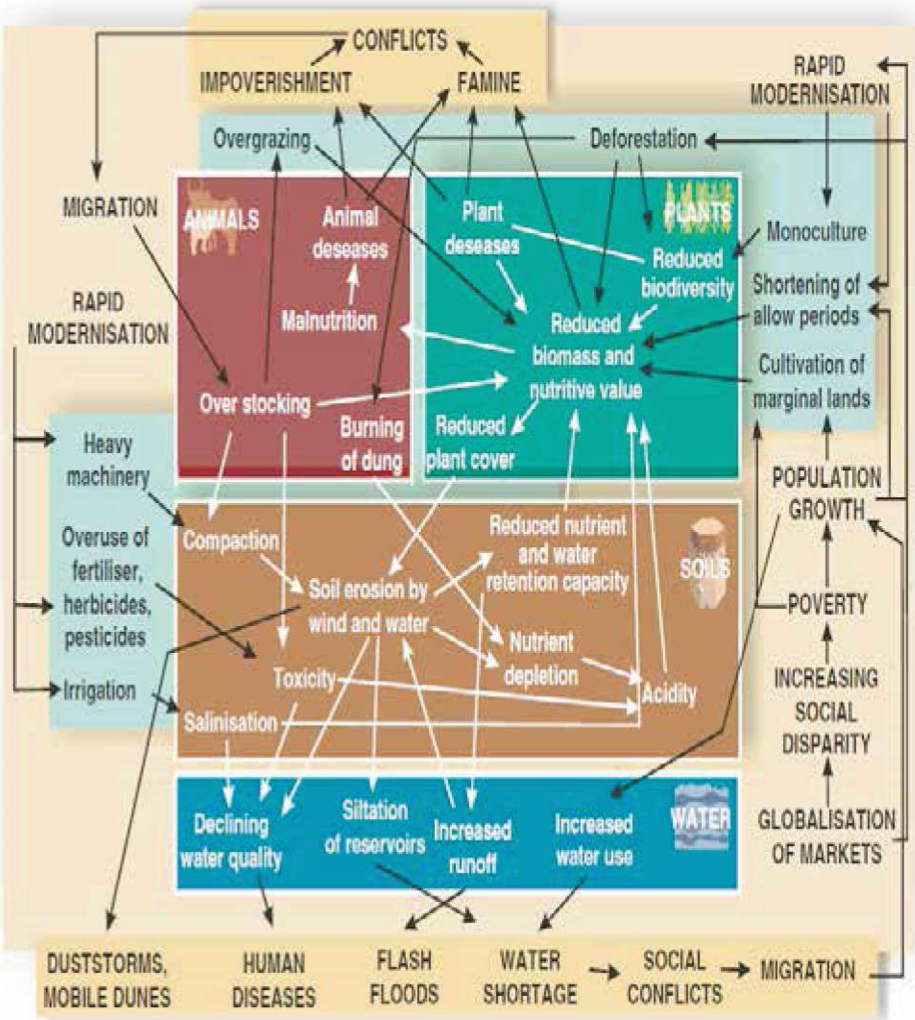

Figure 4.1: Society—land management—natural resources interactions
(Source: Braimoh and Vlek, 2008)

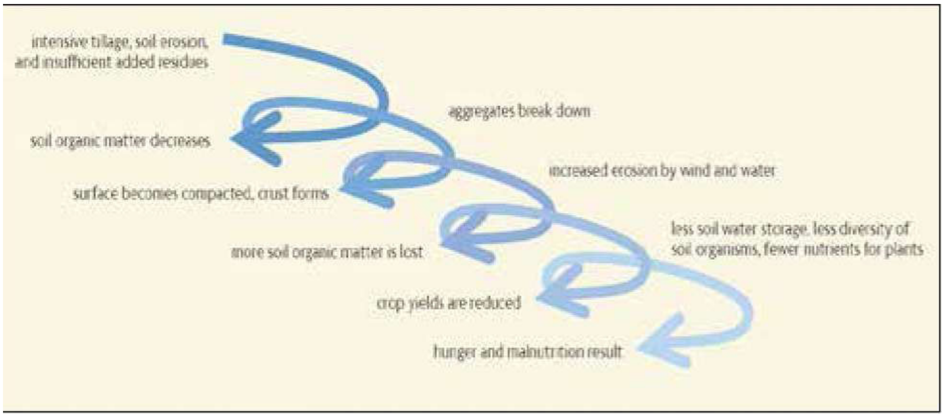

Figure 4.2: The downward spiral of soil degradation (Source: Magdoff and van Es, 2009)

Soil Erosion: Issues and Stakes

Important physical properties of soils related to soil fertility, productivity, and soil quality are: texture, structure, bulk density, porosity, soil water, air, and temperature. Of these properties, only soil texture is a permanent property that cannot be easily altered. The other properties may be readily changed by soil management practices. Physical deterioration of soil involves the destruction of soil structure, dispersion of soil particles, sealing of pores, compression and increasing density, consolidation, compaction and reduced root penetration, low infiltration, water logging and runoff, and accelerated erosion.

Soil Erosion by Water

Erosion is a natural process of detachment of soil particles and their transport and deposition at distant places by natural agents such as water, wind, glacier, and gravity (Osman, 2014). Natural erosion is considered as normal erosion and is usually of little concern from soil quality point of view because its rate is low and soil loss can be naturally compensated by soil formation. Accelerated erosion occurs usually at an alarming rate by human actions such as deforestation, overgrazing, over tilling, and shifting cultivation. In addition, causes of soil erosion include biomass burning, mechanized logging, cultivation up and down slope, continuous mono cropping, and compaction of soil by stock and machinery. These human-induced actions drastically contribute to reducing soil quality and crop yield on-site and damage land, water and installations off-site. It is worth further mentioning that water erosion is a prominent problem of the sloping lands.

Soil erosion can result in on-site effects such as the loss of soil, organic matter and nutrients as well as damage to growing crops, an exposure of plant roots, and a decline in soil fertility and productivity. Some off-site effects of soil erosion are burrowing of crops and installations, siltation of reservoirs, eutrophication of ponds and lakes, pollution of water, etc.

Kohnke and Bertrand (1959) classified water erosion into sheet erosion, internal erosion, and channel erosion. Channel erosion was further divided into rill erosion, gully erosion, and stream erosion. However, the following four types of water erosion are generally recognized: (i) splash erosion, (ii) sheet erosion, (iii) rill erosion, and (iv) gully erosion. Splash and sheet erosion are sometimes called interrill erosion.

Splash Erosion

At the start of a rain event, falling raindrops beat the soil aggregates, break them, and detach soil particles. These particles clog the large soil pores and, thus, reduce the infiltration capacity of the soil. Water cannot enter the soil, and soon a thin film of water covers the ground. Further, raindrops beat the water and splash the suspended soil particles away. Soil particles are transported to some distance by the splashing. The splashed particles can rise as high 60 cm above the ground and move up to 1.5 m from the point of impact. Processes of splash erosion involve raindrop impact, splash of soil particles, and formation of craters.

Sheet Erosion

When a thin layer of soil is removed by raindrop impact and shallow surface flow from the whole slope, it is called sheet erosion. It removes the finest fertile topsoil with plenty of nutrients and organic matter. It is the most dangerous type of soil erosion because it occurs gradually and almost silently leaving little or no signs of soil removal.

Sheet erosion involves the removal of a more or less uniform layer of soil over the whole slope of the land. Soil particles are detached primarily by raindrops and secondarily by frost, hooves of farm animals, tillage, and mechanical action of farm machines. Detached particles are transported by runoff water as overland flow. Sheet erosion is more uniform and gradual, as the surface becomes smoother. However, water may still accumulate even on the smoothest slope. The intensity of accumulation of runoff water depends on the height of the water stream, the coarseness of the surface, vegetation, or crop distribution. Sheet erosion removes deeper layer of soil gradually, if allowed to proceed unhindered and the subsoil is exposed over a large area. The subsoil is usually of different texture and color and is more compacted. However, slopes are often not so uniform over the whole area, and water accumulates in tiny channels, so that the surface is crisscrossed by discontinuous rillets. It is then known as the interrill erosion.

Rill Erosion

When rainfall exceeds the rate of infiltration, water accumulates on the surface, and if the land is sloping, it moves along the slope. On gently sloping lands, with standing crops or in fields that have been recently tilled, moving water concentrates along tiny channels called rills. Rills are less than 30 cm deep. The cutting action of flowing water detaches soil particles, and runoff water carries them away. Rill erosion is often the initial stage of gully erosion. Rill erosion is largely caused as a result of large amounts of material that are released and transported for variable distances in concentrated areas. On the other hand, the flow of water over the surface has a smaller effect on soil detachment, but a larger transportation effect.

Gully Erosion

Gullies are large channels deeper than 30 cm. Gullies develop when large quantities of water accumulate and run through a single channel with high speed in relatively steep slopes. Gullies may also develop by the gradual deepening of rills. There are two types of gullies: ephemeral and permanent. Ephemeral gullies form shallow channels that can be readily corrected by routine tillage operations. On the other hand, permanent gullies are very large and cannot be smoothed by regular tillage (Blanco and Lal, 2008). Gullies of various size and form develop by the gradual deepening of rills. A number of forms may be distinguished in gully erosion. The first form includes gully with a depth between 30 cm and 2-3 m. In this form, typical wash prevails with a marked backward or retrograde erosion and vertical or depth erosion. Gullies have larger dimensions and their development is more complicated. Besides retrograde and vertical erosion, lateral erosion also appears here, together with accessory landslide, soil flow, and other phenomena. Gullies may grow into gorges and canyons in high altitudes and very steep slopes. Gullies may be flat, narrow, broad, and round. Flat forms occur mostly on shallow soil or in connection with a specific lithic structure of the slope. In this form, characterized by a broad V-section, lateral erosion prevails over vertical erosion. Narrow, acute forms are created with a narrow V-section, the breadth of the gully usually being equal to its depth or smaller. Broad gullies have a wide bottom and are U-shaped. Here, lateral erosion prevails over depth erosion. Active gullies maintain steep or even perpendicular sides. It happens frequently that recent forms replace older forms so that their origin and age cannot be assessed from superficial observation. The main feature of gully erosion is the volume and velocity of water at the lowest level. The energy of flowing water increases its cutting and smashing power and often results in bank erosion.

Soil Erosion by Wind

For environmental and pedogenic reasons, soils of the arid and semiarid regions are usually dry, loose, low organic matter containing sandy soils susceptible to severe damage by wind erosion. Human activities such as deforestation, overgrazing, over exploitation of vegetation, soil and water resources have accelerated wind erosion many fold. Wind erosion removes the lighter and less dense soil constituents like organic matter, nutrients, clays, and silts. It significantly reduces soil productivity and crop yield. Many soils have been abandoned, and desertification has advanced in many places as an ultimate result of wind erosion.

Wind erosion is a serious problem in the arid and semiarid regions where vegetation is sparse, rainfall is low, and temperature is high. Potential evaporation is higher than precipitation for most of the year, which causes depletion of soil moisture, organic matter, and structure. Ecosystems in arid and semiarid regions are fragile by nature and are sensitive to human disturbances. Under population pressure and socioeconomic backwardness, human actions cause stresses on all natural resources. Land mismanagement, overgrazing, overcutting for fuel wood and deforestation, and misuse of water resources have been responsible for the loss of natural vegetative cover and hence accelerated wind erosion. As a whole, the increased wind erosion caused by human factors on an average accounts for approximately 78 % of the total wind erosion (Liu *et al.,* 1992).

Wind erosion not only removes soil but also damages crops, buildings, fences, and highways. Wind erosion removes the lighter, less dense soil constituents such as organic matter, clays, and silts. It causes loss of the most fertile part of the soil and significantly reduces soil productivity. If reversion measures are not taken and wind erosion continues for long, it may ultimately lead to desertification. Lyles (1975), estimated that top soil loss from wind erosion causes annual yield reductions of about 9,253 t of wheat and 13,843 t of grain sorghum on 0.5 M ha of sandy soils in southwestern Kansas, USA. Blowing soil impacting plants can also reduce seedling survival and growth, depress crop yields, lower the marketability of vegetable crops, increase the susceptibility of plants to certain types of stress, including diseases, and contribute to transmission to some plant pathogens (Armbrust, 1984; Michels *et al.*, 1995). In the long run, the cost of wind erosion control practices can offset the cost of replanting a blown out crop. Some soil from damaged land enters suspension and becomes part of the atmospheric dust load.

There are three typical processes of soil particle movement during wind erosion. These are, Saltation, Suspension, and Surface creep. These three processes of wind erosion occur simultaneously. Saltation causes other particles to move in suspension and surface creep. Neither creep nor suspension can occur without saltation. Lyles (1988), reported that the following processes are involved in wind erosion: initiation, transport (suspension, saltation, and surface creep), abrasion, sorting, and deposition of soil particles.

Saltation

In saltation, fine soil particles (0.1-0.5 mm in diameter) are rolled over the soil surface by direct wind pressure to some distance and then abruptly jump up vertically to a height of 20-30 cm. Lifted particles gain in velocity and then descend in an almost straight line at an angle 5-12° from the horizontal. The horizontal distance traveled by a particle is 4-5 times the height of its jump. On striking the surface, the particles may rebound into the air or knock other particles into the air before coming to rest. Thus, saltation is a progression of particles of successive jumps. As the saltating particles crash into the surface, they splash up more particles that also bounce across the surface. This bombardment of the surface causes an avalanching effect that spreads out in a fan shape, with more and more soil particles being mobilized downwind. Between 50 and 75% of the soil is carried by saltation.

Bagnold (1941) suggested that saltating particles rebound from a surface at 90° and follow a characteristic path length. It is now shown from wind tunnel experiments using high-speed cine photography demonstrated that saltating grains impacted the surface at an angle with the horizontal of about 10° and on average rebounded at 25°, although the latter depended on particle size and on the configuration and slope of the bed (McEwan *et al.,* 1992; Rice *et al.,* 1995). With non-cohesive sand-sized particulate surfaces, the saltating particles splashed up previously stationary grains.

Suspension

Suspension refers to the vertical uplift and horizontal transport of very small soil particles that are generally removed from the local source area. Suspended particles may end up on some meters or hundreds of kilometers downwind. They can range in size from about 2 to 100 ^m, with mass median diameter of about 50 ^m in an eroding field (Chepil, 1957; Gillette and Walker, 1977). However, in long-distance transport, particles <20 ^m in diameter predominate because the larger particles have significant sedimentation velocities (Gillette, 1977). Some suspension-size particles are present in the soil, but most are created by abrasive breakdown during erosion.

Because organic matter and some plant nutrients are usually associated with the finer soil fractions, suspension samples are enriched in such constituents compared with the bulk soil source. In the Great Plains, Hagen and Woodruff (1973) found that the average dust storm lasted 6.6 h and estimated the median dust concentration to be 4.83 mg m-3. Suspension movements are easily noticed as dust storms.

Surface Creep

Soil particles or aggregates of 500-1,000 ^m diameter are too large to be lifted up in normal erosive winds. They are pushed, rolled, and driven by the impacts of spinning particles in saltation. In high winds, the whole surface appears to be creeping slowly forward. The rippling of wind-blown sand has been attributed to unevenness in surface creep flow (Bagnold, 1941). Surface creep constitutes 7-25 % of total transport (Bagnold, 1941; Chepil, 1945; Horikawa and Shen, 1960). Creep appears nearly passive in the erosion process, but creep-sized aggregates may abrade into the size range of saltation and suspension and, thus, shift modes of transport. Creep aggregates seldom move far from their points of origin.

Abrasion

The percentage of erodible soil (<1,000 pm) in the surface layer is highly correlated with the mass of soil removable from that surface in wind tunnel tests (Chepil, 1958).On long erosion-susceptible fields, the total amount of soil that can be lost is usually several times the amount of erodible material initially present at the surface. Thus, resistance to abrasive breakdown of surface aggregates is important in wind erosion. The abrasion susceptibility of soil can be defined as the mass of material abraded from target aggregates per unit mass of impacting abrader (Lyles, 1988).

Sorting

Unless surface-layer aggregates or particles are homogeneous in physical properties (size, shape, density), which is highly unlikely in agricultural soils, sorting will occur during erosion. Sorting here refers to the selective removal during erosion of aggregates or particles because various sizes move at different mass flow rates. The sorting process over time removes the finer, nutrient- enriched materials, leaving behind those that are coarser and less fertile (Lyles, 1988).

Loss of Nutrients and/or organic Matter

Human-induced soil nutrient depletion is the process by which the soil nutrient stock is shrinking due to continuous nutrient mining without sufficient replenishment of nutrients harvested in agricultural products and of nutrient losses by accelerated soil erosion and leaching (Tan *et al.*, 2005).The general cause of fertility depletion is a negative balance between output (through harvesting, burning, leaching, etc.) and input (through manure and fertilisers, returned crop residues, flooding, etc.) of nutrients and organic matter.

Leaching is the downward movement of soil materials in solution and suspension with percolating water. Soils with high water infiltration rates and low nutrient retention capacity such as sandy soils and well-structured ferralitic soils (Oxisols, Ultisols) with low activity clays and low organic matter contents are particularly susceptible to nutrient leaching.

Nutrients differ in their mobility in soils. Nitrates are more mobile than other anions. Nitrate ions are not attracted by the negatively charged matrix of the top soil. Nitrates are continuously produced in soil by nitrification of ammonia obtained from fertilisers and soil organic matter. Nitrate leaching is a serious problem in sandy and low retentive soils.

When biomass residues, crop residues or litter, are burned, most nitrogen (N) and sulfur (S) in the residue are lost, while mineral nutrients, such as phosphorus (P) and potassium (K), are retained.

Salt-affected Soils (Saline, Sodic and Saline-sodic soils)

Soil salinisation as a process of land degradation is defined as the accumulation of excess salts in the root zone resulting in partial or complete loss of soil productivity and eventual disappearance of the vegetation (Nabhan *et al.,* 1999).Salt-affected soil is simply defined as a soil that has been adversely modified for the growth of most crop plants by the presence of soluble salts, exchangeable sodium or both. Salt-affected soils are normally divided into three broad categories: saline, sodic and saline sodic. Other categories of salt-affected soils though less extensive are commonly met in different parts of the world and include acid sulphate soils, acid soils, degraded sodic soils and magnesium solonetz. The problems of soil salinity occur in all continents and under all climate conditions. They are most widespread in the arid and semi-arid regions, but salt-affected soils also exist extensively in sub-humid climates, particularly in coastal regions where intrusion of seawater through estuaries and rivers, and through groundwater, causes large-scale salinisation.

Soil salinity is a problem in irrigated lands particularly where saline water is used for irrigation. Salinity problems occur as well where crops are grown under rain fed conditions. There salinity has several local names, but is most commonly known as dry land salinity or saline seeps. Although weathering of rocks and primary minerals is the main source of all salt, salt-affected soil rarely forms through accumulation of salts *in situ.*

A soil is said to be saline if the electrical conductivity of its saturation extract (ECe) (saturating the soil with water and taking the extract by suction) is greater than 4 dS m-1 (decisiemens per meter). Saline soils contain excess soluble salts, generally chlorides and sulfates, with some carbonates and bicarbonates, of sodium, potassium, calcium, and magnesium. Soil salinity is harmful for plants barring the halophytes; it causes water stress through osmotic disturbances in plant tissue and by toxicity of some salt constituents. Seed germination, plant growth, and yield of crops are considerably reduced by soil salinity. Sometimes it causes crop failure. Some soils are naturally saline. They are formed by processes called primary salinisation or natural salinisation. Some soils are made saline by mismanagement of soil and crop, particularly improper irrigation and drainage, that is, changing the hydrologic balance. This is known as secondary salinisation or human-induced salinisation.

Salinisation, both natural and human induced, may occur in two climatic settings - arid and semiarid and humid regions. In arid and semiarid regions, scarcity of water due to low rainfall and high evaporation does not allow necessary leaching of salts. Moreover, there is a net capillary rise of water which brings salts to the surface soil. In humid areas, on the other hand, excess irrigation or poor drainage cause the groundwater table to rise to the root zone of plants and make the soil saline. Oldeman *et al.* (1991) estimated that worldwide 76.6 M ha lands are affected by human-induced salinisation, but they did not differentiate salinity in the irrigated and non-irrigated rain fed areas.

Acid Soils

Soil acidity is indicated by the concentration of hydrogen (H+) ions in soil solution. When (H+) ions predominate over (OH-) ions, the soil is said to be acidic. The predominance of (H+) and (OH-) ions is expressed by soil pH. The pH is the negative logarithm of the hydrogen concentration (moles per liter), and its scale ranges from 1 to 14. A pH of 7.0 is taken as the neutral point, with values below 7.0 being acidic and above 7.0 being alkaline. Because the pH scale is logarithmic, soil with a pH of 5 is 10 times more acidic than soil with a pH of 6 and is 100 times more acidic than soil with a pH of 7. There are two types of soil acidity: active acidity created by the predominance of (H+) ions in solution and reserve or exchangeable acidity characterized by the predominance of exchangeable H+ and Al3+ ions on exchange sites of soil colloids. The larger the percentage of exchange sites occupied by aluminum and hydrogen, the lower is the pH and the higher is the acidity of the soil.

Acidification can occur naturally in soils developed from acidic parent materials due to release of acid-forming chemical compounds, in high rainfall areas due to prolonged leaching of bases, at higher elevations due to erosion, and under intensive weathering over a long period of time due to predominance of iron and aluminum oxides. But agricultural practices may accelerate or create soil acidity within a short time. Acidification in agricultural soils may be due to application of nitrogenous fertilisers, leaching of nitrates, removal of produce, and buildup of soil organic matter (Upjohn *et al.*, 2005).

The amount of acidification that results from using nitrogenous fertilisers depends on the fertiliser type. Fertilisers that contain nitrogen as ammonium, e.g. ammonium sulfate, acidify the soil within weeks after application. The most important acid-forming reaction for fertilisers is microbial oxidation of ammonical fertilisers to nitrate forms. Slightly acidifying fertilisers include: urea, ammonium nitrate, and urea ammonium nitrate solutions. These products are slightly acidifying because they contain ammonium or produce ammonium when applied to the soil. Moderately acidifying fertilisers include: di-ammonium phosphate (DAP) and highly acidifying fertilisers: Ammonium sulfate, mono- ammonium phosphate (MAP). These fertilisers are very acidifying and should be avoided if possible. Approximately 8 kg of agricultural limestone is needed to neutralise the effects of 1 kg of these fertilisers. For example, if the grower applied a 50 kg MAP or ammonium sulfate, 400 kg of lime would have to be applied. Usually farmers apply the fertilisers, but not the lime and therefore, the soil becomes acid in the long run.

Leaching of nitrate is a major cause of agricultural soil acidification. Nitrate is derived from the biological oxidation of ammonium or added as nitrate containing fertiliser. Ammonium is obtained in soil from fertilisers and mineralization of organic matter. The chemical processes that produce nitrate nitrogen from ammonium leave the soil slightly more acidic. This acidity is neutralized by plants discharging an alkaline substance as they take up nitrate nitrogen. While the plants continue to take up all the nitrate nitrogen, the acid/alkali balance of the soil surrounding the roots remains in balance. Leaching breaks the balance of the acid/ alkali processes and results in increased soil acidity. Nitrate leaching has important environmental impacts. Leached nitrates from agricultural lands may pollute ground and surface water.

Acidic soils may have some or all of the following problems: reduction in the amount of nutrients being recycled by soil microorganisms (e.g. nitrogen supply may be reduced); phosphorus in the soil may become less available to plants; induced deficiencies of calcium, magnesium, and molybdenum; aluminum and manganese toxicity to plants and microorganisms; and uptake of heavy metals by plants.

Soluble and exchangeable ions are the available nutrient forms in soil. Soil pH regulates the solubility of elements and compounds in soil and governs the availability of plant nutrients in soil. When soil pH decreases from 6.5 (i.e. as the soil becomes more acidic), the solubility of some elements including Fe, Al, Mn, Cu, and Zn increases, while the solubility of some elements (e.g. Ca, Mg, and Mo) decreases. On the other hand, when soil pH rises above 7.0, solubility of Ca, Mg, and Mo increases and that of Fe, Al, Mn, Cu, and Zn decreases. In strongly acidic soils, solubility of Al along with Fe and Mn increases to such an extent that they become toxic to many plants. Moreover, plants may suffer from Ca and Mg deficiency in acidic soils. At low pH (<5.5), phosphorus is precipitated with Al, Fe, and Mn as their polyphosphates. At high pH (>8.0), P is precipitated with Ca. At both soil acidity and alkalinity, P availability is reduced to deficiency levels. Availability of P is usually higher in the pH range of 6.5 and 7.0. Boron deficiency may also occur in strongly acidic and strongly alkaline soils. Availability of macronutrients (Ca, Mg, K, P, N, and S) and Mo and B is restricted at low pH. On the other hand, availability of most micronutrients (Fe, Mn, Zn, Cu, Co) increases at low pH. The most satisfactory plant nutrient levels occur at a pH range of 5.5-6.5.

Nutrient most important aluminum (Al) and manganese (Mn) toxicity can occur in acidic soils when the pH is 4.8 or lower (Slattery *et al.,* 1999). In strongly acidic soils (pHW< 4.3), aluminum and manganese become more available in the soil solution and are harmful to plant roots. Aluminum toxicity is the most common plant symptom on acidic soils and causes root stunting (Slattery *et al.,* 2000). Reduced root growth impedes nutrient and water uptake, resulting in decreased production. Some plants are more tolerant than others to high levels of Al in the soil solution. Important productive plants such as alfalfa, *phalaris,* canola, and barley are difficult to establish and grow in acidic soils. Both low pH and toxic aluminum irreversibly affect the establishment of alfalfa. The growing of deep- rooted perennial pastures (such as alfalfa and *phalaris)* is seen as an answer to slowing the acidification process. Aluminum may block the uptake of Ca and may precipitate P in plant body. It may interfere with P metabolism including ATP and DNA functions. Plant roots become stunted with little branching; root tip and lateral roots become brown. Plants suffering from aluminum toxicity produce symptoms in leaves that resemble P deficiency.

Toxicity by oxidised Fe frequently occurs in soils of pH below 4.0. Manganese toxicity is likely in soils having 200-5,000 mg kg-1 Mn. Manganese concentrations in the range of 0.2-12 mM have been reported to produce severe growth limitations in solution culture studies of species such as cotton, sweet potato (Mortley, 1993), sorghum (Mgema and Clark, 1995), and wheat (Taylor *et* al.,1991).

Waterlogged Soils (Gleysols)

Water logging is a state of saturation of soil with water for a prolonged period. Soils may, sometimes, be saturated with water for a very short time, say some hours, as during flash floods in piedmont areas. This temporary stagnation is not regarded as water logging. This water drains away easily. Water logging is a condition of soil when draining excess water is difficult and requires time, labor, planning, and energy. Water logging develops due to many different causes, including natural conditions and human activities. Natural conditions include heavy rains, low lands, clay soils, flooding, and presence of impervious subsoil. Human activities include faulty irrigation, inadequate drainage, surface sealing, and deep soil compaction by tillage implements. Wetlands are permanently waterlogged. Water logging also occurs when the groundwater table rises to the root zone and remains there for a considerable period of the year. Water logging may also occur as a form of standing water in the farm, which does not lower with time (Murty, 1985). Worldwide, about 10% of all irrigated land suffers from water logging. As a result, productivity has fallen about 20% in these croplands.

Natural conditions responsible for water logging include heavy rains, low lands, clay soils, flooding, and presence of impervious subsoil. Human activities that create or aggravate water logging include faulty irrigation, inadequate drainage, and surface sealing as well as deep soil compaction by tillage implements.

Wetlands are naturally and permanently waterlogged, but we are primarily concerned with arable lands because water logging hampers the growth of most crop plants. The most important causes of water logging are the poor drainage due to compaction and the rise of the groundwater table. Compaction including surface sealing, crusting, hard setting, and deep compaction results from organic matter depletion, structure deterioration, dispersion, compression, and consolidation. These processes occur due to inappropriate tillage and applied pressure by the heavy load of farm machineries. Soil compaction reduces hydraulic conductivity, thereby reducing both infiltration and percolation. Rainwater or irrigation water cannot move to the groundwater table deep in the regolith and drain away. In some situations, water accumulates and the groundwater table rises toward the surface of the soil in absence of significant base flow. Usually, a small area is irrigated in small farm holdings, so that over-irrigation is done and high percolation compels the groundwater table to rise. Rising groundwater table prevents root respiration and restricts their functioning. Elevated groundwater table may also create salinity and reduce crop yield.

In soils where there is a deep compaction, plant roots are confined to the loose surface soil, and excess irrigation water cannot pass readily through the impervious layer. It creates shallow root system and leads to water logging. In some cases, an impervious stratum may occur below the top layers of pervious soils. In this case also, water seeping through the pervious soils will not be able to go deep and, hence, quickly results in water logging. In the absence of satisfactory natural drainage, well-planned artificial drainage systems are needed to be installed. Often, drainage systems do not work satisfactorily, neither they are sufficiently deep, nor they are adequately frequent.

Water logging reduces aeration. After some days of flooding, the oxygen content in soil may completely deplete. Growth of crop plants and yield are reduced by altered physiological processes due to low oxygen and reduced root respiration in waterlogged soils. Often, water logging is responsible for crop failures. In addition, water logging does not allow following a definite crop calendar. The normal cultivation operations, such as tilling and plowing, cannot be easily carried out in wet soils.

Plowing, sowing, and planting are delayed by water logging. Water logging converts many croplands into wastelands. Rising water table brings dissolved salts in groundwater to the surface soil. Water continuously evaporates leaving the salts in soil. Thus, a high water table creates soil salinity, which is difficult to reclaim. Soil salinity reduces productivity. Many soils have become saline and out of cropping due to faulty irrigation in different countries.

Sandy Soils

Sandy soils occur in all parts of the world. Sandy soils cover about 13% in Sub- Saharan Africa and are widely spread in the Southern and Eastern parts of

Africa. Most sandy soils are located in arid or semiarid regions (van Wambeke, 1992). Sandy soils are characterized by less than 18% clay and more than 68% sand in the first 100 cm of the solum. Sandy soils may occur in the following Reference Soil Groups: Arenosols, Regosols, Leptosols and Fluvisols (FAO, 2001). These soils have developed in recently deposited sand materials such as alluvium or dunes. They are weakly developed and show poor horizonation. Both chemical fertility and physical stability are weak in these soils. Characteristic properties of sandy soils are high water permeability, low water-holding capacity, low specific heat, and often minimal nutrient contents because their low cation exchange capacities and high risk of nutrient leaching. The porosity in sandy soils is usually smaller than in clayey and silty soils. Sandy soils have fairly high bulk densities.

In sandy soils, unlike other soils, the elementary fabric can be easily loosened by tillage practices. Thus greater porosity can be produced easily by tillage but its stability is very weak and compaction by wheels or other actions can produce a dense structure with adverse physical properties. This leads to a decrease in the water retention properties and hydraulic conductivity, an increase in the resistance to penetration and sensitivity to surface crusting. Sandy soils are prone to wind and water erosion due to their weak structure and low OM content (FAO, 2001).

Vertisols

Vertisols are a group of heavy-textured soils which occur extensively in the tropics, subtropics and warm temperate zones and are known as Dark Clays, Black Earths, Black Cotton soils, Dark Cracking soils, Grumusols and Regurs in other classification systems (Dudal, 1965). Vertisols occur dominantly in level landscapes under climates with a pronounced dry season. Characteristics features of vertislos are a vertic horizon (a clayey subsurface horizon with polished and grooved ped surfaces ("slickensides") or wedge-shaped or parallelepiped structural aggregates) within 100 cm from the soil surface. They have 30 percent or more clay in all horizons to a depth of 100 cm or more, or to a contrasting layer (lithic or paralithic contact, petrocalcic, petroduric or petrogypsic horizons, sedimentary discontinuity, etc.) between 50 and 100 cm, after the upper 20 cm have been mixed. In addition, Vertisols exhibit wide cracks, which open and close periodically. Although vertisols, have high water-holding capacity making them suited to dry land crop production in semi-arid environments with uncertain and heavy rainfall they have a number of problems. Due to their high clay content, the physical properties of Vertisols are greatly influenced by moisture content; usually, these soils are too sticky and unworkable when wet, and very hard when dry. The soil moisture range in which the physical condition of Vertisols is suitable for tillage and planting operations is quite narrow. Deep Vertisols have impeded drainage in the rainy season with consequent loss of trafficability; poor air-water relations are suspected.

Polluted Agricultural Soils

Soil pollution is the accumulation of a substance, native or introduced, in soil at a level harmful for the growth and health of organisms, including microorganisms, plants, and animals (Osman, 2014). Hazardous substances find their way to the soil with domestic, municipal, industrial, mining, and agricultural wastes and industrial and agrochemicals such as fertilisers and pesticides. The most important categories of soil pollutants are the persistent organic compounds such as polycyclic aromatic hydrocarbons PAHs, Polychlorinated biphenyl PCBs, Polychlorinated naphthalenes PCNs, and Polycyclic Hydrocarbons and Esthers, PHEs and heavy metals such as Pb, Cd, As, Hg, Zn, and Cu. These substances, above a critical level, are toxic to plants and animals, including human. As source of pollution, municipal wastes can be grouped into five different categories according to Osman (2014), biodegradable (food and kitchen waste such as meat trimmings or vegetable peelings, yard or green waste, and paper), recyclable materials (glass, plastic bottles, other plastics, metals, and aluminum cans), inert waste (construction and demolition wastes; inert materials are those that are not necessarily toxic to all species but can be harmful or toxic to humans. Municipal wastes may contain non-biodegradable organics and heavy metals. Another source of pollution can be sewage sludge which is usually a liquid mixture, composed both of solids and of dissolved organic and inorganic materials. Sewage sludge may contain organic waste material, traces of many pollutants used in our modern society, pathogenic bacteria, viruses, and protozoa along with other parasitic helminths which can give rise to potential hazards to the health of humans, animals, and plants.

Most sources of soil pollution consisted also of agrochemicals which include various chemical substances used for production and protection in agriculture. In most cases, it refers to the broad range of pesticides, including insecticides, herbicides, and fungicides. It may also include synthetic fertiliser, hormones and other chemical growth agents, and concentrated stores of raw animal manure. Most agrochemicals are toxic, and their bulk storage may pose signify cant environmental and/or health risks, particularly in the event of accidental spills. Atmospheric deposition, mining, radionuclides in soil, heavy metals etc. are also various sources of soil pollution.

Available options for Managing Problem Soils in Africa: Lessons and Prospects

Control of Water Erosion

Several agronomic and engineering practices are employed for the control of water erosion. These are no- tillage, minimum tillage, mulching, strip cropping, contour cropping, contour strip cropping, and terracing, but several methods are needed to be integrated for an efficient soil erosion control. Control of soil erosion by water is based on the following principles:

- Reducing raindrop impact: this can be achieved by providing a cover on the soil during the rainy season. Dense forest canopy, close-growing crops such as cover crops and mulches on the bare or cropped soils can provide necessary protection against raindrop impact;
- Stabilising soil aggregates: stable soil aggregates are obtained in soils supplied with sufficient organic matter. Aggregation improves porosity and infiltration and reduces runoff;
- Increasing infiltration and reducing runoff: infiltration can be increased by mulching and by modification of the slope. Organic mulches soak water and allow water more time to infiltrate. Level lands have more infiltration capacity than sloping soils;
- Reducing velocity of runoff: velocity of runoff can be reduced by modifying the degree and length of slope through terracing and contouring. Contour cropping, strip cropping and contour strip cropping effectively reduce runoff velocity. When velocity of runoff is reduced, rate of infiltration increases;
- Minimum disturbance of soil: tillage makes the soil more erodible. Conservation tillage systems, including no-tillage, minimum tillage, and subsoil tillage are efficient soil conservation practices;
- Preventing concentration of runoff water in channels: leveling previously developed rills, growing crops closely, and keeping crop residues in field prevent concentration of runoff water;
- Carrying runoff water safely out of field: runoff water can be driven safely out of the field by grassed waterways;
- Integrating erosion control measures: usually, no one method alone is sufficient for the control of soil erosion. For example, integrating mulching with no-tillage can effectively reduce erosion;
- Regular maintenance of erosion control measures: practices for erosion control need to be maintained regularly. Terraces may need mending and barriers may need reconstruction.

Wind Erosion Control Measures

Many conservation practices can be implemented to control wind erosion. Conservation practices are designed to either reduce the wind force at the soil surface or create a soil surface more resistant to wind forces. Some practices also trap saltating particles to reduce the abrasion of soil surfaces downwind. Effective soil conservation methods have been used successfully for the reduction of wind erosion, restoration of crop production, and rehabilitation of soils to agriculture.

These measures include stabilising soil, ridging and roughening soil, cover crops, residue management, mulching, mechanical barriers, and windbreak. Some innovative measures have been employed in stabilization and rehabilitation of dunes, such as straw checkerboard barriers in Michigan, USA, and Mauritania in West Africa.

Management of Saline Soils

Two important approaches to soil salinity management are (i) selection of salt-tolerant crops and (ii) removal of excess salts from the root zone. Several salt-tolerant crops can be grown. Removal of salts by irrigation and drainage and drawing the salty water safely may be financially impracticable in some situations. Whether the reclamation will be cost-effective or not depends on salinity level; cost of water and labor, crop return, etc. Reclamation is relatively easy if the soil is saline alone, but difficult if it is saline - sodic or sodic.

Saline soil management involves growing salt-tolerant crops and leaching of salts below the root zone. If there is a salt crust on the surface of the soil, salt farming may be more profitable than cropping. For cropping, decrusting may be done mechanically and with soil flushing. However, decrusting followed by flushing has not been very successful for increasing crop yields. But some soils may need decrusting before leaching. Effective leaching may be achieved by flooding and draining soils. Some soils are only slightly saline. For shallow- rooted crops, the salts may be driven below the root zone by temporary leaching. This technique will need less water than normal leaching. Furrow irrigation with suitable seedling placement may also be satisfactory. Drip irrigation at the root area also dilutes salts and keeps the salts apart. If the soil is considerably saline, it needs removal of excess soluble salts by thorough leaching. However, a reliable estimate of the quantity of water required to accomplish salt leaching is required. The salt content of the soil, salinity level to depth to which reclamation is desired, and soil characteristics are important factors determining the amount of water needed for reclamation. A useful rule of thumb is that a unit depth of water will remove nearly 80 % of salts from a unit soil depth.

Management of Acidic Soils

Despite major difficulties for agricultural use, acidic soils can be very productive if lime and nutrients are applied at proper time and quantity (Box 4.1). For management of acidic soils, the pH need to be adjusted to a desired level by liming, following adequate irrigation and drainage and selecting suitable crops. Liming is an efficient way of increasing soil pH and reducing toxicity of iron, aluminum, manganese, and molybdenum.

Liming also stimulates biological activity in soils and increases cycling of nitrogen, phosphorus, and sulfur. It increases P availability to plants. It improves soil structure, porosity, aeration, and water movement in soils. However, over liming reduces the availability of phosphorus and causes deficiencies of micronutrients such as manganese, zinc, copper, and molybdenum.

Box 4.1: Long term effect of lime and phosphorus fertiliser on maize production on acid soil of Uasin Gishu County (Kenya)

The students should be able to:

— Manage phosphorus deficient acid soils for improved crop production;

— Discuss yield benefits due to use of lime and phosphorus on acid soils.

Soil fertility related constraints limiting agricultural production include soil acidity, deficiencies of N, P and low soil organic matter in Kenya (Buresh *et al.,* 1997; *Kisinyo et al.,* 2014). In medium to high rainfall areas, acid infertile soils occupy 13% of land areas in Kenya. Low soil P and Al toxicity in acid soils reduce maize grain yields by 16 and 28%, respectively. Due to soil fertility-related constraints, the staple food maize grain yields among smallholder farmers are normally < 1.0 ton/ha yr-1 in Kenya.

Acid soils have:

— Low soil pH, low levels of base cations, low available P.;

— High exchangeable Al.

Most improved maize varieties grown by farmers in Kenya are sensitive to acid soils. Attempts to manage acid soils include:

— Use of lime;

— Use of organic material;

— and Planting of crop germplasm tolerant to soil acidity.

A study was carried out to determine the immediate and long term effects of lime as calcium oxide and P fertiliser as triple superphosphate on maize performance. Other common liming materials commonly used for soil acidity management are calcium carbonate, calcium magnesium carbonate (dolomite) and slaked lime among others. A number of phosphate fertilisers such as Single superphosphate, phosphate rock and di-ammonium phosphates among others may be used for correction of soil P deficiency. Soil samples were taken and analysed for both chemical and physical analysis prior to planting in the year 2005 at Kuinet site in Uasin Gishu County, Kenya. The treatments comprised of three levels of lime (0, 2, 4 and 6 t/ha) and 3levels of P fertiliser (0, 26 and 52 kg/ha). Lime and P fertiliser were applied once in long rain year 2005. Yield data were collected up to end of year 2008 and are given in Table 4.2.

Table 4.2: Effects of lime and P fertiliser on a four year mean maize grain yield (t/ha)

Lime (t/ha)	P fertiliser (kg P / ha)			
	0	26	52	Mean
0	2.258	3.231	3.968	3.152
2	2.632	3.368	4.085	3.362
4	2.818	3.645	4.330	3.598
6	3.006	3.880	4.505	3.797
Mean	2.679	3.531	4.222	

Source: Kisinyo, 2011

Questions:

Refer to the elements of information given in the Case Study, to answer the following questions:

- Explain what kind of fertilisers and liming materials should be used on such soils, giving reasons;
- Determine % yield increments due to lime and P fertiliser applications, giving reasons.

Describe the correlation between the inorganic input and maize grain yield.

Control of Water Logging

Water logging can be controlled only if the passage and quantity of water into the subsoil is reduced; the rising of the groundwater table is prevented, and the drainage of excess water is improved. The inflow of water into the underground reservoir may be reduced by reducing the intensity of irrigation. The outflow of water may be increased by deep and frequent interceptor and field drains. The groundwater table must be maintained well below the root zone. Generally, keeping the water table at least about 3 m below the ground surface is desirable. This can be achieved by different drainage systems. Seepage water can be prevented by interceptor drains. Stagnant water can be removed by field drains, surface or subsurface. The drains must be regularly monitored. Many soils become waterlogged by flooding from canals and rivers. Small- and large scale embankment have been successfully employed in different regions.

Control of Nutrient/organic Matter Loss (Example of Biological nitrogen Fixation - NBF)

Based on information from literature, three stipulations are presented, depending on total N demand by crops: (i) for symbiotic N fixation in leguminous species, (ii) for chemoautotrophic N fixation in wetland rice and (iii) for non-symbiotic fixation (Box 4.2).

Box 4.2: Multipurpose nitrogen fixing trees and their associated micro symbionts for soil nutrient enrichment in semi-arid zone of Segou region (Mali)

The objective of the case was to develop a low cost, sustainable and high yield agroforestry system which reverses the trends of land degradation and decreasing crop production in semi-arid area of Segou region in Mali.

After working through the Case Study, the student should be able to,

- Select *rhizobia* genotypes which could improve the nitrogen fixation potential of *Sesbania sesban, Gliricidia sepium* and *Pterocarpus erinacus.*
- Use molecular biological techniques to study the biodiversity, the persistence and spreadness of introduced and indigenous micro symbiont *(rhizobia* and *mycorrhiza)* strains.
- Assess the risks of invertebrate pests on *Sesbania sesban.*

The Case Study addresses the following issues: increasing decline in crop yields associated with several factors, namely soil fertility depletion, acidification, compaction and loss of organic matter. In addition, the scarcity, inappropriateness and cost of chemical fertilisers, soil deficiency in nitrogen, the limited total and available forms of phosphorus as well as the risks of invertebrate pests are known as major constraints to sustainable crop production in this area. The introduction of exotic tree legumes in intercropping systems for improving soil fertility and crop yields is also not widely adopted by the smallholder farmers of the region. Although *Sesbania sesban* and *Gliricidia sepium* are used in agroforestry systems in Africa, the behaviour of some introduced exotic tree legumes in arid and semiarid areas of Mali is little known.

To tackle the major fertility and production constraints in the region, indigenous *(Pterocarpus erinaceus)* and exotic nitrogen fixing trees species *(Gliricidia sepium, Sesbania sesban)* were introduced as alternative agroforestry systems. In addition, field experiments consisted in the inoculation of specific *rhizobia* and *endomycorrhiza* strains for phosphorus supply were carried out. Millet production was assessed in field trials (Cinzana Research Station) and investigation of risks for invertebrates' pests was also performed in nursery and field trials.

Plate 4.1: Inoculant technology

Table 4.3: Field trials - soil characteristics at Cinzana Research Station (24-26 months after planting (Yr 2)

Trees/ Fertilisation	Loamy	Tiny limon	Great Class	Sand limon	C%	MO		N%	pH (KCl)
M (pure culture)	7.71	9.53	15.45	67.31	LS	0.33	0.58	0.07	5.47
Ss+M	7.08	7.53	15.25	70.14	SL	0.46	0.81	0.14	5.69
Ss+M+R	7.26	8.62	24.57	59.55	LS	0.39	0.68	0.07	5.67
Ss+M+PNT	12.25	21.21	9.85	56.65	LS	0.36	0.63	0.35	5.28
Ss+M+R+PNT	9.42	11.12	0.61	78.85	SL	0.33	0.58	0.21	5.66
Fallow	8.39	9.33	18.63	63.67	LS	0.58	1.01	0.21	5.00
M	7;6	9.3	9.4	73.7	LS	0.06	0.6	0.21	4.86
Gs+M	10	12.75	23	54.25	LS	0.43	0.75	0.21	5.64
Gs+M+R	9.08	7.71	14.3	68.91	LS	0.36	0.63	0.07	5.05
Gs+M+PNT	3	10.89	11.81	68	LS	0.12	0.21	0.21	4.93
Gs+M+R+PNT	6.46	7.7	16.95	68.88	LS	0.30	0.52	0.07	5.66
Fallow	19.75	23	0.60	56.5	LS	0.30	0.52	0.21	5.52

M –millet ; R-rhizobia strain; PNT-Natural phosphate rock of Tilemsi; Gs-Gliricidium sepium; Ss-Sesbania sesban

At FAST, higher numbers of nodules (34/pl) were found on *Sesbania sesban* grown on non-sterile soils, whereas lower numbers were obtained with autoclaved soils (5/pl). After three months, a good nodulation was observed on *Sesbania* inoculated with rhizobia strains ISRA 604 using sterile soils.

During year-1 at Cinzana Research Station, the mean survival percentages of *Sesbania* and *Gliricidium sepium* .were 87.25% and 88.06%, respectively. Inoculation with rhizobia strains registered highest values. However, for *Gliricidia sepium89,* 76 were reached when inoculation of rhizobia strains GsK4 is combined with PNT. Lower survival percentage was observed without inoculation. In year2, after 20 and 26 months of plantation, the survival percentage of *Gliricidia sepium* was 49, 95 and 49, 71%, respectively, whereas that of Sesbania sesban also decreased from 1,79% to Zero. Additionally, the roots collar diameters, height and numbers of branches of *Sesbania sesban* were higher than those of *Gliricidia sepium.*

In terms of yields, the highest values were found with P application, whereas the lowest values were recorded in pure cultures of millet.

Results on vertebrate pests showed that insects as thrips, *Ornitacris cavroisi, Drosophila* spp and ladybirds were the main causes of damage on *S. sesban* leaves at FAST, whereas at Cinzana Research Station *Agonocelus,* ladybirds, ants and termites were current. Furthermore, observations revealed that damage and attacks were more important on *S. sesban* than on *Gliricidia sepium.*

Questions:

- Analyse data from Table 4.3 and draw conclusions and recommendations for semi-arid and arid zones of Africa.
- Discuss the importance and practical use of such a case for soil fertility replenishment and sustainable crop production in arid and semi-arid zones of Africa.
- What lessons have you learned from this Case Study and how could you disseminate the experience gained to a wider public?

Management of Sandy Soils

Sandy soils have a large number of unfavorable attributes for sustainable agriculture. Productivity on these soils tends to be low, even when recommended agronomic practices are followed. However, there are a number of promising avenues for sustainable development of agro-ecosystems dominated by sandy soils (FAO, 2001). More generally, tropical sandy soils, more than other soils, therefore require careful management in an environmentally friendly manner. They are best kept covered by vegetation. Where the pre-existing ecosystems were forests or woodlands, a sustainable agro-ecosystem probably needs to incorporate a similar vegetation structure, as plantation crops, plantation forestry, or agroforestry. The soil cover provided by perennial vegetation minimises erosion and nutrient leaching, while the decrease in cultivation intensity and frequency helps maintain soil organic matter levels and soil structure. Ecosystems benefit from restoration of water balance, closed nutrient cycling, and enhanced biodiversity. Agroforestry may provide similar benefits to plantations.

In many parts of Southern and Eastern Africa, sandy soils are increasingly used for arable farming because of pressure on the land forcing the cultivation of such unfavourable soils. In sandy soils, it thus appears fundamental to manage all components that affect soil fertility: Maintenance of soil organic matter is therefore critical in sandy soils. Organic matter levels can be enhanced in sandy soils through minimum tillage, zero burning and retaining crop residues. Low nutrient levels are common on sandy soils, and crops grown on these soils commonly express multiple nutrient disorders which limit productivity of crops. While fertiliser can correct these disorders, it is often difficult to achieve the optimal mix of nutrients and other soil amendments to make it economic. Balanced fertilisation is however very important in sandy soils (Vanlauwe *et al.*, 2002).

Management of Vertisols

Vertisols occur in many agroclimatic conditions ranging from arid to humid and are used for production of different crops under different cropping systems. Although Vertisols are considered highly productive, some of their properties such as: low structural stability, low infiltration rates or low permeability lead to tillage difficulties and make it difficult to exploit their productivity to the full (Coulombe *et al.,* 1996). Therefore the management of Vertisols for crop production concerns the issue of water control- both when there is too much or too little. Drainage is essential for all vertisols occurring in high rainfall areas, or in level or depressed positions that which are susceptible to flooding. Slow internal drainage and negligible lateral movement of water in Vertisols makes subsurface drainage inefficient and practically unfeasible and hence excess water must be removed by surface drainage. Climate, essentially rainfall, except where irrigation is practiced is the overriding determinant in using Vertisols for agricultural production. The total amount of rainfall and especially its distribution dictate the need for water removal or water conservation or water removal in the early part and conservation in the latter part of the season (Pusparajah, 1992). Excess water is usually removed by surface drainage. Various land shaping techniques (tillage) e.g. cambered beds, broad beds and flat beds with furrows, have been used to remove excess water to avoid flooding and water logging of the Vertisols. Vertisols are prone to water erosion due to their slow infiltration. Once the soil is thoroughly wetted and the cracks are closed the rate of water infiltration becomes almost zero. In addition, zero till has proved particularly attractive on clay soils to minimize compaction and induce natural structure formation.

Many Vertisols are deficient in nitrogen, in line with their low organic matter content. Nitrogen fertiliser has to be applied in such a way that excessive volatilization of ammoniacal nitrogen or leaching of nitrate ions are avoided (FAO, 2001). Placement of nitrate fertiliser in the root zone is best in dry regions whereas split banded application is preferred in wet conditions. If nitrogen is supplied in the ammonium form, the exchange complex of Vertisols, which curbs (leaching) losses, retains it. Application of phosphate fertilizers is also recommended because Vertisols are often deficient in P. Application of animal manure and other organic inputs can improve soil organic matter and soil physical properties of Vertisols. Crop residues should be returned to the land instead of being used as animal feed, fuel and building materials. Combining broad beds and furrows with application of phosphorus fertiliser and intercropping of cereals and legumes takes full benefit of crop-livestock interactions in Vertisols.

Management of Polluted Soils

Soil pollutants can be removed by physical methods such as soil washing, encapsulation, and vitrification; chemical methods such as immobilization, precipitation, and oxidation; and biological methods such as microbial and phytoremediation. Hyperaccumulator plants are often employed for the remediation of soils polluted with heavy metals.

Soil washing is usually done as an *ex situ* remediation process which employs physical and/or chemical procedures to extract metal contaminants from soils. During soil washing, (i) those soil particles which host the majority of the contamination are separated from the bulk soil fractions, (ii) contaminants are removed from the soil by aqueous chemicals and recovered from solution on a solid substrate, or (iii) there is a combination of both (Dermont *et al.,* 2008).

In soil flushing, an aqueous solution is injected into the contaminated zone of soil followed by extraction of groundwater and elutriate (flushing solution mixed with the contaminants) and aboveground treatment and discharge. The basic principle of encapsulation is the underground construction of an impermeable vertical barrier to allow the containment of gases and liquids, whereas solidification is done through the addition of binding agents to a contaminated material to impart physical stability to contain contaminants in a solid product. Stabilisation (fixation) involves the addition of reagents to the contaminated soil to produce more chemically stable constituents.

The most important chemical parameters in the precipitation process are pH and concentration of metal ions. Heavy metals can be precipitated as insoluble hydroxides, sulfides, carbonates, and others by adding precipitants (digested sludge, Fe salts, calcium hydroxide, Al salts, etc.). They are then separated by different solid/liquid separation techniques.

Chelating agents such as ethylene diamine tetraacetic acid (EDTA), nitriloacetic acid (NTA), diethylene triaminepenta-acetic acid (DTPA), and S,S—ethylene diamine disuccinic acid (EDDS) can form strong metal—ligand complexes and are thus highly effective in remediating heavy metal-contaminated soils (Osman, 2014). In bioremediation, organisms are employed in extraction and removal of metals from the contaminated soil. Organisms include microorganisms and higher plants.

Conclusion

Sub-Saharan Africa is particularly vulnerable to threats of soil degradation mainly due to climate variability and long-term climate change. This is due to various factors including fragile soil resources with high rates of erosion and land degradation. To overcome these major issues, the chapter specifically highlighted and discussed the processes, factors, and causes of soil degradation, as well as the strategies and technological options to reversing the degradation trends. In this respect, solutions to the challenges faced by farmers in addressing key soil degradation attributes and their sustainable management options for resilience were comprehensively discussed. The chapter further brought concrete and relevant case studies from Kenya and Mali specifically to clarify and illustrate the identified key soil degradation issues.

Questions for Discussion

1. Define the following terms (i) soil fertility, (ii) soil health, (iii) soil productivity, (iv) soil resilience, (v) soil performance, and (vi) soil quality. Explore relationships among them.
2. What are the causes of soil degradation? What are the types of soil degradation? Discuss the extent of global soil degradation in Africa. Refer to specific examples.
3. What do we mean by: problem soils? Discuss the risks and constraints associated with these soil types as well as their management requirements for sustainable crop production in Africa.
4. Discuss the institutional initiatives for the sustainable management of problem soils in Africa. Mention the laws of sustainable soil management.
5. Explain geological and accelerated erosion. What are the causes of accelerated soil erosion? Discuss the on-site and off-site effects of soil erosion caused by water.

6. Give an account of different types of soil erosion by water. Distinguish between interrill and rill erosion. Which type of water erosion will create the most severe management problems?
7. What are the principles of soil erosion control? Explain that for an efficient control of erosion you need integrated efforts.
8. Narrate natural and human-induced causes of soil acidity. Discuss the effects of Al and Mn toxicity on plants.
9. Explain liming, lime requirement, and quality of lime. How do you determine lime requirement of a soil? Discuss the factors affecting lime requirement of soil.
10. How does soil mismanagement create soil salinity? Why is soil salinity a prominent problem of arid and semiarid regions? Explain leaching requirement.
11. What are wastes? List different soil pollutants and their sources. Discuss modes of disposal of wastes in the environment.
12. Agrochemicals are a major source of soil pollution — explain. Give a list of pesticides that contain hazardous compounds. Discuss the factors that affect the persistence of pesticides in soils.
13. Discuss *in situ* and *ex situ* remediation of organic pollutants.
14. "Bioremediation of organic pollutants is environmentally more acceptable." Discuss.

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5

Agronomic Practices for Managing Risks

I.I. Mudita, B. Toure, D. Nyadanu and G. Alemayehu Damot

Summary

This chapter deals with use of agronomic practices in managing risks such as weather risks, biological risks and natural disasters in agriculture. Agricultural risks expose farmers, agribusiness entities and governments to potential losses and cause economic problems to farmers and the whole value chain. Agronomic practices can be adopted by smallholder farmers to minimize yield losses or total crop failure as a result of unfavourable climatic conditions. These practices are easy to apply and require very little external inputs, hence every African farmer can adopt them. The chapter highlights knowledge generated through research and case studies on the practicability of the agronomic practices. It explores the extent to which the practices help in minimizing yield losses and avoid total crop failure due to unfavourable climatic conditions. Different levels of the value chain or the agricultural sector in general have varying capacities to manage risks and these depend on the severity of any given risk and the available resources. By managing agricultural risks there is enhanced potential to increase productivity and thereby boost investments in agriculture and guarantees agriculture as a business.

Resume

Pratiques Agricoles pour la Gestion des Risques

Le chapitre traite des pratiques agronomiques dans la gestion des risques, tels que les risques climatiques, biologiques et les catastrophes naturelles en agriculture. Les risques en agriculture exposent les planteurs, les entreprises agricoles et les gouvernements a des pertes potentielles et posent d'enormes problemes aux planteurs et a toute la chaine de valeurs. Les pratiques agricoles peuvent etre adapteespar lespetitsplanteurs, en vue de minimiser les baisses de rendement ou laperte totale des cultures, en egard aux conditions climatiques defavorables. Ces pratiques sont faciles a appliquer et necessitent des inputs exterieurs et favorisant ainsi leur adoption par chaque planteur africain. Le chapitre met l'accent sue les connaissances acquises par la recherche et des etudes de cas sur la praticalite des techniques agricoles. Il explore le niveau auquel ces pratiques peuvent-ils aider a minimiser les baisses de rendement et d'eviter les pertes totales des cultures a cause des conditions climatiques defavorables. Des niveaux differents de la chaine des valeurs ou du secteur agricole, en general, possede des capacites variables de gestion des risques et ceux-ci dependent de l'ampleur / gravite dun risque donne et des ressources disponibles. La gestion des risques en agriculture, permet un potentiel accru d'amelioration de la productivity et donc d'accroissement de l'investissement et garantissant l'agriculture en tant de business.

Introduction

Most farmers in Africa are smallholder farmers and they practice rainfed agriculture, which makes their farming business prone to weather risks (drought, heat extremes, hail, and floods). A major reason of the low and erratic rate of growth in agricultural production is the highly uncertain and unpredictable rainfall (varying season quality, high frequency of droughts and floods) (FAO, 2003). Besides, crops of African farmers are subjected to various production malpractices and biological risks including insect pests and diseases. These smallholder African farmers are vulnerable to poverty and lack the resources to absorb shocks, and hence it is of paramount importance to document risk management tools these farmers can employ to reduce losses and suffering. Agricultural risks expose farmers, agribusiness entities and governments to potential losses and cause suffering to farmers and the whole value chain. Agriculture especially in Africa continues to be risky. However, many risks especially under smallholder farming systems can be mitigated by agronomic practices.

Agronomic practices such as *in-situ* water management technologies; e.g. conservation farming practices, mulching, contour farming practices, ridges, tied ridges, pot holes and filtration ditches can be adopted by smallholder farmers to minimize yield losses or total crop failure as a result of unfavourable climatic conditions. *In-situ* water management technologies in agriculture refers to those practices that farmers can do in their fields i.e. in place where crops are grown or animals are raised. These practices are done in the field in order to conserve soil moisture so that crops will not suffer due to weather risks. *In-situ* water management technologies reduce risks associated with vagaries of weather (Nyagumbo *et al.,* 2009).These practices reduce water and nutrient losses, and maximize the availability of these environmental resources in the root zone of crops; thus rainwater and nutrients are conserved where they fall, *in situ* (Tigere and Mudita, 2013).

At farm level, during the production process, crop diversification, use of improved seed that tolerates harsh conditions and adjustments in plant population and planting dates are some of the tools used in risk management. These practices are easy to apply and require no or very little external inputs, hence every African farmer can adopt them. Biological risks due to invasion by pests and diseases can cause drastic crop losses or failure among farmers and thus they are a risk in crop production. Weeds become a farming risk when they reduce crop yields or lower crop quality. Strategies such as proper land preparation, choice of variety, choice of planting location, time of planting, crop spacings, weed control, pruning, trellising, shade reduction and diversification of crops have proved to be practical among farmers in Africa. Management of such risks requires a holistic approach i.e. Integrated Pest and Disease Management. Risks faced by farmers are numerous and varied, and are specific to the country, climate, and local agricultural production systems.

Learning Objectives

- To minimize losses by adopting agronomic practices, which reduce effects of agricultural risks.
- To analyze the practicability of the various agronomic practices under different farm situations.

Learning outcomes

At the end of this chapter, learners should be able to:

- Describe various agronomic practices applicable to African farmers that reduce weather risks;
- Analyze the various agronomic practices and assess their practicability under different farm situations;
- Assess the benefits derived from the various agronomic practices;
- Compare one agronomic practice against others in order to make decision on best option.

Managing Weather Risks Conservation Farming Practices

Conservation farming practices such as strip cropping, contour farming, zero or chemical tillage, mulch tillage and reduced or minimum tillage are widely practiced in Africa. Conservation farming is any system or practice which aims to conserve soil and water by using surface cover (mulch) to minimize runoff and erosion and improve the conditions for plant establishment and growth (FAO, 2014). It involves planting crops directly into land which are protected by mulch using minimum or no-tillage techniques. Conservation farming systems are designed to use mulch cover to reduce runoff, soil erosion, reduce soil temperature, conserve moisture for plant growth, increase organic matter levels, improve soil structure and fertility and ultimately sustainable productivity. Many individual practices can be integrated into a conservation farming program such as no- tillage, minimum or reduced tillage, agro-forestry, trap cropping, cover and green manure cropping, alley cropping, contour farming strip cropping, organic and biodynamic farming, stubble mulching, and integrated pest management (FAO, 2014).

The three main principles of conservation farming practices are; minimal soil disturbance, permanent soil cover and crop rotations (FAO, 2014; Government of Australia, 2006). The environmental benefits of conservation practices are that they help to conserve soil moisture and reduce soil erosion. Grass strips and mulching enhance soil structure and nutrient status. However, the grass strips and mulching, if not properly applied, can harbour pests and vermin that can destroy crops. Hence, conservation tillage is usually implemented as part of an integrated nutrient and pest management strategy. Over 40% of tropical storms result in runoff with the potential to cause erosion. High energy raindrops dislodge soil particles which are carried away in runoff water. Over 100 tonnes of soil per hectare per year can be lost from exposed land in the tropics. Mulch cover protects the soil by absorbing raindrop impact, increasing infiltration and slowing the speed at which water runs over the land, thereby reducing soil movement. With 80 to 100% mulch cover there is a 90% reduction in soil loss rotations (Government of Australia, 2006). Erosion rates will vary depending on storm intensity, soil conditions and other factors but surface cover has the potential to decrease soil loss by 90% (FAO, 1993). Moisture availability determines crop and pasture productivity. Crop failures can occur despite ample rain because much of the moisture is lost through runoff and evaporation.

In Zambia, the Golden Valley Agricultural Research Trust (GART) has been promoting ripper-based conservation tillage (Samazaka *et al.,* 2003). An example is the Magoye ripper, an animal-drawn implement developed and promoted in Zambia. Samazaka *et al.* (2003) reported overall positive results such as saving on land preparation costs. Conservation tillage is widely practised in Eastern and Southern Africa (Kenya, Malawi and Zimbabwe) and has gained momentum because of the current high level of environmental awareness (UNEP, 1998). Conservation tillage is part of extension training in most countries in these regions. The technologies are very effective in minimising soil disturbance and in controlling erosion losses. However, the degrees of effectiveness and suitability of conservation tillage techniques vary with each particular practice, although all are suited to agricultural operations throughout the African continent (Oldreive, 1993). In terms of cultural acceptability; there are no cultural norms against any of the conservation tillage techniques (UNEP, 1998). Indeed, minimum tillage techniques mimic traditional agricultural practices in many African countries.

Strip Cropping

Strip cropping is the farming of sloping land in alternate, contoured strips of inter-tilled row crops and close growing grasses (or ground cover crop), aligned at right angles to the direction of natural flow of runoff. The close-growing strips slow down runoff and filter out soil washed from the land in the inter-tilled row. This control of runoff and erosion also allows increased opportunity for infiltration of the runoff and, thus, increased moisture in the soil. The strip widths can be varied depending on the soil type and slope. Strip cropping is effective on well-drained soils on slopes of 6 to 15%. Strip widths and spacings can be designed to suit machinery and farm operations, while the grass strips can help provide grazing for farm animals during winter, depending on conditions. Grass strips can also enhance soil structure and nutrient status. However, if not managed correctly, strip cropping can leave grass strips which can harbour pests and vermin that can destroy crops. Also, competition between main crop and strip crop may occur, thus proper choice of the crops is important (UNEP, 1998).

Contour Farming

Contour farming involves aligning plant rows and tillage lines at right angles to the normal flow of runoff. It creates detention storage within the soil surface horizon and slows down the rate of runoff, thus giving the water time to infiltrate into the soil. The contour bunds are earth banks 1.5 to 2.0 m wide, forming buffer strips at 10 to 20 m intervals, and are important for the functioning of the technology. The effectiveness of contour farming for water and soil conservation depends on the design of the systems, soil type, climate, slope aspect and land use of the individual fields. Contour farming is suitable on slopes of between 3 and 8%. Contour farming limits soil loss to about 18 t/ha/year, compared to 46 t/ha/year using conventional tillage (FAO, 1993) and it also conserves soil moisture. Contour farming results in less benefit to compacted or poorly permeable soils because these soils become saturated quickly. This can prove harmful to certain crops. Also, special skills may be required to construct effective contour lay outs. Ineffective lay outs can give rise to difficulties in tillage and crop management, and, on steep slopes, contouring alone can be deleterious, since water concentrating in the furrows may breach the bunds and cause even more erosion. In Malawi, research has shown that contour farming alone can reduce erosion by as much as 50% on moderate slopes. However, on slopes steeper than 10%, other measures should be combined with contour farming to enhance its effectiveness (Mloza-Banda, 2006).

Zero or Chemical Tillage

In this approach, the land is not tilled at all. Chemical tillage uses herbicides to control weeds, avoiding the need to till the soil. A commonly used herbicide is Round up (Glyphosate). This tillage technique conserves water in the soil profile since the soil is not tilled and exposed to the drying (evaporative) elements of the atmosphere. The moisture is retained within the soil profile. The new crop is generally planted directly into the stubble of the previous crop. Zero tillage limits runoff and soil loss, thus it is suitable on most soils and slopes especially on hydromorphic soils with poor internal drainage. It saves energy and time, although the cost of herbicides may offset the savings in time and energy (Oldreive, 1993). Zero tillage is effective in reducing erosion and conserving moisture, compared to conventional tillage. Challenges of this practice are that; the chemicals used under zero tillage can be harmful to the environment, i.e. can cause environmental pollution. Zero tillage requires significant inputs of chemical herbicides (Concern Malawi, 2011). The cost of these chemicals can be quite high, rendering the whole technique unviable in addition to cause considerable harm to the environment.

Mulch Tillage

Mulch tilling involves covering bare soil with mulch or plant litter to reduce evaporation of soil moisture and minimizing the erosive energies of rain falling directly onto soil particles. The mulch reduces runoff and improves infiltration of water into the soil. The mulch is usually crop residue such as maize stover, sorghum trash and wheat straw. In cases where these are not available, or are used to feed animals, gravel can be used as a mulch. Mulching conserve moisture and enhance soil structure and nutrient status especially if there is earthworm activity. In addition, weed growth is suppressed in a completely environmentally- friendly manner. Unfortunately, the mulch, if not properly applied, can harbour pests and vermin that can destroy crops (Concern Malawi, 2011), hence, conservation tillage is usually implemented as part of an integrated nutrient and pest management strategy.

Reduced or Minimum Tillage

Reduced tillage is a practice in which the soil is tilled to some extent but not completely inverted. There are several ways of achieving reduced tillage. For example, the plough can be supplemented with a disc or a chisel harrow, and the land ploughed in narrow strips, coinciding with the spacing of the row crops, leaving the intervening space untilled. Reduced tillage means a smaller volume of soil is exposed to erosion and moisture loss by evaporation; hence, conserving moisture. Minimum tillage reduces soil losses to about a tenth of that of tilled lands (Concern Malawi, 2011). Reduced tillage is suitable under most conditions, provided other factors, like slope and rainfall intensity are taken into account in the practices. Reduced tillage conserves soil moisture better than conventional tillage methods. There are lower land preparation costs, reduced soil compaction and aggregate breakdown, and less area of ploughed surface is exposed to erosive rains.

Ridges

Ridges are widely used in various crop fields to serve different purposes. When used in crop production systems, ridges serve a dual purpose i.e. to conserve moisture in arid environments and to facilitate drainage in high rainfall areas i.e. to reduce waterlogging. When ridges are used to reduce waterlogging they are sometimes referred to as drainage ridges. Waterlogging causes oxygen deficiency and interferes with mechanical weed control, which in turn may cause yield reduction (Russell, 1997).

The practice of planting or seeding crops on ridge tops, along ridge sides, or in the furrow is called ridge tillage. Careful consideration should be practised in selection of fields where ridges are to be made; avoid fields that are very irregular and uneven since these will result in low points in ridges where water may collect and overflow the ridges leading to serious gully erosion (Biscoe, 1987). When ridges are not aligned with contours there is a risk of erosion during heavy rain (Rowland, 1993). Ridges may also lead to high runoff and soil erosion rates on light soils (Rowland, 1993). In light soils, farmers are therefore advised to reduce frequent cultivation (frequent cultivation destroys surface structure), and incorporate plant residues to improve infiltration, reduce runoff and increase soil water storage.

Runoff rates vary between 2 and 32% depending on rainfall, soil type, cropping system and management practices (Rowland, 1993). Ridges are constructed across the slope to contain surface runoff and control excess runoff rates at non-erosive velocities, thus conserving water to increase crop productivity. A seven to thirteen-fold decrease in erosion and runoff was observed in parts of West Africa due to ridging (FAO, 1993). It is this impact that ridges achieve, for which their continued use is advocated in Malawi where most of the country lies on moderate to steep slopes. Remaking ridges every season on the contour is a conventional land preparation practice in Malawi. In Zimbabwe ridges are widely used in tobacco production to drain off excess water. Other crops commonly grown on ridges include potato, sweet potato, groundnuts and yam. In sweet potato production, planting on ridges is valuable where runoff control is necessary (Rowland, 1993). In groundnut and bambara nut production, ridges are recommended in heavy soils to facilitate lifting at harvest. Ridges in low rainfall conditions offer an increased soil surface area for evaporation, and may accentuate plant water stress, leading to reduced peg penetration and decreased yields (Rowland, 1993).

Under smallholder farming systems, where the farmers use hand implements or animal traction and low-value subsistence crops, the ridge-furrow system used along the contour is a satisfactory method of enhancing infiltration and reducing runoff. The problem, however, is the fact that ridging interferes with the hydrologic pattern of runoff water, increases the micro-topography of the field being cultivated, and may cause increased runoff locally. Great care is therefore needed in planning and laying out the ridges.

Contour Ridges

Contour ridges were introduced in Zimbabwe indiscriminately for use in smallholder farming areas in the 1930s without considering rainfall conditions, to combat accelerated erosion that had become rampant after the introduction of the plough in the 1930s (Alvord, 1958) The use of mechanical contour ridges was thus resisted by farmers and was seen as a tool of oppression due to their enforcement, high labour demand, 15% land taken out of production and irrelevance to drought prone regions where water is scarce. However, despite those challenges, contour ridges are useful to reduce runoff by controlling water movement over the surface. Contour farming involves aligning plant rows and tillage lines at right angles to normal flow of runoff. It creates detention storage in the soil surface horizon and slows down the runoff thus giving the water time to infiltrate into the soil. The effectiveness of contour farming in water and soil conservation depends not only on the design of the system but also on soil, climate, slope aspect and land use. The beneficial effect is least marked on compact or slowly permeable soils because these become saturated quickly compared to highly permeable soils (Aina, 1993).

Contour ridges, sometimes called contour furrows or micro-watersheds, are small earthen ridges, 15 to 20 cm high, with an upslope furrow which accommodates runoff from a catchment strip between the ridges. The catchment strip is usually uncultivated, but, where contour ridging is used to control erosion rather than for water harvesting, the whole area may be cultivated. This is a micro- catchment technique. The objective of the system is to collect local runoff and store it within the soil profile in the vicinity of the plant roots. Micro-catchment contour ridging is usually not designed to accommodate overflow, so the system should be protected with a cut-off drain. Runoff is collected from the uncultivated strip between ridges and stored in the furrow. On sloping lands it is important to plough along the contour (or across the slope) and not up and down the slope. This helps reduce soil erosion and keep moisture in the soil for the benefit of plants to yield better. If you plough along the contour, rainwater will not run down through the field, thus soil erosion is minimized. Rainwater will be stored in the furrows and will infiltrate into the soil (Tigere and Mudita, 2013). This practice is very much applicable to farmers who practice dryland or rainfed systems in areas that receive little rainfall and in years when rainfall is limited.

Contour ridges for crop production are applicable to all soils which are suitable for agriculture, however, heavy and compacted soils may be a constraint to construction of the ridges by hand. In terms of slope, from flat up to 5% is acceptable. The topography must be even, i.e. areas with rills or undulations should be avoided. Contour ridges are limited to areas with relatively high rainfall, as the amount of harvested runoff is comparatively small due to the small catchment area (FARMESA, 2003). Contour ridges technique has application for high moisture requirement crops such as sugarcane and timber. The ridges are built exactly on the contour and the crop is planted on the ridge. This not only has the advantage of creating surface storage to entrap all the rain that falls, but because the ridge is constructed largely of topsoil, the young growing plant has the benefit of an artificially-deepened and fertile medium. Its young roots are, however, kept clear of occasionally saturated conditions. Soil temperature on the ridge is also increased, to the benefit of early spring-planted crops (Russell, 1997).

The height of a ridge is a function of the slope of the land i.e. the steeper the slope, the taller the ridge should be, in order to entrap the runoff. Level ridges on sloping land should be planned and constructed carefully and regularly maintained. They should be restricted to land no steeper than 10 to 15%, to deep and well-drained soils, and to high water-use crops and those that give a good ground cover or supply of surface litter (Russell, 1997). A method which can be used to improve the safety of the contour ridge system is tie ridging. Adjacent ridges are tied one to another by a series of cross berms of the same height as the ridges, in order to prevent water moving more than 5 to 10 m along them. The cross-ties can be constructed manually or mechanically (Russell, 1997).

Tied Ridges

Tied ridges are a practice that reduces runoff by controlling water movement over the surface. The principle of this practice is to minimise the concentrations of runoff volume and to slow down the runoff velocity, allowing the water more time to soak into the soil, thus limiting its capacity to transport soil particles and diminishing its ability to cause erosion. By so doing, risks associated with runoff are reduced. Tied ridging system is a type of land management whereby the ridges are "tied" to each other at regular intervals by cross-dams, thus blocking the furrow, thereby minimizing run-off and facilitating storage of water. At regular intervals, cross ties are built between the ridges, about two-thirds the height of the ridges, so that if overflowing occurs, it will be along the furrow and not down the slope (Elwell, 1993; Vogel, 1992). Tied ridges are made at planting or at first weeding and they are common in cotton, maize, cowpeas, millet and sorghum in the semi-arid tropical areas of Africa where yield for those crops is enhanced. The system involves planting on ridges, or ridging up after planting, then blocking the furrows at regular intervals. These "ties" are more frequent on steeper ground than flatter ground (Oldreive, 1993). Tied ridging is also a useful technique for farming areas with poor soil physical properties, low fertility, and probable drought. The bunds increase water infiltration, improve soil physical properties in addition to decrease runoff and erosion. Consequently, fields with tied ridges have greater water storage capacity than either flat or open ridged fields.

Tied ridging has been extensively practised in semi-arid tropics as an *in-situ* soil and water conservation technique, with a beneficial effect of reducing runoff and soil loss to enhance grain yield (Nyagumbo et al, 2009). In Southern Africa, tied ridges are widely used in commercial farming situations as a means of controlling soil erosion. The technique of ridging and tied ridging in Zimbabwe is widely documented (Nyagumbo *et al.,* 2009). It was researched on-station at Chiredzi and Makoholi Research Stations in Southern Zimbabwe and on-farm in Domboshava, Chiredzi and Chivi Communal Areas in Zimbabwe. In some instances there was resistance in the adoption of the technique mainly due to shortages of labour and draft power. Tied ridging is labour intensive and the ties can be broken in heavy storms, resulting in substantial soil loss due to erosion (Oldreive, 1993).

Ridge-tying is an effective soil and water conservation system especially in arid and semi-arid regions (< 1000 mm annual rainfall), on gentle slopes (< 7%) but not in wet years or more humid areas (Aina, 1993). The effectiveness of tied- ridges depends on soil, slope, rainfall and design characteristics. Tied ridge technology was successfully used in West Africa in Niger, Mali and Burkina Faso to improve soil moisture conditions and physical properties with significant benefit for cotton, maize, cowpeas, millet and sorghum producers in the semi- arid areas (Kimenye and Bombom, 2009). Compared to the flat or open ridged fields, tied ridges resulted in yield increases of about 40% in maize trials with improved varieties. Similar increases in maize grain yield of about 63% and 37% were observed up from 30% and 23% in Ethiopia (Kimenye and Bombom, 2009). Effect of ridges on soil water content, root growth, water use and yield of cowpea *(Vigna unguiculata* L. Walp) was studied in the Sudan Savanna of Burkina Faso and results were positive. Root growth increased significantly and grain yield increased by 51% (Hulugalle, 1987). In Zimbabwe most of the equipment used for ridging and tied-ridging are locally manufactured, designed to be animal- drawn and do not require any special skills to operate or maintain. The ridges can sometimes be tied using hand hoes. In terms of the effectiveness of the technology, tied-ridging produces better crop yields than conventional tillage (Elwell, 1993) and reduces runoff compared to conventional tillage (Table 5.1).

Table 5.1: Effectiveness of tied-ridging technology at Domboshava (Zimbabwe)

Tillage Treatment	Rainy Seasons	Surface (mm)	Runoff (%)	Soil Loss (t / ha)
Conventional Tillage	1988-89	6.9	7.0	1.7
	1989-90	274.3	23.3	9.5
	1990-91	15.0	2.0	1.1
	1991-92	9.4	2.2	1.0
Tied Ridging	1988-89	2.3	0.3	0.2
	1989-90	116.5	9.9	2.2
	1990-91	1.4	0.2	0.3
	1991-92	0.1	0.02	0.1

Adapted from: Munyati, 1997

Research conducted in Zimbabwe from 1988 to 1996 showed that tied ridging and mulch ripping on a 4.5% slope drastically reduced erosion and increased maize grain yield, compared to conventional tillage (Table 5.2). The cumulative total soil loss for the eight years determined (1988-1996) was lowest for the tied ridging treatment (5.9 t/ha) and the maize grain yield was highest (33.18 t/ha) for tied ridging treatment compare to conventional tillage and mulch ripping treatments. The results showed that tied ridging reduced soil loss and increased maize grain yield (Table 5.2). In years where there is above normal rain, soil loss is higher due to runoff. Therefore, tied ridges can be used to reduce that runoff and subsequent soil loss, which in turn will enhance soil moisture conservation and increase crop yields.

Table 5.2: Soil loss (t/ha) and grain yield (t/ha) from different tillage treatments at Domboshava (1988/89 — 1995/96 seasons). Figures for grain yield (t/ha) are shown in brackets.

Year	Rainfall (mm)	Tied Ridging		Conventional Tillage		Mulch Ripping	
1988-89	905	0.2	(5.03)	1.7	(3.82)	2.0	(3.81)
1989-90	1180	2.2	(4.56)	9.5	(2.76)	2.6	(2.07)
1990-91	739	0.3	(4.56)	1.1	(3.06)	0.6	(3.96)
1991-92	438	0.1	(0.75)	1.0	(1.16)	0.3	(0.34)
1992-93	797	0.9	(6.57)	11.8	(5.10)	1.1	(4.25)
1993-94	610	0.2	(5.95)	1.5	(4.59)	0.6	(5.69)
1994-95	480	0.7	(2.39)	10.3	(2.38)	0.6	(3.46)
1995-96	865	1.3	(3.37)	4.2	(3.10)	0.2	(3.86)
Cumulative total	6014	5.9	(33.18)	41.1	(25.97)	8.0	(27.44)

However, the disadvantages of tied ridges are that tied ridgers require new or additional equipment, and substantial time and effort is required to prepare the lands each year, thereby increasing the farmers' costs. In situations where there is flooding, the ridges can collapse due to overtopping, leading to greater soil losses (Elwell, 1993). In Malawi, tied ridges are unpopular among smallholder farmers as the practice formed part of forced labour during the colonial era (Materechera and Mloza-Banda, 1994)

In terms of further development of the tied-ridging technology there is great potential for its use in the arid and semi-arid regions of Zimbabwe. The acceptance and adoption of the technology rests much with the effort put in the research and extension services, with the government playing a pivotal role. The technology is easy to adopt if the farmers are mechanized and have adequate draft power due to substantial time and effort required for land preparation (Elwell, 1993).

Pot Holes

Potholing is a technique of harvesting and conserving water by digging small holes in between the growing crop using a hand hoe to collect runoff water. There is a lot of runoff water near paths and roads or around anthills where the soil is hard or compacted. The best place to use pot holes is in such areas. The run-off water collected in the pot holes will provide the crop with water to help it yield better. It will also reduce soil erosion thus help protect lands or fields from erosion. After 3 or 4 rains the pot holes will fill up with soil but by this time the crop would have benefited from the harvested water. According to Kumwenda and Saka (1998), potholes are used to harvest and store water for use by the crop during dry spells. Potholes are more attractive than ridges and tied ridges as they give higher yields than planting on ridges and are less labour intensive. Thus potholes are a practical soil-water conservation practice, which may increase yields especially in drought years (Nhira et al., 2008).

Mulching

Mulch is any material placed on the soil surface to conserve moisture, increase the storage of soil water, lower soil temperatures around plant roots, reduce evaporation and runoff, prevent erosion and reduce weed growth. Natural mulch consists of dead leaves, twigs, fallen branches, pruning material from trees and hedges, crop residues, wastes from agricultural processing or from forestry and cover crops. Mulches can be derived from either organic or inorganic materials. Organic mulches not only conserve moisture, but they also feed plants, earth worms and microbes by composting at the moist earth surface. Mulches facilitate formation of crumb soil structure, which improves infiltration and water holding capacity on the humus and clay particles for future plant use. Farmers can adopt natural mulching to cropping practices by using available living or dead organic matter and inorganic materials. Uprooted weeds can also be used as mulch where mulch material in unavailable. The mulch should ideally have a carbon to nitrogen ratio (C/N) between 25-30 for easier decomposition and to avoid temporary depletion of nitrogen. Mulch insulates and protects soil from drying and hard-baking effects caused by evaporation of water from soil exposed to hot sun and winds. Application of surface crop residue mulch seems to be the best soil management practice for increased soil moisture conservation and improved crop performance in rainfall marginal areas of Kenya (Gicheru, 1994).

A mulch cover enhances the activity of soil organisms such as earthworms (UNCTAD, 2003). They help to create soil structure with plenty of smaller and larger pores through which rainwater can infiltrate easily into the soil, thus reducing surface runoff. As the mulch material decomposes, it increases the content of organic matter in the soil. Therefore, mulching plays a crucial role in soil moisture and fertility management. Mulched soils are cooler than non-mulched soils and have less fluctuation in soil temperature. Optimum soil temperatures and less moisture evaporation from the soil surface enable plants to grow evenly. Mulches break the force of rain and irrigation water thereby preventing erosion, soil compaction and crusting. Mulched soils absorb water faster and prevent splashing of mud and possibly plant disease organisms onto plants and flowers during rain or overhead irrigation. The mulch covering excludes light which prevents germination of many weed seeds. Fewer weeds provide less competition for available moisture and nutrients. Using mulches to control weeds is safer than applying herbicides or cultivating which can damage tender, newly formed roots, and in some instances have residual effects that may harm the succeeding crop. Therefore mulches are important for conserving moisture, slowing flood waters, reducing evaporation and runoff, reducing pesticide use, producing healthier plants, smothering weeds and saving money by recycling materials considered waste.

Adequate or durable mulching material is less readily available in regions with long dry seasons so farmers are recommended to use alley cropping, no tillage practices and cover crops e.g. cowpeas. Mulching with crop residues increases soil moisture storage and maintain a high water content in the upper soil layer. Organic residues not fit for animal feed can be used (Palaniappan and Sivaraman, 1996). The higher crop yields associated with mulched fields show that risks in crop production can be minimized.

The effectiveness of this practice for risk management is more pronounced in post rainy season than in rainy season (Palaniappan and Sivaraman, 1996). The kind of material used for mulching greatly influences its effect. Materials that easily decompose protect the soil only for a short time, but provide nutrients to the crops while decomposing. Hardy materials decompose more slowly and therefore cover the soil for a longer time and protect soil against moisture loss and erosion (UNCTAD, 2003).

Constraints of mulching are that slugs, snails, ants or termites may find ideal conditions for living under a mulch layer and can multiply quickly to cause damage to the crops. There is also an increased risk of sustaining pests and diseases with mulching. Damaging organisms such as stem borers may survive in the stalks of crops such as maize, cotton or sugar cane (UNCTAD, 2003). Plant material infected with viral or fungal diseases should therefore not be used if there is a risk that the disease might spread to the crop.

Cover Crops

Cover crops such as cowpeas (*Vigna unguiculata*), soyabeans (*Glycine max*), Mucuna pruriens utilis, *Pueraria phaseoloides*, *Centrosema pubescens*, *Setaria spp*. and S*tylosanthes spp*. are useful in achieving in situ mulch. In some farm situations, these cover crops are planted during the fallow period in rotation with food crops to conserve soil water, improve water use efficiency, control weeds and/or add organic matter. The effectiveness of cover crops in soil and water conservation however depends on species characteristics such as ease of establishment, vigour of growth, depth of rooting, rapidity of establishment of surface cover, resistance to pests and diseases and multiple uses. The most important characteristic of an ideal cover crop is ability to grow fast and cover the soil permanently (IFOAM, 2010).

Keeping the soil covered is a fundamental principle of conservation agriculture. Crop residues on the soil surface protect soil surface after harvesting. Additional cover crops may be needed if the gap is too long between harvesting one crop and establishing the next. Cover crops improve the stability of the conservation agriculture system, not only on the improvement of soil properties but also for their capacity to promote an increased biodiversity in the agro-ecosystem. Cover crops are beneficial in stabilizing soil moisture and temperature, protect the soil during fallow periods, mobilize and recycle nutrients, produce additional soil organic matter and improve soil structure, break compacted layers and hard pans, permit a rotation in a monoculture and control weeds and pests. Cropping systems should be designed in such a way that the soil is almost permanently covered with plant canopy. In arable crops, careful timing of sowing and planting can help to avoid uncovered soil being washed away during the rainy season. After the main crop is harvested, a green manure crop may be sown (Infonet Biovision, 2012).

Subsistence farmers in Sub-Saharan Africa intercrop cowpeas, a cover crop with maize, millets, sorghum and cassava (IFOAM, 2010). In Zambia, an experiment was conducted to determine effects of maize-cowpea intercropping systems on weed intensity. Visual weed score assessment revealed that live soil cover with cowpeas in the intercrop reduced weed infestation (Table 5.3).

Table 5.3: Effect of maize-cowpea intercropping system on weed intensity

Cropping System	Weed Score (2009-10)		Weed Score (2010-2011)	
	Chisamba	Magoye	Chisamba	Magoye
Maize-cowpea intercrop	3.4 3.6	3.4 3.6	3.0	3.8
Maize monocrop	5.7 3.4	5.7 3.4	3.4	3.8

[1]Weed Score Key (1-9): 1 = no weeds; 9 = Severe weed infestation

(Source: Simunji et al., 2001)

Alley cropping

Alley cropping is an agro-forestry system integrating trees and shrubs with annual food crop production (Kang *et al.,* 1990). In this system arable crops are grown in the spaces between rows of planted woody shrubs or trees, which are pruned during the cropping season to provide *in situ* green manure, to provide biomass, enhancing the nutrient status and physical properties of the soil and to prevent shading of crops. The beneficial effects of the system in reducing erosion, surface runoff and soil moisture loss depend on the proper choice of the protective species. Positive results have been obtained in alley-cropping arable crops (such as maize) with *Gliricidia* and *Leucaena.*

Alley cropping improves or maintains crop yields by improving soil fertility and micro-climate through cycling of nutrients, mulching and weed control. This can be achieved by using specific tree species that produce foliage and fix nitrogen, enriching the soil. By planting deep-rooted trees and shrubs that grow quickly in hedgerows, essential plant nutrients are recycled to the benefit of crops planted in alleys between the hedgerows. Furthermore, a good mixture of trees and shrubs can provide animal fodder, protection against soil erosion, shade and windbreaks. Alley cropping is mostly used in humid or sub-humid tropical areas on fragile soils and seems to work best where farmers need to intensify crop production but have soil fertility problems. The technique of alley cropping requires careful planning and management. It is preferable that the species used have a light open crown that lets sunlight penetrate the under-storey. It is also possible to prune species with a denser crown. The trees used must also be capable of rapid resprouting after coppicing.

Advantages of alley cropping are; improvement of soil fertility, structure and micro-climate conditions, thereby benefiting crops, and trees used can provide products of commercial and subsistence value. However, there are also disadvantages associated with the practice such as; the technique will take some years to establish, so farmers will have to wait for the benefits, farmers may not have the capital available for the investment in trees, alley cropping requires considerable labour and management, results will be poor if planting and pruning schedules are not carried out properly, and competition with crops for water and nutrients. It is important to plant trees with deeper roots than those of the crops grown alongside. From an agricultural point of view, successful systems are those that have symbiotic affects. Shrubs and trees act as a wind break, facilitate nutrient cycling, suppress weed growth, decrease runoff and reduce soil erosion. A key element of this agro-forestry practice is, therefore, to select species and mixtures with desirable characteristics (Kang *et al.,* 1990). Alley cropping systems can be practiced by farmers to manage risks associated with adverse weather conditions.

Managing Risks Associated With Varietal and Cultural Practices

Crop production is the output of series of cultural practices including crop variety and site selection, land preparation, soil fertilization, seeding, soil cultivation and weeding, harvesting, and threshing. Each of these cultural practices should be carried out as per recommendations. Malpractices of these cultural practices cause great crop losses. Therefore, understanding the effects of each cultural practice on crop yields is paramount for minimizing the losses.

Poor crop varieties and seed quality attribute to yield losses from 25 up to 100%. Therefore, choosing good varieties with high quality seeds is the primary practice for successful crop production. Good crop varieties possess the following characters: high yielding, high adaptation to the area, resistant/tolerant to the major diseases/insect pests of the crop, good market quality, low shattering ability, easily threshed, and palatable straw to animals. Similarly, good quality seeds are of high purity, high viability, above 90% germination capacity, vigorous seedling and free from diseases, insect pests and weeds.

It is important to select a site that does not have a history of pests and diseases problems. Aphids favour warm conditions, so to effectively manage aphids especially in potato production where they transmit viral diseases, grow the potatoes in cold areas. The time of year will influence what crop problems you have. Select a production period that will minimise pests and diseases. Foliage diseases are usually worse in warm, wet weather, *Heliothis* is usually worse in warm weather and mites prefer warm, dry conditions. To effectively manage these pests, avoid the time when they are prevalent. Adjusting the timing of planting or harvest is another cultural control technique. The earlier planted tomatoes are far less likely to be infested by the tomato fruitworm than those planted later in the season. Rainfed maize in Southern Africa is planted after the effective rains with 24 mm of rain, thus enabling the crop to take full advantage of the season and the 'nitrogen flush' (Nhira *et al.*, 2008).

Thorough land preparation is essential to allow time for the complete breakdown of crop residues and any green manure crop, thus also assists with plant establishment. It reduces the risk of waterlogging, and plant loss from damping- off and other soil-borne diseases and pests. Cultivation reduce the number of soil-borne insects, including over-wintering *Heliothis pupae*, a process known as pupae busting. Tillage exposes some pests and pathogens to vagaries of weather and thus killing them. Mechanical disturbance of the soil that destroy pests in a variety of ways, for example, by directly destroying weeds and volunteer crop plants in and around the field also help in controlling pests and diseases.

During seeding (planting), important aspects that should be well considered are: time, rate, depth and method of seeding. Time of seeding is largely dictated by rainfall pattern, crop type, soil moisture and temperature. Local knowledge and experience of a given area plays a great role in setting the time of planting of a crop. But, indeed, farmers are complaining about climate change that causes shifting the rainfall patterns which in turn affect their cropping calendar adversely. Too early or late planting of a given crop from its recommended time affects crop productivity negatively. Thus, keeping the right time of planting is very essential to minimize crop losses caused by either too early or too late planting.

Seeding rate and crop density has also a marked influence on crop productivity. The optimum plant density of a crop varies upon seed purity and viability, seed size/weight, seeding time, soil type, soil fertility and moisture. Considering these factors and recommended rates, seeding rate of a crop should be set at its theoretical optimum rate so as to optimize its productivity with a minimum risk of loss due to low or high crop density. Based on seed size, soil type and moisture, the seed must also be planted at its optimum depth. Although it requires special implements or more labour for planting/seeding, row method of sowing/planting is better than that of broadcast and uses less seeds, less fertilizers, less labour for weeding, and results in higher yield per unit area. Soil moisture management can be achieved through regulating plant density to match rainfall amount, distribution and duration. Where rainfall amount is limited, farmers are advised to plant their crops wider apart to reduce competition for the available moisture. Densely populated crops compete for the available resources and also create a microclimate within plant canopy, thereby reducing ventilation and increasing prevalence of diseases.

Poor farm hygiene results in losses from pests and diseases. Good farm hygiene is one of the simplest and most often overlooked methods of pest management. It results in fewer pests and diseases developing on and being spread around the farm. Good farm hygiene includes crop rotation, cover cropping, rogueing and crop hygiene. In tomato production, trellising is a common practice done to ensure crop hygiene thereby reducing disease prevalence. Pruning is common in fruit trees, whereby diseased or pest damaged or overgrown parts of the plant are removed to avoid infection of healthy parts of the plants and ensure free circulation of air within plant canopy in order to reduce disease prevalence. Avoid double cropping with beans, especially where Sclerotinia rot or red root is a problem. Old crops and their residues, weeds and volunteer plants can habour pests and diseases, so they should be destroyed. Diseased crops and plant material should be destroyed as they provide overwintering pest habitat. Plough in crops as soon as harvesting is completed to reduce local area build-up of pests where sequential plantings are made. Weeding remove insect pest and disease hosts and improve spray coverage and air circulation in crop canopy. Weeds are the most single factor affecting crop yields mainly because they compete for water and nutrients. Weed management is therefore an integral component of both soil and water conservation (Kabambe and Kadyampakeni, 2008). Weed management can be achieved by use of machinery e.g. harrow, disc or cultivator, use of chemicals (herbicides), use of hoes and/or use of mulch.

Acacia leaves when used as mulch has been reported to suppress witch weed through their allelopathic effect on the witch weed seeds (Chanyowedza and Chivinge, 2002).

Managing Disease and Insect Pest Risks

Pests and diseases cause significant yield and quality losses to crops and have a serious impact on the economic output of a farm, thus they pose a risk in crop production. Agronomic practices can be employed to manage pests and diseases. Such practices are also referred to as production factors. They include activities routinely carried out as part of the farming operations. They can be manipulated to make a crop less attractive, unavailable, better able to withstand damage and/or less palatable to pests. There are many agricultural practices that make the environment less favorable to insect pests. These include land preparation, weeding, crop rotation, selection of planting sites, choice of cultivars, use of trap crops, sanitation and adjusting the timing of planting or harvest. The simplest and cheapest methods of controlling diseases and insect pests are preventive measures. As the term implies, preventive measures are practices or methods of controlling diseases, insect pests, alien weeds and rodents by excluding or avoiding their introduction through quarantine at different levels. Practices such as crop rotation, crop diversification, intercropping systems, choice of resistant cultivars and use of therapeutic measures are common among African farmers in managing disease and insect pest risks. Box 5.1 contains a Case Study of agronomic practices to mitigate risks by smallholder farmers in Zimbabwe. Having studied this chapter, students will be able to study the problem(s) faced by the farmers, and address the questions contained therein.

Crop Rotation

Crop rotation is the practice of growing a series of different types of crops in the same area in sequential seasons . The practice is highly recommended for management of e.g. potato beetle. The beetles overwinter in or near potato fields and they require potato or related plants for food when they emerge. With cool temperatures and no suitable food, the beetles will only crawl and be unable to fly. Planting potatoes away from the previous year's crop prevents access to food and the beetles will starve. The severity and incidence of plant diseases can also be minimized by crop rotation, and selection of the planting site may affect the severity of pest infestations. Rotations with crops from a different family break the pests and diseases cycles e.g. rotating potato and maize.

Crop Diversification

Farmers are advised to diversify their farming enterprises in order to effectively manage risks in agriculture. Having more than one enterprises on a farm spreads risks and avoids total failure. The low mobilizing capacity of smallholder farmers and the risks involved in crop production in drylands necessitate the development of viable alternative technology to make the dryland agriculture sustainable. Production in the dryland areas can be substantially increased through appropriate soil and water management practices including planned use of watersheds, water harvesting techniques, soil moisture conservation and cropping systems. Not all drylands are suitable for crop production (Palaniappan and Sivaraman, 1996). Some lands may be suitable for range or pasture management, while others are suitable for horticulture or agroforestry systems. All these systems, which are alternative to crop production are referred to as alternative land use systems and they can be practiced as a way of diversifying farming activities among farmers. Integration of farming with other land use systems are less risky but are rather sustainable. Conventional crops sometimes fail to provide stability of production over a period of time due to weather aberrations and/or pests and diseases. Alternative land use and diversification are a means of stabilising the productivity of such lands (Palaniappan and Sivaraman, 1996).

Another management strategy recommended among smallholder farmers to manage risks associated with biological risks and adverse weather conditions is diversification of enterprises by growing different crops and varieties. In a poor season, one crop or one crop cultivar may do better than the other and so shields the farmers against total crop failure. Maize is the most grown cereal for household consumption in Southern Africa and almost every farmer grow the crop even in areas where the crop fails year after year due to limited soil moisture. Under such situations farmers are advised to grow maize cultivars in different maturity classes and with varying tolerance to pests, diseases and drought. In addition the farmers can grow drought tolerant crops such as sorghum or grow pests and disease tolerant crops e.g. finger millet and bitter cassava. It is important to have a wide range of crop species and crop cultivars on the same farm in a particular year to mitigate the adverse effects of pests, diseases and vagaries of adverse weather. Farmers are advised to support optimum crop diversification and intercropping techniques. Through crop diversification, they will rely on a wide range of cash and food crops. This is important since most food crops are very sensitive to weather and biological risks.

Intercropping Systems

Intercropping is the growing of two or more crops simultaneously on the same field (Ofori and Stern, 1987). Intercropping is one of the important features of farming in developing countries and is a practical solution to biological risks (insect pests, weeds and diseases). Intercropping systems that include a crop with good ground coverage such as cowpeas tend to suppress weeds, thus protecting the crop against weed risk. Complete crop cover and high plant density available in intercropping systems cause severe competition with weeds and reduce weed growth (Palaniappan and Sivaraman, 1996). Maximum intercrop yields and weed suppression are obtained with total crop densities significantly higher than those used for monocultures. Smother intercrops and live mulch intercrop are high density, additive crop mixtures that offer great promise as a means to weed control (Osiru and Wiley, 1972). In these situations, low growing weed suppressive species such as cowpeas are sown between rows of the main crop species.

Growing crops of varying heights help to reduce pest incidence since the taller crop can be a barrier to pests of the shorter crop. Inclusion of a non-attractive crop in intercropping reduces spread of pests (Palaniappan and Sivaraman, 1996). In cereal-legume intercropping systems e.g maize and cowpeas, the cover crop cowpeas reduces the spread of *Phytopthora* contaminated soil through surface water and antagonistic microflora. Cover crops reduce the soil splash during rainy days and the movement of disease propagules. Build-up of microbial population suppressive to Phytopthora lowers disease incidence under cover crop conditions (Sarma et al, 1991). Thus intercropping is effective in lowering populations of soil-borne diseases. Intercropping systems such as coffee-banana intercropping can be practiced to lower temperature in crop canopy to enhance yield. Research in Uganda showed that shade can reduce the temperature in the under-storey plants by up to 2°C (IITA, 2012). It was also observed that the low temperatures reduce disease incidence. Leaf rust incidences were 50% lower in coffee that was shaded by banana compared to the unshaded crop (IITA, 2012).

Intercropping systems can also be applied to management of weather risks. In addition to technical complementarities of intercropping systems, reduction of risk due to vagaries of weather and meeting the subsistence requirement of farmers make this system attractive among the resource poor smallholder farmers for stable and sustainable income (Palaniappan and Sivaraman, 1996). Delayed onset of rains, mid-season dry spells and early stoppage of rains pose risks in crop production. For such aberrant weather conditions, intercropping systems have been found to be a practical way of managing the risks by shielding farmers against total crop failure. Intercropping is more important on small farms in drylands than on large farms which are irrigated (Palaniappan and Sivaraman, 1996). Frequent failures of rainfall are quite common in most parts of tropical Africa. To tide over such situations, intercropping systems have been practiced by farmers to minimise the weather risks and ensure some return to the farmer.

Choice of Resistant Cultivars

Farmers are advised to select those cultivars that resist or tolerate a wide range of pests and diseases. It is also important to use pest-free transplants. Where crop transplants are infested with insect pests, farmers using these transplants are at risk of reduced yield and quality. Farmers are advised to always use certified seeds, which are free from pests and diseases. It must be noted at this point that choice of resistant varieties is also applied to management of weather risks. Most African farmers are in marginal areas and even in good years when they receive good rains, usually the rain season is very short. In such situations, farmers are advised to choose drought tolerant cultivars and plant with the first rains.

Agronomic practices that enable farmers to adapt to the effect of mid- and end- of-season drought have been found to increase maize productivity in the West African savannas. Several strategies have been developed for the conservation of soil and water to maintain productivity including rainwater harvesting, live barriers, supplementary irrigation, minimum tillage, mulching, bunded basins, and tree planting (Drechsel *et al.,* 2004). A central approach to increasing crop production in the dry savannas is the planting of well-adapted cultivars at the optimum date. The short growing season and frequent droughts require early and extra-early maturing crop cultivars with drought tolerance. Late- and medium- maturing cultivars should also be drought tolerant and planted earlier than the early maturing cultivars. Early maturing cultivars can be planted between mid- June and 25 July in the Guinea savannas and between the first week of July and mid-July in the Sudan savanna (Kamara, 2013).

Therapeutic Measures

Therapeutic measures are sometimes referred to as curative measures, and they are applied after the occurrence of a disease or an insect pest infestation in a crop field at above its economic threshold level. Therapeutic measures are generally subdivided into physical/cultural, biological and chemical therapeutic methods. Rogueing and burying diseased plants, digging a ridge between infested and non-infested parts of the crop field with armyworm, draining wet soil against damping-off disease, shading coffee seedlings against leaf spot disease are some practices of physical/cultural therapeutic methods. Different kinds of biological agents can also be used to control some crop diseases or insect pests. After the eve of industrialization, chemical therapeutic methods have widely been used in controlling the infestation of diseases and insect pests. Now, there are various forms and types of pesticides including fungicides, bactericides, insecticides and herbicides to control fungal diseases, bacterial diseases, insect pests and weeds, respectively. Some of the pesticides which were widely used earlier e.g. DDT have been identified as dangerous for both human health and environment and their use in agriculture has been banned.

Box 5.1: Case Study — Agronomic practices for managing risks

The objective of this case study is to make learners critically analyse agronomic practices and devise strategies and approaches that would make farmers adopt them.

Agro-ecological classification of Zimbabwe divided the country into five regions based on mean annual rainfall and was done in the 1960s (Vincent and Thomas, 1961). Region IV "Semi-Extensive Farming Region" experiences fairly low total rainfall (450-650 mm) and is subject to periodic seasonal droughts and severe dry spells during the rainy season. The rainfall is generally too low and uncertain for cash cropping except in few localities, where limited drought-resistant crops can afford a sideline.

The smallholder farmers in this region practise rainfed agriculture, which makes their farming business prone to weather risks in addition to biological risks and natural disasters. Dependency on rainfed farming leads to low productivity for the main crop - maize. The farmers are therefore vulnerable to poverty and lack resources to absorb shocks. However, many of these risks can be mitigated by appropriate agronomic practices. Although these farmers have been advised to adopt more productive drought resistant crops such as sorghum and millets, they have resisted and insist in growing maize. As they continue growing maize with low productivity, and their farming business prone to weather risks, poverty is perpetuated.

Most smallholder farmers are resource poor and therefore it is recommended that they use appropriate agronomic practices to manage risks in agriculture. These practices require very little external inputs and every African farmer could adopt them. Unreliable rainfall results in low crop productivity and farmers suffer crop losses. Given the unreliable rainfall, it is therefore important that farmers are convinced to adopt appropriate agronomic practices in order to conserve soil moisture to enhance crop productivity.

Questions

– Discuss reasons that lead to resistance of Region IV farmers to change from maize farming.
– Recommend policy interventions that could lead to farmers adopting appropriate agronomic practices.

Conclusion

The chapter highlighted some of the agricultural risks that expose farmers to potential losses and cause suffering to the farmers and the whole value chain. Various agronomic practices have been discussed and these practices can be adopted by smallholder farmers to minimize yield losses or total crop failure as a result of unfavourable climatic conditions. These practices are easy to apply and require little external inputs, hence every African farmer can adopt them. Different farmers can adopt different practices depending on the prevailing farm situation and the environment. Research on agronomic practices conducted in Africa has been highlighted in this chapter and shows that the practices are applicable in Africa. Management of agricultural risks has significant potential to increase productivity, thereby enhancing investments in agriculture and guarantees agriculture as a business.

Questions for Discussion

1. Describe the various agronomic practices applicable to African farm situations.
2. Explain in detail how these agronomic practices are used to reduce weather risks and biological risks at various farm situations.
3. Critically analyse the various agronomic practices and assess their practicability under different farm situations in different regions.
4. What are the benefits of using agronomic practices to manage risks in agriculture over other strategies of risk management.

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6

Crop Breeding for Agricultural Risk Management

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Summary

Agriculture in Africa is faced with many risks including climate change, poor soil fertility, emergence of new pests and disease problems. Most African farmers still cultivate landraces which are low yielding, prone to pests and diseases and deficient in major nutrients and amino acids. Consumption of such crops result in nutrient deficiency diseases or malnutrition. In Africa, human population continues to increase however arable land is under increasing demand for rapid urban development. The question is how Africa would feed herself in the face of all these challenges or risks in her agriculture. Changes in the agriculture sector are needed to meet these challenges. What role does crop breeding has to play? Crop breeding is urgently needed to improve yield of existing varieties. If the yield of existing varieties continues to stay the same in the face of decreasing arable land area and increasing climate change, then there is a higher risk of food insecurity and starvation ahead. Plant breeding is the science and art of genetically manipulating plants. The aim is to make the expression of certain traits of the plant permanent by modifying the genotype. The modification of traits is brought about through a series of activities such as setting of objectives, creation of variation, selection, evaluation, multiplication and distribution. Existence of genetic variation of crop plants is pivotal for progress in crop breeding. Creation of genetic variation could be by natural or through artificial means. Some of the natural means by which variation can be created include germplasm collection, domestication and introduction. The artificial methods of creating genetic variation include hybridization, mutation, polyploidization, genetic engineering and somaclonal variation. The approaches of using crop breeding to address risks in agriculture include breeding for resistance to biotic and abiotic stresses, breeding for high yield and high nutrient composition. Details of these approaches and some of their success stories in management of risks in agriculture in Africa are discussed in this chapter.

Resume

Selection varietale pour la gestion des risques en agriculture

Le changement climatique est et continue d'etre un defi pour les agriculteurs afri- cains principalement en raison de son role dans l'accroissement des risques en agriculture. Les modifications au niveau des precipitations et des temperatures, en quantite et de calendrier a considerablement affecte l'agriculture et l'elevage d'animaux. Une intervention s'est averee capable d'attenuer les effets climatiques de l'agriculture et donc reduire les risques agricoles dans les systemes agroforestiers. Ce dernier a ete largement salue a travers les composantes de l'arbre quipossedent de nombreux caracteres utiles tels que la fixation de l'azote, la sequestration du carbone, la liberation des elements nutritifs du sol et un systeme racinaires quipeut atteindre et extraire l'eau nappespeuprofondes. En realite, les arbres agroforestiers, fournissent et regulent divers services essentiels qui attenuent les risques agricoles dus aux caprices de changement climatique. En limitant les effets des changements climatiques, les systemes d'agroforesterie fournissent des gains substantiels et des benefices pour les praticiens de l'agriculture, car elle reduit les risques agricoles.

Afin d'ameliorer l'adoption des systemes agricoles, de nouvelles politiques qui promeuvent les pratiques agroforestieres doivent etre etablies et adoptees.

Introduction

The international community faces great challenges in the coming decades including reining in global climate change, ensuring food security for the growing population, and promoting sustainable development. The future pressures on agriculture will be substantial. Food production levels are on a knife edge and vulnerable to weather fluctuations. Demands on production from agriculture are expected to increase sharply in the 21st century with demands for cereals in particular expected to rise by 70 % from 2007 to 2050 (FAO, 2007). This development is driven by foreseen demands on food supply from a forecasted world population of 9 billion people in 2050 and changing consumption patterns.

Effects of climate change such as long-term changes in average temperatures, precipitation, and climate variability threaten agricultural production, food security, and the livelihoods of the poor. Climate change occurring over the years is making some regions or countries drier and others saltier or floody and also causing an upsurge in the incidence of pests and diseases. Effects of climate change have been projected to decrease annual precipitation and higher temperatures leading to reduction in yield among the principal agricultural crops.

Most agricultural soils are depleted in nutrients and the soils can no longer support maximum crop production without application of fertilizers. Some crops or varieties of crops are deficient in certain essential nutrients. Consumption of such foods would result in nutrient deficiency diseases or malnutrition.

Malnutrition is prevalent in developing countries. For example, most cereals are deficient in lysine and threonine, whiles legumes tend to be low in Cysteine and methionine. There is increasing consumer and end user pressure for improvements in food and feed quality including the reduction of deleterious traits and the improvement of health benefits and functional food traits.

Human population continues to increase however arable land is under increasing demand for rapid urban development. Such demands include settlement on new lands and the demand for alternative use of land (e.g. for recreation, industry, roads) to meet the general needs of modern society. As a result, more food will have to be produced on less land. According to United Nations, the increase in population would be more in less developed countries (Figure 6.1).

Population in millions

Figure 6.1. World population growth, 1750-2150. Source: United Nations, World Population Prospects, The 1998 Revision and estimates by the population Reference Bureau (Source: UN, 1998)

If these predictions are true, then our poor farmers in Africa who still cultivate landrace varieties of crops which are characterized by low yield and susceptibility to pests and diseases are likely to experience adverse effects of climate change and declining poor soil fertility. Africa must arise and prepare or else there is a higher risk of food insecurity and starvation ahead of us.

Changes in the agriculture sector are essential to meeting these challenges. Agriculture provides the main source of livelihood for the poor in developing countries, and improving agricultural productivity is critical to achieving food security as well as most of the targets specified under the Millennium Development Goals (Rosegrant *et al.*, 2006).

The question is how would less developed countries be able to feed their teeming populations in the face of challenges of climate change, pests and diseases and conversion of arable lands for other uses?

The seemingly impossible challenge is to produce more food, feed and other commodities but with reduced environmental impact whilst coping with a more variable and unpredictable climate. Efforts are needed to facilitate development of high yielding and resistant varieties to enhance the resilience of the agricultural sector, ensure food security, and reduce rural poverty. Development of drought resistant varieties would be beneficial to crop production in areas of marginal or erratic rainfall regimes. Breeders need to develop new cultivars that can resist biotic (pests and diseases) and abiotic (drought, cold, flood, heat) stresses. Plant breeders also need to improve the nutritional status of crop plants and to eliminate certain toxic substances in certain crops.

Learning Objectives

The objectives of this chapter are to explain:

1. How to use plant breeding to manage risks in agriculture;
2. Plant breeding and activities involved in plant breeding;
3. The need and importance of plant breeding in managing agricultural risks;
4. Steps in plant breeding and their role in risk management;
5. Risks associated with use of landrace varieties or non-breeding of crop plants.

Learning outcomes

After completing this chapter, the student should have a general understanding of:

1. Plant breeding and activities involved in plant breeding;
2. The need and importance of plant breeding in managing agricultural risks;
3. Steps in plant breeding and their role in risk management;
4. Risks associated with use of landrace varieties or non-breeding of crop plants;
   a) Using plant breeding practices in managing agricultural risksBreeding for high yield;
   b) Breeding for resistance to pests and diseases;
   c) Adaptation of crop plants to environmental stress- drought adaptation;
   d) Adaptation of crops to climate change
   e) Breeding for high nutrient composition.

What is Plant Breeding?

Plant breeding is the science and art of genetically manipulating plants to perform new roles or enhance existing ones. It is a science because plant breeding is grounded on scientific principles and disciplines. It is an art due to the fact that plant breeders depend on intuition, skill and judgment in their work. A good breeder should have a keen sense of observation. Several outstanding discoveries were made just because the scientists who were responsible for these events were observant enough to spot unique and unexpected events. For example, the «akokorabedi» cocoa variety, which means an old man would enjoy the fruits of his labour, an early bearing variety, was selected and developed as a result of keen observation. It was not the initial objective of the scientist involved in its development.

The Concept of Breeding Crops

Plant characteristics are controlled by hereditary factors or genes. These genes are expressed in an environment to produce a trait. It follows then that in order to change a trait or its expression, one may change its genotype or the environment. Changing the environment essentially entails modifying the growing or production conditions. This may be achieved through an agronomic approach, for example, the application of production inputs (e.g. fertilizers, irrigation). Although this means is effective in improving certain traits, these expressions of the plant are not permanent. Once the application of the production inputs are stopped, the plant reverts to its original status. The aim of plant breeding is to make the expression of certain traits of the plant permanent by modifying the genotype.

The desired change in crop plants and the benefits it inures to our farmers is brought about by a series of inter-related activities as shown in Figure 6.2.

These activities include, having an objective, creation of variability, selection, evaluation, multiplication and distribution. The breeder must first define a clear breeding objective and ascertain its importance, feasibility and cost- effectiveness.

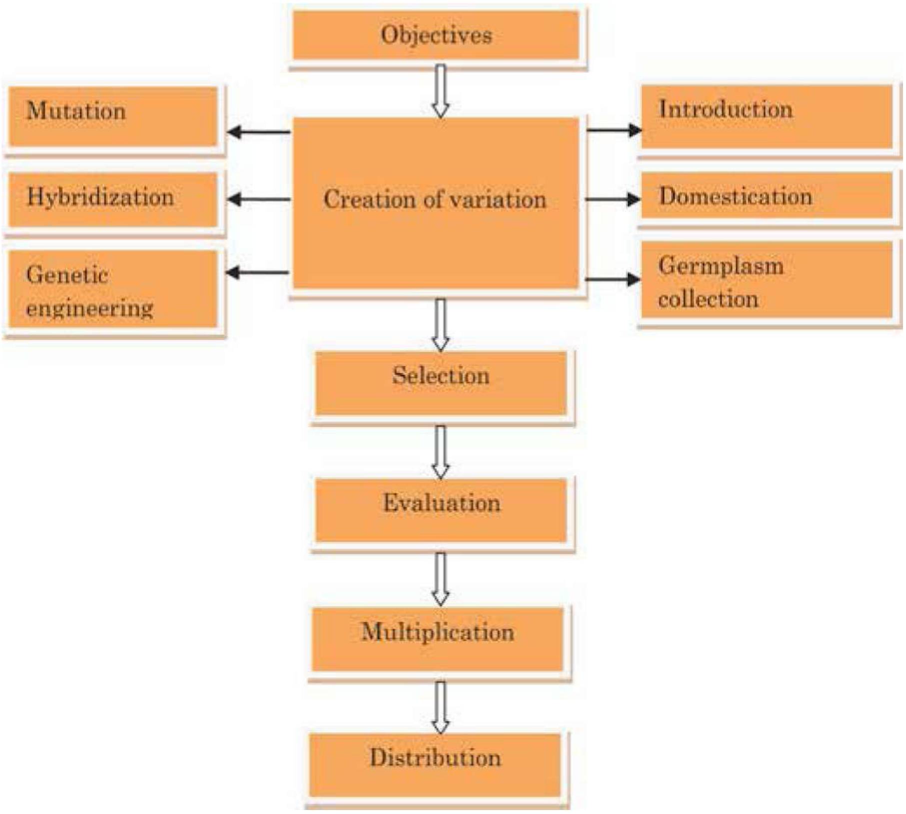

Figure 6.2. Activities involved in plant breeding

This may be for the benefit of the producer (e.g., high yield, disease resistance, early maturity, lodging resistance) or the consumer (e.g., high nutritional quality, enhanced processing quality). Genetic variability is a prerequisite for any improvement in a crop. Thus, in any breeding programme, this is always the first step after setting objectives, unless variation pre-exists. Genetic variation may be created by germplasm collection, domestication, plant introduction, hybridization, polyploidy, mutation, somaclonal variation and genetic engineering.

Germplasm Collection and Conservation

Plant germplasm used in plant breeding are natural resources that are susceptible to erosion from use and abuse. It is important that they be collected, properly used, managed and conserved to avoid irreparable loss of previous genetic material (Acquaah, 2007). Germplasm is the lifeblood of plant breeding without which breeding is impossible to conduct. It is the genetic material that can be used to perpetuate a species or population. Germplasm provides the materials (parents) used to initiate a breeding program. Sometimes, all plant breeders do is to evaluate plant germplasm and make a selection from existing biological variation. In collecting and conserving germplasm, it is important to take into consideration genetic resources of wild crop relatives and neglected and underutilized crop species (NUS). When breeders need to improve plants, they have to find a source of germplasm that would supply the genes needed to undertake the breeding project. If the diverse forms of these crops are not collected and conserved, they could be lost forever. Attempts are being made in Ghana to conserve genetic resources of NUS crops (Box 6.1). Forgetting wild crop relatives and NUS therefore mean losing important sources of genes for the future. However, crop wild relatives and neglected and underutilized crop species play an important role in nutrition, food security, health and livelihoods of families and communities in Africa. To avoid risks of introducing g new diseases and pests into the country, it is important to pass the germplasm through quarantine inspection procedures, if it is introduced from foreign countries. It would be examined for presence of pathogens and pests. The same procedure need to be followed, when a material is to be exported to other countries as well. Along with a phytosanitary certificate, the material is provided to the user. These operations are done under plant quarantine regulations to ban the entry of any plant material carrying harmful organisms.

Approaches to Germplasm Conservation

There are two basic approaches to germplasm conservation - *in situ* and *ex situ.*

In Situ Conservation

This is the preservation of variability in its natural habitat in its natural state (i.e., on site). It is most applicable to conserving wild plants and entails the use of legal measures to protect the ecosystem from encroachment by humans. These protected areas are called by various names (e.g., nature reserves, wildlife refuges, natural parks). Environmentalists and commercial developers often clash on such restricted use or prohibited use of natural resources. This approach to germplasm conservation is in discriminatory with respect to species conserved (i.e., all species in the affected area are conserved).

Box 6.1. Conservation of Neglected and Underutilized Vegetables in Africa: Advances at the College of Agriculture Education, University of Education, Winneba, Ghana

The objective of this cases study is to help students explain the need to conserve neglected and underutilized crop species.

Throughout the tropical world and particularly in West Africa, a large number of traditional vegetables have long been known and reported to play important roles in food security for people living in both rural and urban areas (Ukpong and Idiong, 2013). Indigenous vegetables are rich in vitamins (especially A, B and C), minerals, fibers, carbohydrates and proteins and some even possess medicinal properties. They represent affordable but quality nutrition for large proportion of populations and offer an opportunity for improving nutritional status of many families. With the recent wave of economic depression and its attendant effect on the purchasing power of the population of less developed nations, it has become obvious that locally neglected and underutilized (NUS) food crops species will play an increasing role in the food, nutrition and health security of the rural people and the increasing urban poor. Thousands of species, a great part of the plant biodiversity used around the world have never entered a gene bank. If genetic resources of these neglected but very important crops are not collected, they could be lost forever. Recent studies on NUS crops in Ghana by Dr.

Daniel Nyadanu and others have led to collection and conservation of local accessions of some indigenous vegetables in Ghana. Some of these NUS crops include *Solanum macrocarpon, Solanum torvum* and *Corchorus olitorius.* The seeds of the accessions have been conserved at the gene bank of College of Agriculture, University of Education, Winneba, Ghana. Currently characterization and ethnobotanical studies are been carried out on these crops. Lack of these information places them in the danger of continued genetic erosion and disappearance which would further restrict their improvement through breeding. Apart from conservation of NUS crops, what policy measures would you urge your government to put in place to ensure utilization of NUS crops.

Ex Situ Conservation

In contrast to in situ conservation, ex situ conservation entails planned conservation of targeted species (not all species). Germplasm is conserved not in the natural places of origin but under supervision of professionals off site in locations called germplasm or gene banks. Plant materials may be in the form of seed or vegetative materials. The advantage of this approach is that small samples of the selected species are stored in a small space indoors or in a field outdoors, and under intensive management that facilitates their access to breeders. However, the approach is prone to some genetic erosion (as previously indicated) while the evolutionary process is halted. The special care needed is expensive to provide. If these diverse forms are not collected and conserved, they could be lost. One of the factors of such loss of genetic resources is deforestation. While deforestation shows signs of slowing down, 13 million hectares of forest were still lost each year in the last decade, most of that in Africa and Latin America (FAO, 2010). This results in landscape fragmentation that restricts gene flow, lead to genetic erosion in forest ecosystems and woodlands, threatening both wild species and crop wild relatives. Agricultural landscapes also suffer genetic erosion as traditional landraces and neglected and underutilized crops are rapidly disappearing. Such genetic erosion means that future options for domestication, breeding and evolution could be irreversibly lost, a fact that is being recognized through the development of a 'Red List' for cultivated species. Climate change will speed up these processes. The rate of loss of genetic resources is projected to increase as the world gets hotter.

Managing Plant Genetic Resources

The key activities of curators of germplasm banks include regeneration of accessions, characterization, evaluation, monitoring seed viability and genetic integrity during storage, and maintaining redundancy among collections. Germplasm banks receive new materials on a regular basis. These materials must be properly managed so as to encourage and facilitate their use by plant breeders and other researchers.

Domestication

Domestication is the process by which genetic changes in wild plants are brought about through a selection process imposed by humans. According to Pourkheirandish and Komatsuda (2007) plant domestication is defined as the evolutionary process whereby a population of plants becomes accustomed to human provision and control. It is an evolutionary process in which selection operates to change plants genetically, morphologically and physiologically (Acquaah, 2007). Like evolution, domestication is also a process of genetic change in which a population of plants can experience a shift in its genetic structure in the direction of selection imposed by the domesticator. It is generally considered to be the end-point of a continuum that starts with exploitation of wild plants, continues through cultivation of plants selected from the wild but not yet genetically different from wild plants and ends with the adaptation to the agro ecology through conscious or unconscious human morphological selection and hence genetic differences distinguishing the domesticated species from its wild progenitors (Dansi *et al.*, 2012). There are various stages of domestication. These stages as defined by Vodouhe *et al* .(2011) and Dansi *et al* .(2012) are as shown in Table 6.1.

It is through these stages of domestication that certain plants that were wild and not consumed became accepted and used by communities to help enhance nutrition and food security.

Table 6.1. Stages of crop domestication

Step	Description
Step 0	Species entirely wild and collected only when needed
Step 1	Wild species maintained in the fields when found during land preparation
Step 2	Farmers start paying more attention to the preserved plants for their survival and their normal growth. A sort of ownership on the plants starts
Step 3	The reproductive biology of the species is understood and multiplication and cultivation of the species in the home gardens or in the selected parts of cultivated fields are undertaken
Step 4	The species is produced in sole cropping and harvested using traditional practices
Step 5	To improve the quality of the product, farmers adopt specific criteria to select plants that better satisfy people's needs.
Step 6	Development of appropriate pests and disease protection and food processing methods.

(Source: Vodouhe et al., 2011)

Genetic Engineering

Plant genetic engineering is the use of recombinant DNA technology to produce crop plants to meet specific needs. Such crops or plants are referred to as GMO crops or transgenic crops. Genetic engineering could be used to create variation among plant materials. Plant genetic engineering could be used to manage risks in agriculture. One route by which progress in engineering insect resistance in transgenic plants has been achieved is by using the genes of Bacillus thuringiensis (B.t.) that produce insect toxins (so called B.t. toxins). B.t. is a bacterium that produces a crystalline protein during sporulation, which, when cleaved to the mature toxin peptide, produces paralysis of the mouthparts of specific insects and so leads to their death. Thus it provides a useful tool for insect control. For example, transgenic tomato, cotton, maize, tobacco containing the B.t. gene exhibit resistance to insect pests. However, despite the usefulness of genetic engineering in plant breeding, there have been a number of concerns that have arisen over its application. There are some uncertainties or risks as to how to determine exactly expression of a new inserted gene since during the life time of the cell, expression of genes may change. Some people are reported to be allergic to GMOs. Too sensitive persons could disappear from population. The possibility of migration of inserted genes from cultivated plants to weeds and wild species. The possibility of transfer of genes to microorganisms leading to appearance of high tolerant injurer insects, and pathogens (viruses, fungi and bacteria). GMOs may have toxic effects on non-target organisms (butterfly, bees, and birds). These uncertainties could be managed by being careful and applying regulations guiding the use of GMO crops (Dhan Prakash *et al.,* 2011).

The next step of plant breeding after creation of variation is selection which involves identification and isolation of plants with desirable traits based on the set objectives. Selection is essentially based on phenotype. The efficiency of this activity determines the success of a breeding programme. The potentially selected cultivars are evaluated in the field for yield and other characters and compared with the existing best varieties known as checks. Evaluation is usually done at different locations over several years to identify the most promising cultivar for release as a commercial variety. Before a cultivar is released, it is processed through a series of steps, called the seed certification process, to increase the experimental seed, and to obtain approval for release from the designated crop certifying agency in the state or country (Aquaah, 2007).

Risks Associated with unavailability of Improved varieties of Crops

Farmers plant what breeders develop. In any country where plant breeding is not practiced, farmers still grow landrace varieties. Landrace varieties are not improved and thus are low yielding. The crops perform below the potential of the crop. Even if farmers use inputs like fertilizers, they still have low yields due to the non-improvement of the varieties. In Africa, many farmers still cultivate landrace varieties. Many of these landrace varieties are susceptible to diseases and pests. Severe attack and infection of pests and diseases drastically reduce the yield of the crop causing farmers to have little for their efforts. The nutritional content of most landrace varieties are low. They are usually deficient in some important nutrients. The landrace varieties are still in various stages of domestication. Many of them have undesirable traits like thorns, small seeds, late maturing, longer duration of cooking, tedious harvesting and processing approaches and poisonous chemicals (Nyadanu *et al.,* 2014b).

Critical Need for Plant Breeding in Addressing Risks in Agriculture

Plant breeding offers a mechanism for helping to address some of the world's most pressing and current concerns. One of the greatest challenges facing modern plant breeders is ensuring global food security in the face of a host of global and local risks. The current food supply is expected to be insufficient to support projected population growth, both in quantity and nutritional quality, thus necessitating plant breeding efforts that can increase production while using less land and fewer resources.

Breeding of High Yielding varieties

Yield is a generic term used by crop producers to describe the amount of the part of a crop plant of interest that is harvested from a given area at the end of the cropping season or within a given period. The plant part of interest is that for which the crop producer grows the crop. It could be the leaves, fruits, stems, roots or flowers or any other morphological part. It could also be the chemical content of the plant such as oil, sugar or latex. In certain crops such as cotton, the plant part of economic interest to the producer is the fiber. Yield is the best measure of the integrated performance of a plant (Aquaah, 2007). Yield may be divided into two types; biological yield and economic yield. Biological yield is the total dry matter produced per plant or per unit area (i.e. biomass). Economic yield represents the total weight per unit area of a specified plant product that is of marketable value or other use to the producer. The producer determines the product of economic value.

Yield depends on biomass and how it is partitioned. To increase yield, the breeder may breed for increased biomass and efficient partitioning of assimilates. The efficiency of biomass production or assimilate partitioning is estimated by calculating harvest index. Harvest index is the proportion of the plant that is of economic value. It is calculated as a ratio as follows:

Harvest index = (economic yield /biological yield) (Aquaah, 2007).

The theoretical value of the harvest index ranges from 0.0 to 1.0. The higher the harvest index, the more economically desirable the genotype, because it translocates more of the assimilates into the economic parts of the plant. Yield is a complex trait. In an effort to manipulate crop yield, plant breeders attempt to construct the path by which the reproductive, developmental and morphological features of plants in a crop stand contribute to the yield of a specified product. The pathways to yield are collectively called yield components (Box 6.2).

Box 6.2: Yield Components Analysis of Selected Accessions of Sorghum *(Sorghum bicolor* L. Moench) in the Upper East Region of Ghana

The objective of this case study is to help students identify yield components of crops and the possibility of manipulating them to increase yield.

Sorghum is an important staple food crop in the northern regions of Ghana. The crop is used locally to prepare several meals such as 'tuo zaafi', porridge, cake and to brew a local beer known as 'pito'. Despite the important role of sorghum in nutrition and economy of Ghana, it attracts little research attention and recently low economic yield of sorghum is a great disincentive to farmers. Understanding of yield components of sorghum is needed to improve yield of existing local varieties. Nyadanu and Dikera (2014) analyzed the yield components of four local varieties of sorghum; Banina, Kadaga, Naga red and Kapala. The sudy wascarried out at Navrongo in the Kassena-Nankana district of the Upper East region of Ghana. The varieties were evaluated for yield traits using Randomized Complete Block design with four replications. The results revealedthat, significant variations were recorded among the yield traits studied. High values for phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) was recorded for harvest index and number of grains per panicle. High heritability accompanied with high genetic advance (GA) was observed for number of days to flowering, number of primary panicles, weight of grains per panicle, and days to maturity. Banina variety produced the highest number of leaves, panicle height, panicle width, plant height, number of grains per panicle, weight of grains per panicle, economic yield and biological yield. There was also significant and positive correlation between characters studied. Principal components analysis revealed that Banina was the highest yielding variety and number of grains per panicle was the principal contributing factor to the high yielding character of this variety. Genetic improvement of number of grains per panicle by plant breeders could help to develop higher yielding varieties for enhancement of nutrition and livelihoods of the rural poor in the northern regions of Ghana.

Based on your understanding of yield components of sorghum, identify yield components of other important crops and demonstrate how you can manipulate them to increase yield.

Plant breeders seek to influence yield by manipulating its components to positively affect photosynthesis. A breeder is also interested in stability of yield over seasons and years. This is done by determining genotype environment (GxE) interaction. In breeding for high yield, it is important to select against factors causing yield loss. For example, pre- harvest sprouting in groundnut (Box 6.3)

Box 6.3: Breeding Against Pre-Harvest Sprouting in Crops: a Case Study in Groundnut *(Arachis Hypogaea* L.)

The objective of this case study is to help students make recommendations as to how to use results to make recommendations to overcome pre-harvest sprouting in groundnut and to analyze the importance of the results to policy makers. Groundnut *(Arachis hypogaea* L.) of the family Fabacea is an important legume crop in Africa. The most important use of groundnut is in the production of oil which is used for cooking in most parts of the world. However, groundnut production of groundnuts is affected by low yields due to unequal maturity of pods. While some pods are matured, others remain young or immature. If farmers want to wait for the immature pods to mature for harvesting, those already matured sprout or germinate leading to loss of yield. Also, insect damage to pods tended to increase with delay in harvesting of pods due to increase in insect population with time. Pre-harvest germination is a serious factor affecting yield of groundnut in Africa (Kombiok *et al.,* 2012; Yoga *et al.,* 2014). Yield losses due to in situ germination in bunch varieties have estimated to range between 20 and 40 percent of total yield (Reddy *et al.,* 1985), (Nagajum and Radder, 1983). One of the possible ways to manage the problem is to develop high yielding varieties of groundnut that have synchrony of maturity of pods. Nyadanu *et al.* (2014a) that varieties of groundnut varied significantly in percentage sprouting of nuts (Figure 1).

Based on these results, what recommendations can you make for breeding against pre- harvest sprouting in groundnut? Of what importance are these results to policy makers?

Breeding for Stress Resistance

Stress is defined as the adverse conditions for crop growth ad reproduction imposed by either environmental factors or biological factors. Hence stress is of two types, biotic and abiotic. Stress caused by biological agents or factors like diseases, insects and parasitic weeds is called a biotic stress. When the stress is caused by environmental factors or non-biological factors, it is known as abiotic stress. Abiotic stress is usually caused by factors like deficiency or excess of nutrition, moisture, temperature and light, presence of harmful gases or toxicants and abnormal soil conditions like salinity, alkalinity and acidity (Sanjay 2005).

Disease is basically a change from the state of metabolism necessary for the normal development and functioning of an organism. An abnormal growth and development of the plant will cause a reduction in biological yield and invariably in economic yield, hence, the need to control pathogens and insect pests in crop production. Diseases and insect pests may adversely affect yield and general performance of a plant by causing complete plant death, stunted growth, partial plant death or direct product damage (Sanjay2005).

Breeding for Resistance to Diseases and Pests

Genetic resistance refers to those heritable features of a host plant that suppress or retard evolution of a pathogen or insect. In other hands genetic resistance is the ability of some genotypes to give higher yields of good quality than other varieties at the same initial level of disease or pest infestation under similar environmental conditions. Therefore, resistance is defined in relation to susceptible varieties. Breeding for resistance to pests and diseases is different from breeding for yield and physiological traits. Breeding for yield entails the manipulation of one genetic system- plants. Breeding for resistance to biotic stresses on the other hand involves the manipulation of two genetic systems- one for plants (host) and the other for the organism (pathogens) - not independently, but with regard to the interaction between the two systems (Acquaah, 2007). There is triangular interaction of host- pathogen-environment in resistance breeding, whereas in productivity breeding the interaction is between genotype and environment only.

Resistance reactions can be categorized into two major kinds-vertical or horizontal-based on their epidemiological status and stability of resistance. Specific resistance of a host to the particular race of a pathogen is called vertical resistance. This type of resistance is governed by one or few genes and thus is referred to as oligogenic resistance. Vertical resistance displays discontinuous variation among genotypes and classification of genotypes into resistance and susceptible classes is possible. Horizontal resistance is the resistance of a host to all the races of a pathogen. This type of resistance cannot be easily overcome by new races of a pathogen because of polygenic control.

The resistance of a host and the virulence of a pathogen has a genetic basis. For each gene that confers resistance in the host, there is a corresponding gene in the pathogen that confers virulence to the pathogen and vice versa. This host- pest interaction is called the gene-for-gene hypothesis. J.A. Brownig simplified the hypothesis by comparing the interaction between the genetic systems of the host and pathogen to a set of locks and keys. The host has the locks-each locus that conditions resistance to a pathogen is a potential for a lock. The locks are equivalent to dominant alleles that inhibit pathogen establishment in the host plant. To succeed, the pathogen must have the appropriate key (a virulent allele) to open the lock, or the host must have no lock for the key.

Disease resistance is governed by a number of morphological, physiological, histological and biochemical features of host plant. Resistance to black pod disease in cocoa was observed to be associated with morphological and physiological features such as epicuticular wax, thickness and moisture content of pod husk (Nyadanu, 2011; Nyadanu *et al.,* 2011; Nyadanu *et al.,* 2012). These traits confer disease resistance by checking the entry of pathogen into the host tissues. Biochemical studies revealed that high content of tannin; prot catechuic acid and catachol silica, alkaloids, phenol and riboflavin were associated with disease resistance in various crop plants. Nyadanu *et al.*, 2013 observed that, carbohydrates, proteins, flavonols and lignins were associated with resistance to black pod disease in cocoa. Most of these chemical compounds are toxic to pathogens and therefore prevent the establishment of the pathogen into the host tissue.

Sometimes, a breeder is interested in transferring a number of genes conferring resistance to different races of a disease into a cultivar. In such cases, gene pyramiding is used. Gene pyramiding refers to incorporation of two or more major genes in the host for specific resistance to a pathogen. In gene pyramiding, all major genes are incorporated in a single cultivar. Combinations of many major genes for specific resistance provide protection against many new races that can develop in the pathogen.

In breeding for resistance to diseases and pests, it is important to screen existing varieties using reliable screening methods. Promising varieties are selected for further improvement. For example, in breeding for resistance to post-harvest microbial rot in yam, existing varieties of yam in Ghana were evaluated for resistance against the disease (Box 6.4).

The application of molecular markers has allowed the genetics of quantitative resistance to be determined and quantitative trait loci involved in resistance to be identified. Molecular markers have also contributed to improved breeding strategies for monogenic resistance genes in order to combine them in the «gene pyramiding) strategy for a more durable resistance genes.

Box 6.4: Evaluation of Yam Varieties for Resistance to Post-Harvest Microbial Rot

The objective of this case study is to help students demonstrate other strategies to complement breeding to manage risks of microbial rot in yam.

Yam (Dioscorea spp) constitutes an important staple food in the tropics. It is a major source of carbohydrates, vitamins and dietary fibres .Ghana exports about 12,000 tonnes of yam annually which generates foreign revenue for the country (MIDA, 2012). One of the major diseases affecting yam production in the tropics is internal microbial rot. Internal rot is the condition that develops in yam tuber where the whole tuber appears very much wholesome and attractive, but have developed rapid and extensive breakdown of internal tissues. This condition, with time renders the whole tuber rotten. Rot from microbial infection of healthy tubers reduce their table quality and renders them unappealing to consumers. Okigbo and Ikediugwu (2000) indicated that between 20 and 39.5% of stored tubers may be lost to rot. Aidoo (2007) reported observations from farmer's field and discussions reveal that some farmers in Ghana lose as high as 70% of their stored yam to rot. Some white yam varieties such as 'dente', 'pona' and 'labreko' that are preferred by most consumers in Ghana, do not store for more than six months due to infection by rot microorganisms. As a result, farmers sell their produce immediately after harvest. This has resulted in low incomes or reduced profits. This practice also affects farmers' food security particularly in the off-season. Several microorganisms have been associated with rot in yam. They are made up of fungi including Aspergillus niger, Lasiodiplodia theobromae, Fusarium solani, Penicillium spp.,Rhizopus stolonifer and Mucor spp. (Acholo *et al.*, 1997; Cornelius and Oduro, 1999, Okigbo and Ikediugwu, 2000).

Adaptation of Crops against Effects of Climate Change

Climate change and its potential implications for agricultural water use create increasing uncertainty for planning. It can significantly increase production risk and rural vulnerability, particularly in regions that already suffer from chronic soil and water resource scarcity or high exposure to climatic extremes, such as droughts and flooding. Natural adaptation and selection are unable to keep up with the rate at which climates are changing. Artificial selection within breeding programs for traits such as water use efficiency may effectively respond to climate change and accelerate our efforts to feed current and future human populations. Drought is the most important effect of climate change in developing countries. It is responsible for severe shortages of food and famine.

Drought is defined as the condition of soil moisture deficiency or water scarcity (Diffenbaugh *et al..*, 2015). Drought occurs both above ground (atmospheric drought) and below ground (soil drought). Soil drought is more common. The effect of drought varies among species and also depends on the stage of plant growth and development at which the moisture stress occurs. Drought at flowering may cause significant flower drop and low fruit set. Similarly, when drought occurs at fruiting, there will be fruit drop and or partially filled or shriveled fruits. As the demand for water exceeds supply, a plant develops what is called plant water deficit. Water deficit causes reduced cell expansion, reduced water use and reduced plant productivity. Reduced cell expansion also adversely impacts meristematic development of yield components, leading to potentially small reproductive organs and hence reduced yield (Diffenbaugh *et al..*, 2015).

Managing Drought Stress

When there is drought stress it is important either to develop stress resistant cultivars or to modify the environment by using agronomic practices such as irrigation, fallow and use of ground cover for soil and water conservation. Breeding of crop varieties resistant to stress environment is the most practical way of solving such problems.

Breeding for Drought Resistance

The ability of crop plants to grow, develop and reproduce normally under moisture deficit conditions is known as drought resistance. In order to formulate effective breeding objectives in a drought breeding programme, the breeder should understand the nature of the trait to be manipulated. Crop plants have various mechanisms of resisting drought. They include escape, avoidance, tolerance and recovery. With escape, using early maturing cultivars may allow the crop to complete its life cycle before the onset of drought late in the season. Some plants avoid drought stress by decreasing water loss, for example by having cuticular wax or by using stomatal characteristics such as shape, size and orientation of leaves. The ability of crop plants to withstand low tissue water content is known as drought tolerance. Drought tolerance is more desirable since the crop can produce more yields at lower water potential. Because drought varies in duration, some species are able to recover after a brief drought episode. Traits that enhance recovery from drought include vegetative vigor, tillering and long growth duration.

Most drought breeding research is conducted under managed stress environments. A common facility for such research is the rainout shelter. This is essentially a mobile roof that protects selected plots from rain. This makes drought resistance breeding tedious and expensive. To get around this problem, some breeders use large populations. Some also use molecular markers to tag and select certain drought-related quantitative trait loci (QTLs) to aid in the selection process. Because drought resistance breeding is expensive, it is important developing countries adopt public-private partnership approach to manage risks of drought (Box 6.5).

Box 6.5: Breeding for Drought Resistance Varieties of Crops: the Role of Public-Private Partnership in Breeding Maize in Zimbabwe

The objective of this case study is to reconcile the role of public and private sector in developing drought resistant varieties. It would also help students to brainstorm the possibility of extending these roles to other crops.

Experts agree that climate change is manifesting itself in the form of prolonged drought in many parts of Africa. This is having a devastating impact on millions of resource- poor, small-scale farmers. The prolonged drought affecting East Africa is making global headlines. Food Agriculture Organistaion estimates that, because of drought, Kenya's maize crop, which accounts for 80% of the country's annual cereal production, will drop by more than a quarter below its usual level. The World Food Programme estimates that across East Africa, more than 20 million people are on the brink of starvation and in dire need of food aid.If the climate predictions are correct, Africa's toughest days are still ahead of her. We must prepare. There is a need to adapt to climate change by improving yield stability in the face of climate stress. Scientists and even political leaders recognise that drought tolerance is one of the most desirable traits to target in breeding better crops for Africa.

The Scientific and Industrial Research and Development Centre (SIRDC), in partnership with the University of Zimbabwe and Biotechnology Research Institute (BRI) have developed a drought-resistant variety of maize seed called Sirdamaize 113. The African Agricultural Technology Foundation is also leading a public-private partnership called Water Efficient Maize for Africa, which aims to develop drought-tolerant maize using conventional breeding, marker-assisted breeding, and biotechnology. These drought- tolerant varieties will help stabilize maize yields and assure small-scale farmers of harvests, especially during periods of moderate drought.

Based on the information on the role of public-private sector in Zimbabwe, extrapolate the possibility of extending these roles to other crops such as rice, sorghum, millet, cassava and other staples.

Breeding of Quality Traits

Consumer quality traits, such as flavour, nutritional value, colour and firmness are becoming increasingly important in current plant breeding programs. Quality refers to the suitability or fitness of an economic plant product in relation to its end use. Quality consists of several features of a product. For example, colour, shape, size, nutrient composition. Quality could be classified into three types; market quality, industrial quality and nutritional quality. The market quality consists of fitness of a product for marketing. It consists of uniformity in shape, size, colour and texture in food and vegetable crops. The industrial quality consists of suitability for industrial products. For example, in cotton, fibre length, strength, fineness, maturity, uniformity and colour are desirable traits.

The key components of food that impact nutrition are carbohydrates, fats, proteins, minerals, water, vitamins and fiber. The first three components provide caloric energy, while proteins, minerals and water play a role in tissue and structure. After satisfying calorific energy needs, proteins are the next most important nutritional component of a diet. Crops that feed the world are primarily cereals, root and tubers, and legumes. Unfortunately, they are nutritionally inadequate in providing certain amino acids required for proper growth and development of humans and monogastric animals. For example cereals are generally deficient in lysine and threonine, whereas legumes are generally deficient in sulfer amino acids. An example of crop breed for improved quality trait is the quality protein maize (Box 6.6). Quality protein maize may be described as an extension of the improvement of high lysine maize. Quality protein maize has les of the indigestible prolamine- type amino acids that predominate in the protein of normal maize. Instead, quality protein maize cultivars have about 40% of the more digestible glutelins and a balanced leucine:isoleucine ratio for enhanced niacin production upon ingestion.

Protein content of crop plants could also be improved by using genetic engineering. Nutritional quality augmentation through the addition of new qu al it y tr ai ts , re mo vi ng o r re du ci ng u nd es ir ab le t ra it s or o th er manipulations, is an important goal in the bioengineering of food crops. One of such crops produced using genetic engineering is the «golden rice». Golden rice has been genetically engineered to produce carotene. This rice produces provitamin A, the precursor of vitamin A, which does not occur in the endosperm of rice.

Box 6.6: Quality Protein Maize Obatampa in Ghana

The objective of this case study is to demonstrate to students' practical example of quality trait improved through crop breeding.

Maize is a major cereal crop for both livestock feed and human nutrition, worldwide. As with all cereals, maize proteins, however, have poor nutritional value for monogastric animals, including humans, because of reduced content of essential amino acids such as lysine, tryptophan and threonine. Maize proteins contain on an average about 2% lysine, which is less than one-half of the concentration recommended for human nutrition by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 1985). Therefore, healthy diets for humans and other monogastric animals must include alternate sources of lysine and tryptophan. From the human nutrition viewpoint, lysine is the most important limiting amino acid in the maize endosperm protein (Kies *et al.,* 1965), followed by tryptophan (Bressani, 1975). Besides, amino acids are often lost from foods processed from grain meals, as in the case of maize. For this and other reasons, it is valuable to adopt a genetic enhancement strategy in which essential amino acids are either incorporated or increased in grain proteins. The Crops Research Institute of Council for Scientific and Industrial Research in Ghana successfully developed quality protein maize and named it Obatampa which literally means a good mother. This variety has been multiplied and grown all over Africa for its nutritional value. Nutritional importance of Obatampa was evaluated extensively. Kenkey is a popular local food in Ghana. Kenkey was produced from normal maize, Okomasa, and Obatampa. Weaning rats were fed ad labium on Kenkey based diets which served as the sole source of protein and amino acid, for 28 days. Analysis of samples of the kenkey revealed that processing and cooking of raw grains into Kenkey reduced the lysine content by 13% and the tryptophan content by 22% (Ahenkora et al. 1995). However, Kenkey from Obatampa contained 51% more lysine and 63% more tryptophan than Kenkey from normal maize. Rats fed the Obatampa diet had a better feed conversion ratio and higher protein efficiency ratio values than their counterparts fed a normal maize Kenkey diet (Ahenkora *et al*., 1995). Current efforts in quality protein maize development in sub- Saharan Africa largely follow the Ghana model because of the success story of Obatampa. To date, quality protein maize varieties have been released in many sub-Saharan countries.

Studies have revealed that seed growers do not maintain genetic purity of these varieties. If that is the case, the seed that farmers buy and plant is no more a quality protein maize. What policy measures would you advise stakeholders to put in place to ensure genetic purity of quality protein maize varieties?

Conclusion

Improving the yield and quality of major food crops in Africa in the face of climate change and new pest and disease threats is at the heart of the global food security challenge and depends largely on access to novel sources of genetically improved varieties. Access to continued genetic improvement and diversity will enable our farmers to remain competitive and profitable and help to feed a growing population. Breeders need to rise up to risks in Africa's agriculture. It is important African governments maintain a vibrant investment in plant breeding industry in order to ensure food security for all.

Questions for Discussion

1. When breeding new cultivars, it would always be important to consider or predict events that are likely to occur in the future. Critically imagine and predict some events that are likely to occur in the future that you would like to consider in setting your breeding objectives.
2. Briefly discuss major reasons why you would include wild relatives and neglected and underutilized crop species in collection and collection of national germplasm.
3. Plant genetic engineering is known to be useful in developing cultivars to manage pests and diseases and risks of climate change. The government of your country is reluctant in adopting genetically modified crops . Critically evaluate advantages and disadvantages of biotechnology and advance

arguments to affect policies of your government on how to use genetic engineering to manage agricultural risks.

4. Your country is currently battling with risks of pests, diseases, drought and low soil fertility. Discuss how you can use plant breeding to manage these risks in your country.
5. Climate change is a topical issue in Africa currently. Breeding for resistant cultivars is considered as the best method to manage risks of climate change. As a result, non-professional plant breeders have found themselves using breeding procedures to manage the situation. Critically examine the dangers of this practice and the possibility of it worsening risks of climate change in Africa.

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7

Livestock Production in Africa for Increased Resilience

H. Mazengia, K.A. Wondimagegn, B.M.F. Driver and S. Chakeredza

Summary

The chapter explains the major livestock production systems in Africa, the drivers and major trends in African livestock production. Five major livestock species are covered (cattle, sheep, goats, pigs and chickens). The global drivers of the livestock sector are discussed, in particular economic growth and income, demographic and land-use changes, dietary adjustments and technological change. The status of the main livestock production systems is described, with attention to differences in production systems of Africa. The chapter includes three case studies from three African countries (Mauritius, Ethiopia and Zimbabwe), which will assist students to understand how the livestock sector in Africa has faced challenges, and how it can increase its resilience. The case studies aim at equipping students with the ability to balance theory with practice, to study the various perspectives of livestock in agriculture on the African continent and to be able to adapt to challenges in their countries. The case studies do not aim to provide solutions to the students, but rather to put the students in the problem- solver's shoes. The case studies have been designed to probe the student to raise questions and key issues, spur the student to work through the problem(s).

Resume

L' elevage en Afrique pour une Resilience Accrue

*Le chapitre decrit les principaux systemes de production animale en Afrique, les objectifs ainsi que les leviers de changement affectant les methodes d**elevage en Afrique. Cinq especes** principales sont couvertes (bovin, ovin, caprin, porc et volaille). Les principaux facteurs affectant l'elevage au niveau mondial sont discutes, en particulier la croissance economique et les revenus, les changements demographiques et l'utilisation des terres, les comportements alimentaires et les changements technologiques. L'etat actuel, problemes et tendances des principaux systemes de systemes de production animale sont **decrit**s, avec une attention particuliere aux differences entre les r**e**gions d'Afrique.*

Le chapitre comprend trois etudes de cas de trois pays africains (Maurice, l'Ethiopie et le Zimbabwe). Les etudes de cas aideront les etudiants a comprendre comment le secteur de l'elevage en Afrique a releve les defis, et comment le secteur peut accroitre d'avantage sa resilience face aux risques majeurs.

*Les etudes de cas visent a doter les etudiants avec la capacite de lier la theorie a la pratique, afin d'etudier les differents contextes de l'elevage sur le continent africain, et d'etre en mesure de s'adapter aux defis de leur pays. Les etudes de cas ne visent pas a fournir des solutions toutes faites aux etudiants, mais plutot **a** solliciter leur capacite a resoudre des probleemes.*

Introduction

Global human population is expected to increase from the current 6.5 billion to 9.2 billion by 2050. More than one billion of this increase will occur in Africa. Rapid urbanization is taking place and incomes in developing countries are subsequently increasing, and are largely responsible for the large increases in demand for livestock products. Meeting the food demands of a global population expected to increase 9.2 billion by 2050, and improving incomes and livelihoods, will require greater resilience in agriculture production systems. Resilience is a measure of the capacity of a system to withstand stresses and shocks, i.e. its ability to persist in an uncertain world (Wallenberg *et al.,* 2012).

The rural people of Africa live mainly on diverse agricultural activities including farming, livestock keeping and fishing. For example, livestock products alone contribute 40% of the agricultural GDP and 20% of the total GDP in Ethiopia. Animal products such as meat, hides, and skin, contribute 45 % of the USD 6.1 billion GDP (Sere and Herrero, 2009). Similarly, livestock contributes 18% of gross domestic product (GDP) and 30% of gross agricultural product, equivalent to 33% of total export revenue in Chad. It contributes 12% of GDP in Cameroon and in the Central African Republic. Cattle alone contribute 14% of GDP and 35% of the gross agricultural product in some African countries (Mkapado and Kmaduabuchukwu, 2013).

Vast differences in the level of consumption of livestock products exist between rich and poor countries. The level of consumption of milk and meat in developed world is at least five times higher than in developing world. However, in developing countries the demand for livestock are rising rapidly, mainly as consequence increased human population and rapidly increasing incomes. This increased consumption of livestock products is having positive impacts on mortality and cognitive development of children in these countries and the overall food security of developing world. It is also indicate as the source of causes of health problems in parts of developed world (Wallenberg *et al.,* 2012).

The demand for animal protein in Africa is also rising, as the human population keeps growing and the previously depressed economies of the region are gradually picking up. Semi-arid regions with rainfall between 750 and 1500 mm are potentially suitable for livestock rearing in Africa (Mohammed-Saleem and Fitzhugh, 1993). However, these are under-exploited particularly due to tse-tse infestation (Awa *et al.,* 2000). According to Winrock International (1992), 57% of ruminant population in sub-Saharan Africa is located in the arid and semi-arid zones which make up 54% of the total land area of the region. Furthermore, areas traditionally reserved for livestock are being classified as natural parks and game reserves in Cameroon. This acute competition of land use by animals, crop farming, and game reserves contributes to environmental degradation due to excessive exploitation of the vegetative cover of the soil. Thus the goal of increasing productivity to meet up with human population growth is compromised. The crop-livestock integrated systems approach (Mcintire *et al.,* 1992) in the diagnosis of the complex interactions that characterize agriculture in Africa has proved to be a useful tool in identifying pertinent production constraints and opportunities (Herrero *et al.,* 2012). In Africa livestock producers are highly subsistence oriented. Hence, there is growing evidence that economic consideration such as risk minimization and supply security are important in influencing the way African livestock keeper behave.

This chapter provides the basic concepts for understanding the prevailing livestock production systems in Africa and the issues that compromise livestock production and the strategies for increased resilience for African livestock producers.

Learning Objectives

By the end of this chapter, students will:

- Gain an understanding of the risks facing animal production systems in Africa;
- Explore, through Case Studies, strategies that will increase the resilience of the animal production systems in Africa.

Learning outcomes

Having studied the chapter, the students will be able to:

- Discuss the practices of livestock production in Africa for increased resilience;
- Identify key issues and recognise problems of the livestock sector in Africa;
- Assess the risks and uncertainties facing livestock production in Africa.
- Think critically and analytically;
- Propose strategies aimed at increasing the resilience of livestock production systems in Africa.

Drivers of Livestock Production in Africa

Increased Income

Individual consumption of livestock products is closely related to *per capita* income. That is, with growing incomes people typically increase their consumption of meat, milk, and eggs until these products become fully integrated into the daily diet. In high income countries, *per capit*a consumption of meat ranges between 80 kg and 130 kg per year. As incomes in many developing countries have grown rapidly over the past 20 years, consumption levels of meat and other livestock products have also increased. The economies of developing countries achieved an average annual growth of 3.8% *per capita* from 1991 to 2001, up from 2.9% during the ten preceding years (WAAP, 2004).

Increased Human Population

Increases in human populations also add to the demand for animal-source food products. Most African countries still have rapidly growing populations even though percentage growth rates are below their peak in the 1970s. Each year, the human population in developing countries grows by 7.2 million, adding the demand for food products. There are wide differences among developing countries. Population growth has slowed down to 1.6 % in East Asia whereas it has remained high in sub-Saharan Africa (2.8%) and in the Near East/ North Africa region (2.6%). Furthermore, the population structure is also changing. Urbanisation is fast increasing and it is projected that by 2007, the majority of human population will live in cities (World Bank, 2009).

Increasing Share of Livestock Products in the Human Diet

Important changes have occurred in the average diets of people in various world regions. Urban people adopt new eating habits, consuming higher amounts of animal protein, and eating higher proportion of their food away from home. Furthermore, many populations in developed and developing countries are gaining, with declining proportion of the total population younger than 15 years. This also has an impact on total food demand and on the type of food consumed. People in industrialised countries derive more than 40% of their dietary protein intake from food of livestock origin, and little change occurred between 1980 and 2002. Changes have been most dramatic in Asia, where total protein intake rose by nearly a third. In contrast, there has been a decline in livestock consumption in sub-Saharan Africa, reflecting economic stagnation and a decline in available incomes. The increasing share of livestock products in the human diet in many developing countries is a part of a dietary transition that has also included a higher intake of fats, fish, vegetable and fruit, at the expense of staple foods such as cereals and tubers.

Rapidly increased demand for animal-source food products exerts pressures on the livestock sector, which needs to adapt faster in order to cope with demand. These adjustments are based on changing feed resource base, particularly food concentrates. Current and projected levels of livestock production would not be possible without the expanding production and yield increase of crop agriculture. Traditionally, livestock production used to be based on locally available feed resources, including local fodder, crop residues and unconsumed parts of human food-resources that had no value as human food. Traditionally, natural pastures were the venue of livestock production. More recently, however, a growing proportion of pastureland in developing countries are areas which are unfit or marginal for cropping, and degraded arable land is often converted into pastureland. The demand for arable land and the fact that there is basically no additional available land that can readily be converted into pastures, except in parts of tropical Latin America, have important implications for the livestock sector. The lack of new land prohibits a 'horizontal' expansion of existing modes of production, and forces the sector into rapid technological change and search for alternative resources (Akwe, 2004; Wallenberg *et al.*, 2012).

The Resilience Approach to Livestock Production

The concept of resilience makes sense only when applied to a system. A system is a group of interacting components, operating together for a common purpose, capable of reacting as a whole to external stimuli: it is affected directly by its own outputs and has a specified boundary based on the inclusion of all significant feedback (FAO, 2007). A system approach allows shifting from a static, deterministic analysis towards a dynamic, stochastic analysis. Resilience to livestock production is defined as the system ability to maintain a certain level of well-being livestock producers in the face of risks.

A resilience-based approach to livestock production involves a two-step procedure. The steps involve defining the system of interest and specifying issue(s) of concern, which consist of describing:

- The key attributes of the system: the resilience "of what";
- The main disturbances and processes that influence it: the resilience "to what".

These steps are preliminary to resilience assessment and resilience management: the former aims at assessing the current and future states of livestock production system resilience, while the latter focuses on the implementation of actions aiming at restoring, conserving or enhancing the livestock production resilience (Ganya *et al*, 2004).

Livestock Production Developments and Indicators

The different livestock population numbers have been converted into tropical livestock units (TLU) considering the metabolic size of animals of different species. Europe shows slightly decreased animal numbers for all the livestock species, yet there is a surplus of livestock production in Europe today. Africa, Asia and South America show steady increases in TLU numbers. When contrasting the TLU numbers with the output of food products it emerges that high livestock numbers and TLU do not necessarily equate to high productivity. Neither do they reflect the overall utility functions that the various livestock play in each region. For example, whereas cattle TLU in Africa is the same as a cattle TLU in Europe, on average the European cattle are almost 2—3 times bigger and thus the two are not comparable from a productivity point of view. Secondly, the African/Asian animals are used for many more tasks than food production (e.g. draft, energy, social security etc.) compared to animals in temperate climates in the developed world (Biasca, 2012).

Density and Distribution of Poor Livestock Keepers

At the global level, information on the importance of livestock to rural livelihoods is difficult to find. Equally, in 2002 ILRI estimated the distribution of poverty among livestock keepers. Poverty rates clearly differ within and between production systems. The proportional importance of livestock to household income streams differs from one culture to another and within production systems. For example, mixed crop—livestock farmers have multiple opportunities for obtaining income from a variety of sources; thus, income from livestock probably contributes a smaller proportion to their household food basket. By contrast, most pastoralists depend on livestock for a large proportion of their income, although this is changing (Alexandros and Bruinsma, 2012).

Thus, any map of poverty among livestock keepers needs to account for the importance of livestock to income at the household level. In estimating the distribution of poverty among livestock keepers, ILRI in 2002 used proportions of poor livestock keepers as a percentage of the total poor by livestock production system and derived that the density of poor livestock keepers is high throughout South Asia (India, Pakistan and Bangladesh) and in parts of sub-Saharan Africa (SSA). The latter include Nigeria, Ethiopia, Uganda, Burundi, Rwanda, Malawi, and some systems in Kenya, South Africa and Niger. These high densities appear to occur mostly in the mixed systems, these are the mixed irrigated systems in parts of SA, and the mixed rain-fed systems in parts of India and in most of SSA (ASARECA, 2010).In terms of the numbers of poor and, so far as the analysis is capable of distinguishing, the numbers of poor livestock keepers, the critical regions are South Asia and Sub Saharan Africa. ILRI analysis indicates that while the rangeland systems contain relatively few poor (some 60 million), most of these households are dependent on livestock for their livelihoods. Almost half of the poor in rangeland systems are located in SSA. The mixed systems contain large numbers of poor (over 1 billion), and the numbers of poor who depend on livestock are considerable. The mixed irrigated systems contain approximately 103 million poor livestock keepers while the mixed rain-fed system has 366 million poor livestock keepers. In terms of the magnitude of poverty and the importance of livestock to poor households in the developing world, this analysis suggests that there are at least 550 million poor livestock keepers globally (O'Goraman, 2012).

The Role of the Livestock Sector in Africa

Direct food production in terms of meat and milk is a major activity in Africa as in other developing areas. Two-thirds of the gross value of livestock outputs are accounted for by meat, milk and milk production. Livestock output which indirectly contribute to food production such as recycled inputs to livestock, cultivated animal feed, bone meal and poultry litter also contribute the remaining one-third. The latter contribute much less to livestock output in developed countries (Table 7.1).

Output (%)	Sub-Saharan Africa	Developing countries	Developed countries
Meat	47	45	53
Milk	15	15	34
Eggs	5	7	8
Direct food	66	67	95
Draught	31	29	3
Manure	3	4	2
Total	100	100	100

Source: Addis, 1989

Disregarding non-food (e.g. hides and skins) and minor food (e.g. blood) items is estimated that the value of commodity output of livestock in to sub-Saharan Africa is equivalent to 25% of total food production. In 1983, livestock contributed about 8% to overall calorie intakes (the world average was 16%) and 23% to protein intake (world average - 34%. The percentage contribution of livestock products to total calorie and protein intake increased in majority of Sub-Saharan African countries, particularly in East and Southern Africa (Naylor, 2008)

Many people, including some veterinarians and animal scientists, still believe that African husbandmen keep livestock mainly for prestige and as status of symbols or as a means of fostering cultural and social relations. Most believe that African livestock producers are highly subsistence oriented-producing for their own consumption. There is growing evidence that economic considerations such as risk minimisation and supply security are important in influencing the way African livestock keeper behave. Data from field research indicate that most African households do not, in fact, depend for their food wholly on their own farm and animal production. They usually specialize in the production of commodities in which they have comparative advantage, selling these in order to purchase other foods. Pastoralists and holders of large herds are predominant among those who practice specialised production accompanied by exchange. They have good reasons for doing so because the market value of a calorie of dietary energy from milk or meat is usually much higher than that of a calorie from grain. At typical African domestic price ratios, ten calorie in grain can be obtained by the sale of less than two calories in milk or less than half calories in meat. In pastoral systems of dry tropical Africa 50-60% of livestock output is sold. In mixed crop/ livestock systems in the more humid and highland zones of sub-Saharan Africa 35-63% of livestock output is sold (Ganya, 2004).

African pastoralists thus generate a high proportion of their cash income from livestock in order to purchase grains. Even in production systems where livestock provide a smaller proportion of the total value output, the highest income may well drive from livestock (Table 7.2).

Table 7.2: Proportion of total household cash income derived from livestock In selected production systems in Africa

Production system / country	Ecological zone	Production species kept	Cash income derived from livestock (%)
Pastoralists			
Mali	Dry	Cattle	96
Niger	Dry	Sheep/goats	96
Kenya	Dry	Cattle	76
Agro-pastoralists			
Kenya	Dry	Sheep/goats	>90
Mali	Dry	Cattle	39
Mixed Farmers			
Ethiopia	Highland	Cattle	83
Northern Nigeria	Sub humid	Pigs/goats	56
Southern Nigeria	Humid	Sheep/goats	2-13
Zimbabwe	Dry	Cattle	<4

Source: Addis, 1989

Livestock thus provides stability in food consumption. Farmers and pastoralists sell livestock when crops fail to generate the cash needed to purchase high-priced grain. In good years they invest cash surpluses from crops in livestock purchases or they may shift investment from one livestock species to another.

Population growth, rising income and increased urbanization in the African countries as well as the subsidised prices of European beef and dairy exports have helped to stimulate the demand for livestock imports for sub-Saharan Africa. This is particularly true in West Africa where, by 1984, imports accounted for 45% of total dairy consumption by volume: some countries (e.g. Cote d'Ivoire, Ghana) have become extremely dependent on dairy imports.

Whatever increase in aggregate output has occurred is mostly attributed to increases in numbers rather than to increased yield per animal per herd. Africa has about 14% of the world bovine population but produces 16% and 3% of the world beef and milk output respectively. In contrast, developed countries have about 30 % of the world bovine population but produces 71% and 77% of the world beef and milk output.

The number of sheep and goats in Africa constitutes 22% of the world population but contributes only 17% of mutton and goat meat output. The comparable figures for developed countries are 36% of population and 46% of output. The low yields have obviously contributed little to increases in output (Table 7.3).

Table 7.3: Average productivity of animals in Africa compared to other developing and developed countries

Country group	Meat (kg)		Milk (kg)	
	Sheep and Bovine	, goat	Per animal in herd	Per productive cow
Developed	79	6.5	900	3130
Developing	15	4.6	90	600
Africa	14	3.7	40	360

Source: FAOSTAT database, 2011

Livestock Production Systems in Africa

The following general systems of livestock production exist in Africa (WAAP, 2004),

- Pastoral system,
- Agro-pastoral system,
- Ranching,
- Feedlots,
- Commercial systems.

The Pastoral System

The pastoral systems depend on the use of the range land, which is land carrying natural fodder on which grazing livestock depend for subsistence (UNCCD, 2007). The pastoral systems are associated with arid zone, and because of the inadequacy of nutrient supply during the very dry months, the pastoralists are forced to move their herds and flocks to wetter areas. The greater is degree of aridity, the longer is them migration period which results in nomadic pastoralism. Where movement the pastoralist is seasonal from permanent home base for a short period of time this is transhumance. Nomadic pastoralism is practiced in drier parts of arid-zones on the fringes of desert while transhumance pastoralism is practiced in the wetter areas (African Union, 2010).

The pastoralists often herd cattle, camel, donkey, sheep and goats with harder species such as camels, donkeys and goats confined to the drier areas. The mixed species strategy adopted by pastoralists is to ensure complementarily of the different species in range of utilization. This is the direct benefit to pastoralists in terms of cash returns and constant supply of milk throughout the year (FAOSTAT database, 2011).

Thus the major function of livestock in this system is as a source of milk. The larger animals are hardly slaughtered while small ruminants are often served as a source of meat. Nevertheless, the contribution of crops varies depending on the season and the level of interaction with crop farmers or agro-pastoralists from which cereals are purchased or obtained by barter. In some instance there are sales of animals, especially of small ruminants. However, sales of larger animals usually take place to get rid of older or barren animals, unwanted males, old bulls and steers. Usually, pastoralists will not sell off cattle merely to reduce stock as large herds are regarded as status of symbol and they confer prestige. Small stocks are sold to raise funds as the need arises. The productivity of livestock is low because of the poor quality of available fodder and the fact that animals have to cover long distances in search of feed and water (CTA, 2006).

The Agro-Pastoral System

The agro-pastoral systems involving crop and livestock production vary widely not only depending on the relative emphasis on agro-pastoralists and crop production but also on level of interaction between the two practices. The agro- pastoral systems cover the semi-arid, sub-humid and humid zones. A basic difference between pastoralist and the agro-pastoralist is that while the former views livestock as a factor of production - a source of food, income and exchange, the latter views it as indirect means of production for draught power, source of manure, and an insurance against crop failure. The extent to which this interaction between crop and animal production is achieved depends on the agro- pastoralist, ecological factors, the tsetse challenge, human population pressure, cropping pattern and the relative importance of different livestock species and their density (WAAP, 2004).

Ranching

Ranching implies management of animals within confined areas. It is labor extensive and demand adequate supply of feed in terms of grazing and watering. Animals are marketed live for meat, skin and hides. Ranches are found in all ecological zones and in some cases represent a part of heritage of colonial past. The standard of livestock management in ranch is higher than that under the pastoral systems. In addition to feed resource availability, management practices such as adjustment of stocking rate as desirable, rotational grazing and supplementary feed are used to ensure optimum productivity of the livestock. Disease monitoring and control are more effective under the ranching system and the tsetse challenge can be more contained. Livestock under ranching system are more productive in terms of growth rate and reproduction and they produce better quality end-product such as beef. Supervision is more close and thorough and good records of performance are recorded (CTA, 2006).

Feedlots

Feedlot constitute recent development systems of production in sub-Saharan Africa. They depend on intensive feeding of livestock on concentrates and byproducts such as cotton seed cake, molasses, groundnut cake and grains. The use of roughage is minimal. The objective is to rapidly fatten up animals for market. Feedlot practices have been demonstrated to be effective in improving carcass quality in Kenya and in Nigeria (WAAP, 2004). Despite the potential of intensive production system to increase meat from ruminant livestock, the effectiveness of beef in rapid beef, mutton and goat meat production in Africa is doubtful. This is due to the high cost of supplementary feeds particularly grains, the low dressing percentage of the ruminant livestock, the poor premium for high quality meat product and the relatively low feed efficiency of ruminant animals (Van der Lee *et al.,* 2013).

Commercial Systems

Besides ranching and feedlots, commercial systems apply to pigs and poultry production. Commercial pig and poultry production systems are characterized by the use of temperate breeds and strains, high level of concentrate feeding, high capital investment in housing and equipment, high levels of technology and location near urban centers. They are usually specialized by their products, e.g. day-old chicks, eggs or broiler. The steady increase in commercial pig and poultry enterprises, of 1960s and 1970s have been adversely affected by the economic situation in most of Africa, in the last three decades, and compounded by feed supply problem. In Nigeria, for instance, the commercial poultry industry has virtually collapsed due to the high cost of production especially feed, the devaluation of the national currency resulting in high costs of inputs and thus high costs of products (WAAP,2004).

Challenges Facing Livestock Production for Increased Resilience in Africa

The traditional livestock production systems face serious constraints and these are adversely affected livestock productivity in Sub-Sahara Africa. Feed supply, animal health, genotype and livestock management are the main technical constraints that reduce the overall livestock productivity in Africa compared to the rest of the world (UNCCD, 2007).

Feed supply

Inability to feed animals throughout the year is the most widespread technical constraint. In drier regions, the quantity of forage is often in adequate for the number of livestock carried particularly in the dry season. In wet, feed supplies are ample, but forage of low quality with low protein and energy contents. Generally, feed shortages and nutrient deficiencies are more acute during dry seasons. There is a need to develop locally available feed resources and to explore feeds having a high nutritive value, e.g. the use of forage legumes. Plate 7.1 gives some examples of forage legumes that are available for ruminant production in the Republic of Mauritius (Ghurburrun, 2014). Crop residues and industrial by-products that could be fed to animals are largely wasted or inefficiently utilised due to under developed infrastructure for transporting, processing and marketing of feedstuffs. Expansion of poultry and pig production is hampered by lack of reliable supply of concentrate feeds and protein supplements (FAO, 2008; Knips, 2004).

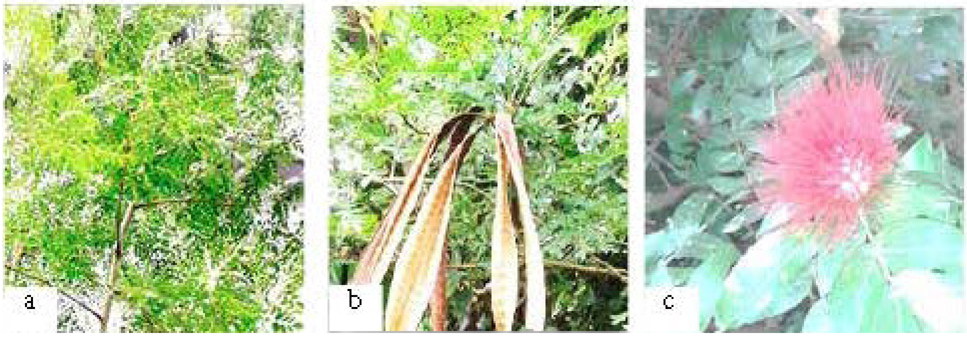

Plate 7.1a: Moringa oleifera; 7.1b: Leucaena leucocephala; 7.1c: Calliandra hematocephala
(Source: Ghurburrun, 2014)

Animal Health

Disease sharply reduces the productivity of livestock in all production systems. The most important animal disease constraints to livestock productivity to sub-Saharan Africa today are the parasitic and viral diseases. This are mainly vector transmitted, are widely distributed and whose severity is strongly influenced by environment. No effective and easily administered vaccines or chemotherapeutic agents exist for these diseases. The most important diseases in this group are: trypanosomyiasis, theileriosis, cowdriosis, babesiosis, anaplasomis dermatophilosis and African swine fever. Epidemic diseases such as contagious bovine pleuropneumonia (CBPP), *"peste des petits ruminants"* are region wide threats that unless controlled, make livestock raising too risky for governments or farmers to invest in improvements. Cooperative efforts between African governments and international agencies are effectively controlling these diseases. A developmental progress, a large group of infectious, parasitic and noninfectious disease associated with intensification will become more important constraints to productivity. The inability of many countries to maintain effective surveillance and control measures and lack of effective means of delivering veterinary services throughout sub-Saharan Africa are major impediments to effective animal disease control. Effects of civil strife and war between countries in many parts of Africa make it difficult if not impossible to eradicate most of trans-boundary diseases. Some of these diseases, especially the zoonotics, severely limit the marketing of livestock products outside the continent (African Union, 2010).

The humid tropical environment is particularly conducive to proliferation of disease and parasites while the arid and sub-humid zones, where most ruminant livestock population is located, have had sporadic outbreaks of serious diseases such as rinderpest, foot and mouth disease and CBPP. The disease problem in Africa is accentuated by the fact that nomadic and transhumant pastoralists move animals indiscriminately across state boundaries in their seasonal search for acceptable grazing lands. This is in addition to the normal international trade in lives animal especially in festivals. Thus continued international effort is required in the control of these diseases. The tsetse challenges have also limited animal production to mainly the trypano-tolerant breeds, which are small breeds and generally of low productivity than the trypano-susceptible ones. Under pastoral the system, veterinary intervention has not made any serious impact due to the fact that the pastoralists are usually on the move. Under feedlots, ranching and commercial systems veterinary medical care delivery is more effective and control measures against diseases such as Newcastle routinely carried out (Sandford, 1982).

Husbandry Practices

There is inadequate understanding of the dynamics of crop-livestock farming systems, which involve a great variation in cropping patterns, market opportunities, livestock alternatives, labour technology and inputs. This constraint is particularly important in sub-humid zones where crop-livestock farming is in early stages of evolution and will be a major importance in the future. Farmers' inadequately developed skills in managing new crop-livestock systems and using new technology are barriers to raising the productivity of livestock sector (Sere and Herrero, 2009).

The level of livestock management under various production systems is low. This is particularly so under the traditional systems. In addition to feeding and disease control, the herd structure is such that unproductive animals are usually retained for prestige seasons. In commercial systems, technical support is inadequate and inputs are substandard. The harsh environment in the arid and semi-arid zones is not optimal for livestock production, while lack of conscious effort to integrate crop and livestock production systems in the agro-pastoral system, is detrimental to both crop and livestock production (World Bank, 2009).

Case Studies: Livestock Production for Increased Resilience in Africa

Box 7.1: Improving feed supply for increased resilience of livestock

The Republic of Mauritius is highly dependent on importation of milk. The local milk production (2012) amounts to 6.5 x 106 L / year, representing only 5.4 % of the demand (120 x106 L / year). Imports (in value terms) have increased by 60% over the period 19972004, whilst in volume terms the rise has been 25 %.

One root-cause problem of the low milk production is the poor management of forages used by smallholder farms. The nutritive value of the forages used does not match the requirements of the animal and the forages are below maintenance requirements of the cows. Typically, the small-scale producers have 10 dairy cows and three follower calves. The cow breed is normally the Holstein-Friesian. The milk yield at peak lactation will average 12-14 L / day, with a total milk yield of 4500L / cow.

Questions

- You are contracted to develop and implement a project of stargrass *(Cynodon plectostachyus* Pilger) production, for conservation as hay, for the small-holder dairying in Mauritius. Use data given in Table 7.4 to assist in your Consultancy Report. Show all your calculations and assumptions used.
- Discuss the scientific rationale that supports your recommendation(s) and demonstrate how a rational management of forages can improve production of smallholder dairying and improve their resilience.
- What are the key recommendations and strategies that you would include in your Consultancy Report for consideration by relevant stakeholders: government; producer cooperatives; NGOs etc.

Table 7.4. Effect of maturity (4-14 week re-growth) on the feeding value of stargrass *(Cynodon plectostachyus* Pilger)

g / kg DM	Week re-growth					
	4-week	**6-week**	**8-week**	**10-week**	**12-week**	**14-week**
Organic matter	916	920	923	920	925	923
Ash	84.0	80.0	77.0	80.0	75.0	77.0
Crude protein	125.5	94.5	71.0	61.5	57.4	53.6
NDF	684	711	722	738	767	777
ADF	400	485	452	443	465	455
ADL	49.8	60.0	67.7	67.1	70.2	82.2
kg DM / ha	4-week	6-week	8-week	10-week	12-week	14-week
	1580	3322	4229	4290	4336	4440

Source: Kavma and Driver, 2012

Box 7.2. Water use efficiency in livestock production

Water availability for livestock is getting worse and particularly in the dry season. With climate change this is envisaged to get worse. In the dry season deaths due to water scarcity occurs. Large ruminants are the worst affected. Smallholder farm families' major source of livelihood is lost. Normally livestock are given water *ad libitum*. In some cases they are taken for watering two times per day following grazing. However, water is getting scarce and intervention measures have to be taken. There are also interactions between quality of food and water level requirement. The level of energy, fibre and the ratio of the two affect water requirements. Most communities keep large ruminants for meat, milk, manure and draft power. They are an integral part of smallholder farm families' livelihoods. A significant amount of time is spent in the dry season by farm families in search of water for their livestock. Livestock losses due to water shortage are worsening the farm families' livelihoods.

It will be important to link the amount of water offered livestock, the frequency of watering and the dietary intake. This case study addressed the effects of type of diet and frequency of watering on the performance of growing cattle given food at maintenance. Three diets with 20:80 (low, L), 50:50 (medium, M) and 0:20 (high, H) roughage to concentrate ratios 10.2, 7.8 and 5.4 MJ ME per kg dry matter were used in combination with free access to water for 2.5 hours, once daily or once every 3rd day. A completely randomized block design with a 3 diets x 2 watering frequencies factorial arrangement of treatments was used. Five animals were allocated per treatment. Dry-matter intake increased as the roughage content of the diet increased ($p < 0\ 05$) but was not affected by the watering regime ($p > 0\text{-}05$). Total water intake was found to be positively correlated with dry-matter intake and increased with dietary roughage level. Animals watered daily drank more ($p < 0\ 05$) water (12 6 *v.* 10-0 kg/day) than those watered every 3rd day. The apparent digestibility of the diets decreased as the amount of roughage increased (diet L 734 g/kg, M 471 g/kg and H 433 g/kg). Similar apparent digestibility was observed under the two watering frequencies (546 g/kg and 547 g/kg)

Type of diet significantly ($p < 0\ 05$) affected the final weights of the steers. Animals given diet H were proportionately 0-07 heavier than those offered diet L corresponding to total weight changes of -0 8 and +18 4 kg respectively. Carcass weight, back-fat thickness and eye muscle area were not affected by the treatments. The chemical composition of the 9 to 11th rib joint was only affected by diet H which gave less fat ($p < 0\ 05$). Water, fat, protein and ash content averaged 607,118,190 and 84 g/kg respectively.

Questions

- What are the conclusions from this work?
- To what extent can you save on water supply without compromising on ruminant livestock productivity?
- What would be the recommendation moving forward?

Box 7.3: Community-based Animal Health Delivery system: impact on control of animal diseases

Community-based animal health delivery systems can make a valuable contribution on improving veterinary services delivery in the more remote and under-served livestock rearing areas of the developing world. This can be achieved by training Community Animal Health Workers (CAHW) and by providing supplies and inputs for animal health service. The government institutions in developing world including Africa face many problems in giving animal health services in remote areas. This is because more logistic and infrastructure is required to deliver the service.

In the Afar Region of Ethiopia, PARC demonstrated that CAHWs can carry out rinderpest vaccination rapidly effectively and cheaply. In 1995, in neighbouring districts of the Afar region, a CAHW project vaccinated 70,000 cattle using 22 CAHWs, 2 Ethiopian Veterinary Service Staff, vehicle and no cold chain. The efficiency of vaccination was 84%. No outbreaks of rinderpest have been reported since this campaign and the area has now been declared provisionally free from disease. The conventional government vaccination teams vaccinated, concurrently, 140,000 cattle using 14 vehicles, 56 staff and a full cold chain. The efficiency of vaccination was 72%.

Questions

- You are contracted to develop and implement a project of CAHWs production, for animal health service delivery, for the small-holder dairying in your country.
- Discuss the scientific rationale that supports your recommendation(s) and demonstrate how community-based animal health deliver improve livestock keeper resilience.
- What are the key recommendations and strategies that you would include in your Consultancy Report for consideration by relevant stakeholders: government; producer cooperatives; NGOs etc.

Conclusion

Livestock provides food, hides, wool, skin, draught power, fertilizer and fuel. Animals are capable of converting the energy of the earth into proteins and other products of high quality nutritional value. Two billion people in developing countries annually cultivate 310 million hectares of land using 280 million draft animals manure provides 5 million tonnes of nitrogen fertiliser annually. Animals and animal products play increasing role in trade. Animals also take a significant part in national economy in many countries. In many of African countries, livestock are the only means of storing wealth contributing to food security. Livestock production systems in sub-Saharan Africa are subsistence oriented and productivity is very low. Among major constraints in livestock development include widespread animal diseases, poor nutrition, poor animal breeding, husbandry practices and shortages of well-trained manpower. This chapter described the current status of livestock production systems, and the drivers and major trends in African livestock production. Five major livestock species were covered (cattle, sheep, goats, pigs and poultry). First the global drivers of the livestock sector were discussed, in particular economic growth and income, demographic and land-use changes, dietary adjustments and technological change. Second, the status of the main livestock production systems was described, with attention to regional differences and major constraints were discussed. Finally, the Case Studies were included to be examined and analyzed by students with the objective of adjusting livestock production systems to external forces.

Questions for Discussion

1. Discuss the contribution of the livestock sector to the GDP of selected African countries.
2. Compare and contrast the livestock production systems in Africa. What are the risks facing each system of production? Illustrate your answer with relevant examples.
3. What are the drivers of supply and demand of livestock products in Africa? Assess how the drivers will change and affect supply of livestock products in selected regions of Africa by year 2050. Use relevant data available from FAOSTAT database to inform your analysis.
4. Define the term "resilience" as used for livestock production systems.
5. Explain how the "resilience approach" will improve the productivity of livestock production systems in Africa.
6. Discuss the challenges facing the livestock sector in Africa for increased resilience.
7. Propose some key strategies that can be put in place in selected countries of Africa for increased resilience of the livestock sector. What will be the benefits to the livelihoods?

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8

Animal Breeding for Managing Risks

K.A. Wondimagegn, H. Mazengia, B.M.F. Driver and S. Chakeredza

Summary

Disaster risk management in animal breeding is a systematic approach of preventing, reducing, mitigating and coping of farm animal breeds and breeding systems with natural hazard risks, and for emergency response, recovery and restocking. Therefore, the objectives of this chapter is to acquaint with disaster risks facing African farm animal breeds /genetic resources and enhance early warning systems, to strengthen disaster preparedness for effective response of all African communities in reducing the underlying risk factors facing indigenous farm animal breeds at all levels. It helps also to use knowledge, innovation and education for building a culture of safety and resilience of sustainable utilization of indigenous farm animal breeds and genetic resources at all levels. So as to achieve these objectives the farmers or pastoralists should understand risks of breeding without having appropriate breeding policies and strategies, risks without having appropriate recording systems, risks arising from inappropriate conservation strategy/system, risks caused by breeding processes, risks caused by climate change, risks from low reproductive performance of indigenous cattle as well as risks in the management of animals breeds and breeding systems at refuge camps in Africa.

Resume

Gestion des Risques par I'Amelioration Genetique des Animaux de Ferme

La gestion des risques dans l'elevage est une approche systematique de prevention, de reduction, d'attenuation et d'adaptation des races d'animaux d'elevage et des systemes d'elevage, aux risques et catastrophes naturelles, et des interventions durgence, la recuperation et le repeuplement. Par consequent, ce chapitre a pour objectif de familiariser l'auteur aux risques auxquels sont confrontes les races d'animaux d'elevage en Afrique et les ressources genetiques, et ameliorer les systemes d'alerte precoce, de renforcer la preparation aux catastrophes pour une intervention efficace de toutes les communautes africaines dans la reduction des facteurs de risque sous-jacents auxquels sont confrontes les races d'animaux d'elevage autochtones a tous les niveaux. Il aide egalement a utiliser les connaissances, linnovation pour instaurer une culture de la securite et de la resilience de l'utilisation durable des races d'animaux d'elevage indigenes et des ressources genetiques a tous les niveaux. De maniere a atteindre ces objectifs, les agriculteurs ou les eleveurs doivent comprendre les risques de l'elevage sans avoir des politiques appropriees d'elevage et les strategies, les risques sans avoir des systemes d'enregistrement appropriees, les risques decoulant de conservation inappropriee strategie / systeme, les risques causes par des processus de reproduction, les risques causes par le changement climatique, les risques de faible performance de reproduction des bovins indigenes ainsi que les risques dans la gestion des animaux de races et systemes d'elevage dans les camps de refugies.

Introduction

The science of animal breeding is defined as the application of principles of genetics and biometry to evaluate the genetic value, to select and breed animals with best breeding value (economically important traits) and improve the efficiency of productions in farm animals. The big question is: what is the best animal with the best breeding value? "Best" is a relative term. There is no best animal for all situations. The kind of animal that works best in one environment may be quite different from the best animal under another set of circumstances. Traits of primary importance and genotypes of most desirable for those traits should be determined. This means that the importance of traits will depend on the physical environment under which animals are kept, the management system as well as economic factors. Similarly, the best genotype depends on the local environment, the management practises in use, and the costs of inputs and prices of animal products. To determine the best genotype, one should have knowledge of environmental, management, and economic components and understand how they interact with the genotype to affect profitability. Failing to realize these, animal breeding will be subjected to risk. Therefore, the genotype of domestic animals determines the degree to which the animals are suited for their function in society. The key in determining the traits of importance and optimal genotypes for those traits is a thorough analysis of the function of the animal in the entire system and an understanding of the many interactions among components of the system.

Disaster risk management in animal breeding is a systematic approach of preventing, reducing, mitigating and coping of farm animal breeds and breeding systems with natural hazard risks, and for emergency response, recovery and restocking. In the context of disasters, risk is the probability of an adverse consequence occurring in animal breeds and breeding system as a result of a hazardous event, and it is influenced by the degree of vulnerability of these breeds to these hazards. Within disaster risk management, disaster risk reduction is "the concept and practice of reducing disaster risks of farm animals through systematic efforts of analysing and managing the causal factors of disasters. This includes reduced exposure of animals and their breeding system to hazards, lessened vulnerability of animals, wise management of animal breeds and the environment, improved preparedness for adverse events that threaten animal breeds and breeding system.

A second big question is: 'how do animals breed so that their descendants will be better than today's breed?' In other words, how are animal populations improved to maximise profitability over time? The purpose of animal breeding is not to genetically improve individual animals, but to improve animal populations. Do Africans balance what is expected from what was is predicted in improving animal population to the traits of interest? If not, what and where are the mistakes and hazard risks facing animal breeds and breeding systems?

To answer these and related uncertainties, this chapter will discus the concepts, risks and risk management directions of breeding polices and strategies, farm animal recording systems, breeding systems, conservation strategies, trans- boundary disease in the refuges and its consequenceincluding admixture of unrecognized breeds at refuges and climate change.

Learning objectives

The general objective of this chapter is to analyse animal breeding problems for managing risks in African context. The specific objectives of this chapter are to:

- Identify and assess disaster risks facing African farm animal breeds / genetic resources and enhance early warning systems;
- Strengthen disaster preparedness for effective response of all African communities in reducing the underlying risk factors facing indigenous farm animal breeds at all levels;
- To use knowledge, innovation and education to build a culture of safety and resilience of sustainable utilization of indigenous farm animal breeds genetic resources at all levels.

Learning outcomes

The reader of this chapter will be able to:

- Identify the underlying risks of farm animal breeds and breeding system and plan in designing appropriate systems for risking and proper utilization of African farm animal breeds;
- Understand preparedness issues in reducing the underlying risk factors facing farm animal breeds, breeding systems and enhance early warning systems in reducing risks;
- Acquire knowledge, innovation and education to build a culture in the society for safety and resilience of sustainable utilization and conservation of farm animal breeds or genetic resources;
- Reduce risks and develop own animal breeds and breeding system.

Policies and Strategies as a Risk in Animal Breeding and Breeding Systems

Breeding Policies

Breed policy plays an essential role in animal breeding as it defines the type of animal to be kept and the sets of required levels of breed, health, nutrition and management. Most countries in Africa have a breeding policy of one kind or another. These of course, vary in their details but tend to centre on the use of indigenous breeds for production and use of the crossbreds between indigenous and exotic breeds varies purposes.

Inclusion of profitable heterosis or complementarity on crossbred genetic evaluation models seems to be important. However, at farm level in Africa, the genotype of crossbred animals kept by producers is likely to include any percentage of foreign genetic material due to *unsystematic breeding practices, unplanned mating schemes, uncontrolled AI services and bull distribution.* There is no controlled breeding in communal grazing areas where exotic bulls are introduced and allowed to indiscriminately mate with local cows. Such schemes have resulted in a complex mixture of genotypes and possibly threats or risks to indigenous Animal Genetic Resources gene pool (IBC, 2004). The superiority of F1 crosses over higher grades of both production and reproduction traits in low input production systems prevalent in the tropics (Rege, 1998). Evidence indicates that some heterotic effect will be lost as a result of such breeding system and lack of policy (Rege, 1998) and recombination losses may appear in *inter se* mating. These are some of the results of lack of appropriate polices in Africa.

If one looks at the Ethiopian condition for example , the major causes risking the diversity of animal genetic resources/ breeds include lack of appropriate breeding policies, poorly designed and managed introduction of exotic genetic materials, natural disasters and civil strife, indiscriminate restocking schemes and weak development interventions (ESAP, 2004 ; Nigatu *et al.,* 2004). The application of AI in indigenous cattle using semen from exotic cattle breeds is, for instance, resulting in unforeseen substitution of indigenous genes by exotic genes (ESAP, 2004; IBC, 2004). Presently there is no clear legal framework or governing policies to regulate crossbreeding or to regulate the importation and distribution of exotic genetic materials (ESAP, 2004). In an increasingly globalised market, the absence of breeding policies and regulations, as well as the absence of gene bank for animal genetic resource conservation, could put indigenous breeds at risk and endanger the future generations of animal in Ethiopia (Desalegn, 2008).

Breeding Programs and Strategies

Sustainable breeding programs and strategies are important for sustainable animal breeding as well as estimating the breeding value of farm animals. A breeding program is the organized structure that is set up in order to realize the desired genetic improvement of the population. Successful genetic improvement requires breeding programs to have (at least) the following components:

- A system to record data on selection candidates. Without data on selection candidates it is impossible to identify the best individuals;

- Methods and tools to estimate the genetic merit (breeding value) of selection candidates. This step is referred to as "breeding value estimation" or "genetic evaluation system";
- A system to select the animals that become parents of the next generation, and mate them to produce the next generation;
- A structure to disseminate the genetic improvement of the breeding program into the production population. In most cases, the breeding population and the production population are (partly) separated. Since the aim is to improve animal production, genetic improvement created in the breeding population should be disseminated into the production population.

Therefore, without designing sustainable breeding polices and systems, animals cannot produce the required products and can be at risk of being out of the system of production.

Recording Systems as Risks in Animal Breeding Systems

Recording systems are the form and process of capturing livestock data, processing it, interpreting and sharing it with, or disseminating to various stakeholders to aid decision making (Mwai, 2007). Record keeping is an essential part of good livestock and farm business management. Recording can be done most easily if animals have some form of identification. Thus, animal recording and identification are inseparable (Solomon Abegaz *et al.,* 2008).

Records are also sets of information required on an animal, for example data on the production systems or conditions under which the captured information was realized (Mwai, 2007). Records are important at many different levels and should serve as the centerpiece of any good management program. The level of record keeping practiced on a certain farm often defines the level of success that the operation can expect to achieve. Records are needed not only for legal, financial and taxation purposes but also for maintaining a permanent record of the farm business, analyzing the business, monitoring day-to-day activities and future planning.

Performance recording is a pre-requisite to effective decision making on breeding program. It should take into account the aggregate effects of the various traits of productive significance and provide a characterization of the environment under which the production is recorded, while no standard system of recording is suitable for all farming conditions.

Convincing smallholders to keep records on the performance of their animals in a situation where animals are not giving them adequate returns is very difficult (Amarasekera, 1998). Not all farmers in Africa have the tradition of keeping farm records. Thus, when the research centers were closed due to political instability, they stopped collecting data on breeding, breeding system, production and productivity. This has generally undermined data analysis and created difficulty in estimating breeding values. Record keeping is not practiced as the owners do not have adequate experience and are not aware of the benefits and given that the majority of animal producers are literate (Sintayehu *et al.,* 2008).

Animal recording is a platform for development and has various forms related to different objectives in respect to the specific local conditions of animal production systems (Amarasekera, 1998). In any new recording scheme, efforts should be made to incorporate, where possible, the existing indigenous systems and institutions to ensure quick adoption and success (Philipson *et al.,* 2006). Effective feedback of information supported with extension services is essential in popularizing the recording systems (Chacko and Kishore, 1998).

The Importance of Record Keeping in Animal Breeding

Setting up of a Breeding Strategy and Successful Genetic improvement

Once a breeding program has started, more record keeping will be needed in order to execute the plan and assess progress. For the flocks from which actual breeding animals are chosen, or in which breeding animals are tested, all the animals should have the appropriate aspects of their performance recorded

(Kosgey, 2004).

Success in genetic improvement to a larger extent depends, among others, on accurate recording of the farm operations and periodic analysis of the data to design future plans and take corrective measures as appropriate (Aynalem *et al.*, 2011). It is only through accurate performance and pedigree recording that the relative genetic worth (breeding values) of each animal can be predicted and knowledge-based selection program can be undertakenthat ensures genetic progress is made in the growth, fitness and milk production. Therefore, if no adequate recording is done, then, no monitoring of herd performance and evaluation of the breeding value is impossible.This leads to risks that undermine indigenous animal.

Selection and Culling

The ultimate goal of a breeding program is genetic improvement of traits defined in the breeding objective for the animal population. The major tool to achieve this is to select the best animals as parents that produce the next generation. Furthermore among these parents to also decide which ones should have the largest number of offspring. Measuring and keeping records of important traits and predicting breeding values without bias is fundamental for a functioning selection program. Therefore, without records, it is impossible to predict breeding values of animals.

Performance records of individual animals are the most reliable tool to use when making selection and culling decisions to improve the genetics of your flock. Faster progress will be achieved if culling decisions are made based on objective information and appropriate records (Awgichew, 2007). Record keeping in modern dairying is a prerequisite for any decisions and control over certain production and reproduction performance of animals in the farm and to measure the profit of any market-oriented farms. Despite this principle, record keeping is not practiced as the owners do not have adequate experience and are not aware of the benefits (Sintayehu *et al.,* 2008).

Some Risks of Inappropriate Record Systems on Animal Breeding in Africa

Effect on Successful Genetic improvement

The absence of coordinated systems for data collection, record keeping and the maintenance of databases for the livestock sector, including a mechanism for feedback and exchange among the stakeholders for development of livestock- related policies have been identified as a major constraint. Such data recording, even on a limited scale, is critical for genetic improvement (Chencha and Kefyalew, 2012)

Biased Selection

Selection accuracy is strongly dependent on the degree of data recording, which requires a range of considerations related to cost and infrastructure. A reasonable selection program should focus on economically important traits / desired genotypes/ identified to meet the goals of the enterprise. To do this, a farmer or pastoralist should select and choose breeding stock based on performance records of traits that can be readily measured and accurately evaluated (Awgichew, 2007). But, no records and no appropriate selection at the farmer or pastoralist level.

Unplanned Cross Breeding and incidence of inbreeding

Due to subsequent uncontrolled breeding at the community herd level, a wide array of blood groups and combinations of different genotypes are now prevalent. AI combined with poor recording at smallholder farms has also contributed to this situation. Similar problems have also appeared with sheep and goat. The modern trend in artificial insemination is to use the tested sires for only relatively short periods of time, after which they are replaced with younger sires, which presumably have made even better records. The uncontrolled use of AI and the widespread crossbreeding activities are definitely lead to the replacement of local stocks through prolonged dilution (Awgichew, 2007).

Effect on the Wise Use of Animal Genetic Resources (AnGRs)

The wise use of AnGRs includes abroad mix of ongoing activities that must be well planned and executed for success and compounded over time, hence with high value. It requires careful definition of breeding objectives, planning, establishment and maintenance of an effective and efficient animal recording and breeding strategies. The absence of livestock breeding policy, strategies and action plans has led to the uncontrolled interbreeding and crossbreeding of a number of species of animals, thus affecting the use, development and conservation of AnGR. This has also an impact on potential cooperation with other countries and international organizations.

Several constraints have been identified that limit the adoption and practice of livestock recording in developing countries (Kosgey *et al.,* 2011). Besides the institutional and policy cum political neglect, there are important technical reasons that explain why livestock recording remains particularly scarce or of low quality.

The key constraints to animal recording in developing countries include:

- Inadequate and unsupportive policies and infrastructure;
- Weak or non-existent organizations and institutions to carry out and support recording systems;
- Lack of appropriate related legal frameworks resulting in inadequate and weak partnerships, networks and collaboration;
- Small and dispersed herds/flocks, leading to high transaction costs;
- Limited capacity and understanding of livestock recording, processing of information and feedback both at farmer level (because of illiteracy) and at institutional level;
- Inadequate resource mobilization and allocation to support pilot activities for livestock recording systems.

High levels of bureaucracy and a lack of transparency in information sharing resulting from politically motivated movement of breeding animals have negatively impacted the adoption of recording. These past experiences and a lack of integration between various services within the livestock sectors operating in developing countries have greatly hindered the adoption of recording by livestock keepers in developing countries (Kosgey *et al.,* 2011)

In summary, with out good record keeping systems, there will be a risk of lacking appropriate information on aids in efficient management of the herd, evaluation of animal breeds for selection, control of inbreeding and aid in breeding planning, in culling low performers, in gross margin analysis, to assess profitability/losses and credit/loan access, to rationalize labour, in disease management and aids in feed planning and management.

Recommended Solutions for Reducing Risks

- Adequate and supportive policies and infrastructure should be provided to carry out and support recording systems. Organizations and supportive institutions should be involved.
- There should effective breeding strategy based records with follow ups of the breeding plan operation.
- Livestock farmers represent the most important stakeholders of identification and recording. These farmers should be trained on the benefits of animal identification for breed improvement and management and be convinced them to adopt the training.

Risks Underlying on the Number of Total Population Rather Than on the effective Population Sizes

In any one generation, effective population size Ne is roughly equivalent to the number of breeding individuals in the population. This is equivalent to a contemporary effective size. Ne is strongly influenced by long-term history. This is equivalent to a species' evolutionary effective size. Historically, epidemics, inter- or crossbreeding, civil conflict and migration of people caused extinction of breeds or strains. Indiscriminate interbreeding or crossbreeding and civil conflicts are the major causes for breeds or strains classified at risk in Africa. Small effective population size is a result of genetic erosion. Small populations are at risk if no measures are taken. The estimation of the effective population size (N) offers the possibility to use one objective indicator for monitoring and planning purposes. Ne is calculated using the number of females (Nf) and males (Nm) used for breeding in a population (Falconer and Mackay, 1996):

$$^{N}e = (^{4N}m\ N)\ ^{/}\ (^{N}m\ ^{+}\ f$$

Example: In some rural areas two flocks of goat populations (510 goats with 10:500 male to female ratio and 110 goats with 10:100 male to female ratios are found. The effective population size of the flock found in the ratio of 10:500 will be 39.2; for 10:100 itwill be 36.4 and for the whole goat population (510 +110 or 20: 600) 77.42 animals will be effective to produce the next generation. This means that from the total of 620 goats, only 77.42 of the will produce their next generation in the coming years and the remaining 542.58 will not be able to produce their offspring due its unbalanced sex ratio.

The rate of inbreeding increases as effective population size decreases. An effective population size of less than 50 animal for a given strain or breed, leads to high inbreeding coefficients (F>1%) per generation and results in decreasing reproductive and productive performance. Such populations are vulnerable to sudden or persisting environmental threats/ risks. Comprehensive breeding programmes or simple action plans for the genetic improvement of local populations avoiding genetic erosion are absent in most African countries.

Risks Arising from inappropriate Conservation Strategy / System

Conservation of local breeds of farm animal genetic resource is part of animal husbandry and should be based on complete information on distribution, structures, trends, productive and adaptive performances of populations of the existing breeds. Although much information is lacking, conservation of farm Animal Genetic Resources (AnGR) in the Ethiopian perspective for example should be viewed from the rational utilization and protection of existing genotypes from genetic erosion (IBC, 2004). Unfortunately, no conservation activities of farm AnGR have so far been practiced in the country, except for limited activities that are meant to maintain pure stocks of three cattle and one sheep breeds. Conservation measures for threatened breeds have already been established in some countries (FAO, 2007a) and are a priority of the global plan of action for animal genetic resources (FAO, 2007b). Loss of animals as a result of droughts and floods, or disease epidemics related to climate change may thus increase (FAO, 2008). If breeds are geographically isolated (endemic) - as is the case for some local and rare breeds — there is a risk of their being lost in localized disasters. Most conservation programs are based in developed countries with strong collaboration between gene banks and the animal breeding industry.

Farmers with economically competitive breeds or genetic types should take care of their own preservation. The economic and environmental conditions are changing and genetic types which are superior under one set of conditions may be inferior under a different set of conditions. As the changes are gradual and different breeds or types are not generally compared under exactly the same conditions, the individual breeder usually has no interest inconserving, for future use, animals which the farmer/s, at any given time, considers slightly inferior to those selected for breeding. Risks of animal breeding due to loss of genetic diversity or due to lack of appropriate conservation strategies among populations occurs due to high rate of gene flow from other populations/ breeding processes (Tesfaye, 2004), genetic introgression (Kidd *et al.*, 2009), inbreeding (Fredrickson *et al.*, 2007) and climate change (Boko *et al.*, 2007).

Recommended Solution for Avoiding Risks of Conservation

In situ conservation of livestock breeds is primarily the active breeding of animal populations and their continued use as part of an ongoing livelihood strategy (Solomon *et al.,* 2008). Village-based breed improvement programs are complementary to in-situ livestock conservation objectives. There are more feasible conservation methods at hand under the current circumstances including in vivo conservation. In vivo conservation includes in situ and ex situ methods. Ex situ in vivo conservation is the maintenance of pure-bred nucleus flocks in organised government farms or research farms which can form a repository of the pure breed. A conservation-based breeding program should be based on broader breeding objectives that incorporate the needs and perceptions of the community and maintenance of the genetic diversity such as adaptation traits. Involvement of the farmers in the design and implementation of the breeding program in line with the principles of in situ conservation of genetic resources is one of the options which must be practised.

Risks Caused by Breeding Processes

Genetic introgression

In both domestic and wild animals, genetic introgression between invasive organisms with exotic germplasm and local populations would enhance genetic homogenization, leading to the disintegration of genetic diversity generated by divergent adaptation to heterogeneous habitats (Randi, 2008). Hybridization among local, wild and invasive populations together with habitat degradation and loss of ecological structure as well as unsustainable selective pressures for adaptation to global climate changes, over exploitation and loss of community structure are major hazards to conservation of animal genetic resources (Allendorf *et al.,* 2001; Randi, 2008). Though it is important for farm animals up to some generation, the consequences of genetic introgressions of domestic and exotic germplasm are extensive and includes reduced survival and fitness of even the F1 and F2 generations, (McGinnity *et al.,* 2003). Therefore the genetic introgression between exotic and indigenous animal breeds, not only reduces and fitness of even the F1 and F2 generations but also decrease the productive and reproductive performances ; unless genotype and environmental interactions effects are considered.

inbreeding

Loss of genetic diversity and an increase in inbreeding rates are also critical genetic issues to be considered in animal genetic resources (Ballou and Lacy, 1995). Inbreeding and loss of genetic variation are inevitable consequences of small population sizes (Frankham *et al.,* 2002). The extent to which a population becomes inbred or loses genetic diversity over time depends on a number of factors. These, include immigration, effective population size, generation length, and selection intensity (Jamieson *et al.,* 2006). Small populations face inbreeding, genetic drift (pronounced effects of random genetic drift that lead to erratic fluctuations in allele frequencies) and high susceptibility to catastrophes, diseases and environmental stochasticity (Frankham *et al.,* 2004). Fredrickson *et al.* (2007) disclosed that inbreeding reduces fitness and increases the risk of population extinction. Significant impacts of inbreeding depression on extinction risk in populations with carrying capacities of up to two thousand individuals have been noted (O'Grady *et al.,* 2006). Increased inbreeding rates also have a strong and significant effect on overall population growth rate of small and isolated populations and are associated with inbreeding depression. Moreover, an increased rate of inbreeding also means an increased risk of loss of genetic diversity (Meuwissen, 1991), and a reduced additive genetic variance is expected (Falconer and Mackay, 1996). Small population size animals and the primary factors contributing to extinction are habitat loss, introduced species, overexploitation and pollution. These factors are caused by humans, and related to human population growth (Frankham *et al.,* 2002).

The consequence of the inbreeding process is the reduction in the genetic variability within a population and in performance mainly in traits of animals that are associated with the fitness of an individual. Animals with high inbreeding rates have higher contribution to over all inbreeding of all the populations and hence inbreeding depression (Marshal *et al.,* 2002). Inbreeding allows the rare, harmful recessive alleles to become expressed in the homozygous form, with resulting harmful effects on the offspring such as reduction in fertility, fecundity, offspring size, growth and survival, and physical deformities. Inbreeding can potentially reduce population growth rates and increase extinction. In Ethiopia, due to lack of grazing lands, the indigenous animals are kept together and interbreed themselves with harmful effects on the offspring. The productivity and reproductive performances of the animals are decreasing from time to time. All these lead the farmers to abandon the local animal genetic resources and to shift to exotic germplam, which again reduce their performances especially after third generations.

Crossbreeding

Crossbreeding may increase overall genetic diversity as it introduces new genes in the population and new genotypes (e.g. synthetic breeds). However, the major threat to the adapted indigenous breeds in Africa is indiscriminate or irrational crossbreeding. Crossbreeding can be considered as "a necessary evil" as it delivers the much desired fast growth in livestock productivity and at the same time threatens the indigenous breeds through breed replacement (Solomon *et al.,* 2008).

Rege and Gibson (2003) suggest that, the use of exotic germplasm, changes in production systems, producer preference because of socio-economic factors, and a range of disasters (drought, famine, disease epidemics, civil strife/war), may be the major causes of genetic erosion. Tisdell (2003) suggests that the major causes for threats of animal populations are development interventions, specialization (emphasis on a single productive trait), genetic introgression, the development of technology and biotechnology, political instability and natural disasters. For at-risk animal breeds in Africa, Rege and Gibson (2003) list as major causes the replacement by other breeds, crossbreeding with exotic breeds or with other indigenous breeds, conflict, loss of habitat, disease, neglect and lack of sustained breeding programs among the threats.

Risks Caused by Climate Change

Challenges such as climate change underline the importance of retaining a diverse portfolio of animal breeds (FAO, 2007b). Animal production both contributes to and is affected by climate change (Hoffmann, 2010). There are evidences that animal breed and environmental trade-offs are currently substantial and that these will increase significantly in the future as a result of the increased demand for animal products from the growing population. Some of the most important impacts are those associated with land use change for feed production both for ruminants and monogastrics, which have significant simultaneous impacts on a range of environmental dimensions (land use, emission of gases, water cycles, nutrient balances, biodiversity) (FAO, 2007b). Moreover, livestock mitigation measures could include technical and management options to reduce emissions from livestock as well as the integration of livestock into broader environmental service approaches.

Adapting to global climate change is likely to present a serious challenge to many livestock producers / breeds over the coming decades. The pastoral systems of the world's dry lands are among the most vulnerable, with climate change taking place against the background of natural environments that are already experiencing resource degradation. In general, climate change is likely to present significant problems for production systems where resource endowments are poorest and where the ability of livestock keepers to respond and adapt is most limited (FAO, 2007b). Climate change is adding to the considerable development challenges and this will require more efficient production and breeding systems, careful husbandry of natural resources and measures to reduce waste and environmental pollution (FAO, 2008). Climate change impacts such as rising temperatures and declining rainfall in combination with other stresses could result in the shifting of ecological zones, loss of flora and fauna and an overall reduction in ecological productivity (Boko *et al.*, 2007). There is compelling evidence that in response to on-going changes in regional climates, species are already shifting their ranges (animals in the low agro-ecology are shifting to mid and high altitude agro-ecology (Thomas *et al.*, 2006) and changes in population dynamics (Forsman and Monkkonen, 2003). Other evidences are fluctuation in population growth rates (Grosbois *et al.*, 2008) altered ecosystem functioning (Hays *et al.*, 2005) and that some species are facing extinction, or have become extinct (Foden *et al.*, 2007).

In addition to the physiological effects of higher temperatures on individual animal breeds, the consequences of climate change are likely to include increased risk that geographically restricted rare animal breed populations will be badly affected by disturbances (Hoffmann, 2010). The IPCC (2007), predicts that by 2100 the increase in global average surface temperature may be between 1.8 and 4.0 °C. With global average temperature increases of only 1.5 — 2.5 °C degrees, approximately 20-30 percent of plant and animal species are expected to be at risk of extinction (FAO, 2007b).

Climate Change Effects on Animal Breed and Breeding System in Africa

Africa is characterized by widely diverse climates from desert to forest over comparatively small areas. African countries contribute less in global warming but highly affected. This is because the effects of climate change on livestock production and health are additional significant burden to the already existing problems that hold back livestock and its breed development in Africa. Significantly, the climate variability may have serious effect on African pastoralists whose livelihood depends upon livestock for food, economic security and cultural preservation. The impact of climate change may also increase the problem of water scarcity; pasture land shortage and diseases dynamics. Animal diseases may lead to severe effects on breed survival, profitability marketability, animal health and livelihoods. The rainfall experienced across Africa is highly variable ranging from about 100 mm/year in north-eastern Ethiopia to about 2500 mm/yr in parts of northern Tanzania, with an average annual precipitation of 920 mm/year.

Direct Risks

The direct effect of climate change on animal breeding resulted in the increased ambient temperature and concurrent changes in heat exchanges which causes heat stress that influences growth, reproduction performance, milk production, wool production, animal health and welfare. Heat distress suffered by animal breed reduce feed intake and result in poor growth performance, indigenous animal are heat tolerant animals to the higher temperature. However, extremely higher temperature caused by extremely weather events experienced in this era may affect *B. indicus* or indigenous animal breeds resulting in reduced milk and meat production and reduced time for foraging as they prefer to remain in the shade. The presence of extremes weather events such as drought and floods will create risks on animal breeds and breeding system, and this have been experienced in East Africa, e.g. ENSO in 1997.

indirect Risks

The impact of climate change on the transmission and geographical distribution of animal diseases shows that this has been associated with changes in the replication rate, dissemination of pathogens, vector and animal host populations, which vary with temperature and rainfall. For example, Rift Valley Fever is a viral disease transmitted by mosquitoes that mainly affect livestock and humans. The virus survives in the *Aedes* mosquito eggs during the dry period. During the flood seasons, the virus is transmitted by *Culex*, *Mansonia* and *Anopheles* species.

Solutions for Risks Associated with Climate Change

Animal keepers should be made more aware of climate change and variability so that surveillance systems can be established or improved and the capacity of the system to deal with such changes enhanced.

The development and establishment of coping strategies is a continuous process and need to be improved. However, this remains a big challenge and need to be well addressed by all stakeholders for their valuable contribution. Models have been used that clarify, qualify and quantify the future effects assist in scientific uncertainties and help to focus on research work. Study in climate change on animal health in specific breeds should consider other confounding factors in modelling and such integrated models will be far much useful for decision making policy. The evidence for the relationship between climate change and animal health depends largely on the context, and varies between different livestock production systems.Therefore these models must base on data relevant to the livestock population so that information generated can be applied in other areas with similar climatic conditions and livestock production systems.

Indeed a better understanding of the effect of climate change on animal health, production and breeding is crucial to lessening negative impacts. Unfortunately, the determinants of resilience and adaptation that already reduce this impact are often poorly understood even though are not unique but are needed regardless. For example, adaptive capacity could be increased in the broader context of developing appropriate policy measures and institutional support to help the East African livestock owners to cope with all animal health and breeding problems. In fact, the development of an effective and sustainable animal health service with respective breed , with associated surveillance and emergency preparedness systems and sustainable animal disease control and prevention programmes (e.g. vaccination campaigns against Rift Valley Fever, African Horse Sickness and blue tongue), is perhaps the most important and most needed adaptive strategy. This safeguards livestock populations from the threats of climate change and climate variability.

Risks from Low Reproductive Performance of indigenous Cattle

Domestication and the use of conventional livestock breeding techniques have been largely responsible for the increases in yield of livestock products. Because, the productive and reproductive potentials of Zebu cattle are relatively low, crossbreeding with *B. taurus,* which combines additive, dominance and epistatic effects of the two genotypes, ensures high productive and reproductive performance.

In many cases, reproductive efficiency of animal breed has been measured mainly by considering parameters such as age at first service, age at first calving, days open, calving interval and number of services per conception. Reproductive efficiency of dairy cows for example is influenced by different factors including genetics, season, age, production system, nutrition, management, environment and disease (Shiferaw *et al.,* 2003). Study report indicated the superiority of F1 crosses over higher grades of both production and reproduction traits in low input production systems prevalent in the tropics (Rege, 1998).

Reproductive Performance of the Crossbreds

The productive and reproductive traits in animals are influenced by several genetic and environmental factors. Therefore, any breed development programme would be based on the exploitation of the genetic variation. It is the age at which the breeds attain body weight, body condition and sexual maturity for accepting service for the first time. It influences both the productive and reproductive life of the female through its effect on her lifetime calf crop.

First calving age marks the beginning of cow's reproductive cycle. It is closely related to generation interval and, therefore, influences response to selection. The average age at first calving in *Bos indicus* cattle is about 44 months, compared with about 34 months in *Bos taurus* and *Bos indicus* x *Bos taurus* crosses in the tropics (Mukasa-Mugerwa, 1989). Different type of genotype was the cause to the variation of age at first calving for crossbred heifers. The average month of age at first calving for 50% Friesian 50% Arsi (47.7 months) was the longest and 50% Jersey 50%Arsi (29.2 months) was the shortest estimated. Genetics and management factors especially nutrition determines pre-pubertal growth rates, reproductive development, onset of puberty and subsequent fertility (Shiferaw *et al.,* 2003).

Comparative Reproductive Performances of indigenous Cattle

Indigenous breeds of livestock and poultry have shown exceptional survivability in different regions of world, where newly developed breeds have perished, because most of the indigenous livestock population possess valuable traits such as disease resistance, high fertility, good maternal quality, longevity and possess unique ability to utilize poor quality feed and adoptability in hazer and difficult climate. These diverse animal genetic resources have been and shall be the future base for animal production for surviving humanity since new genes cannot be made but only can be sorted out from the diverse genetic base of the existing population.

These rare breeds often possess traits of special significance to local people and economics and their way of life; make their conservation vital. The majority of African farm animals are indigenous breeds, most of are which resulting from extensive interbreeding. The contribution of this huge resource to the national income and export earning is disproportionately small, owing to low productivity caused by poor husbandry and management systems prevalence of disease and malnutrition and poor genetic potential.

Ethiopian indigenous cattle breeds for example are most of which are non-descript zebu types resulting from extensive interbreeding, with some sanga types existing in the eastern and north-eastern parts of the country. Characterization of some of the well- known indigenous cattle breeds are Abigar, Danakil, Arsi, Arab, Barka, Borana, Abyssinian, Zebu, Arado, Fogera, Horro and Sheko to be the main distinguishable cattle breeds. But theses breeds are highly vulnerable and are in the state of replacement by exotic blood through crossbreeding

The age at first service of local breed cattle in Ethiopia are reviewed presented in Table 8.1. Horro breeds breed heifers (55 months) have the longest AFS, whereas, Ethiopian boran breed heifers (32.4 months) have the shortest AFS from other Ethiopian Zebu breeds. Finding in central highlands and in Addis Ababa milk shed area, the overall means for age at first service was found to be 29.6 months (Yoseph *et al.,* 2003) and 20.1 months (Yoseph, 1999), respectively. Heifers maturing at younger ages are better milk producers and have lower rearing costs (Ruiz-Sanchez *et al.,* 2007). Moreover, irregularities in feed supply and differences in management systems may bring about variations in AFS in different areas.

Estimated age at first calving for indigenous cattle of Ethiopia are ranged from 35-62 months (Ababu, 2002). The longest and shortest age at first calving estimate was Barka and Begait (60 months) and Arsi (32.8 months) breed, respectively. Horro breed (54.15 months) has also relatively taken longer periods to attain

AFC. Average calving interval in tropical breed of cattle varied between 11.13 and 24.33 months. Estimates of calving interval in zebu cattle ranged from 12.2 to 26.6 months (Mukasa-Mugerwa, 1989). The mean calving interval of Metema highland zebu have longer than other local breeds reviewed while Arsi breeds have shorter calving interval with mean estimates of 19.2 months and 14.6 months, respectively. Calving intervals of 12 to 13.5 months are considered as standard value.

The estimated numbers of service per conception for temperate breed cattle were ranged from 1.3 to 1.6 services. Boran breeds required high number of service per conception compare to other local breed type, whereas Barka breeds required low number of service per conception. Days open for some local cows were summarized in Table 8.1. The longest period was estimated for Fogera breed (255.25 months) and the shortest was for Boran breed (170.5 months).

Table 8.1: Reproductive performance (months) of local cattle breeds of Ethiopia for some traits

	* AFS	* AFC	*ci	*NSc	*DO
Fogera breeds	45.1	50.6	18.05	1.47	255.25
Arsi breeds	32.8	32.8	14.6	2	211
Horro breeds	55	54.15	15.8	1.69	152.95
Boran breeds	32.4	44.05	15.82	2.1	170.5
Ogaden breeds	34.4	50.33	16.4	2	195
Begait	53	60	15.26	1.8	210
Barka	34	60	15.3	1.11	253
Metema highland zebu	40.6	46.1	19.2	1.74	204.18

Source : Kefyalew and Checha, 2014 (unpublished review report)

*AFS: age at first service; *AFC: age at first calving; *CI: Calving Interval; *NSC: number of services per conception; *DO : days open

Comparative Reproductive Performance Between Cross and Indigenous Cattle Breeds

Estimates for Age at First Service (AFS) in Ethiopian cattle were reported to be longer for Zebu (Mukasa-Mugerwa, 1989), than for crossbreds (Mekonnen and Goshu, 1996). An earlier age at puberty is observed for F1 Friesian crosses than for indigenous zebu breeds. Different factors advance or delay AFS. Genetics, environmental factors, especially nutrition, determine pre-pubertal growth rates, reproductive organ development, and onset of puberty and subsequent fertility. Substantial evidence exists that shows dietary supplementation of heifers during their growth will reduce the interval from birth to first service, probably because heifers that grow faster cycle earlier express earlier estrus.

The reproductive performance of Zebu, Friesian and their crosses show that the number of services required per conception tends to decrease with increasing Friesian inheritance among dam breeds. Hence, the highest NSC was required for Fogera cows and the lowest for % percent Friesian cows (Mekonnen and Goshu, 1996). Cows sired by local bulls required fewer services while with increasing level of Friesian inheritance, the number tends to increase. Management factors strongly influence NSC. Detection of estrus in Zebu and their crosses is difficult, mainly because of the short duration and the lower intensity of behavioral estrus manifestation. The quality of semen, semen handling, insemination techniques and skills in pregnancy diagnosis affect NSC.

During periods of adequate nutrition, fertility rates were satisfactory even for Zebu cows. According to (Azage, 1989) when there was good rain, pregnancy rates in Boran cows ranged from 80 to 94% in four breeding units. In general, low fertility rates of cattle in the tropics compared to temperate regions are probably related to environmental differences including inadequate nutrition, disease and parasite management as well as due to genetic interactions with these environmental factors (Mukassa-Mugerwa, 1989) (Table 8.2).

Table 8.2. Reproductive performance (months) of crossbred genotypes

Crossbred genotypes	AFS	AFC	ci	NSC	DO
50% HF x Arsi	17.5	47.7	31	20	82.9
50% HF x Boran	13.8	32.5	26.7	1.72	127
50% HF x Barka	12.9	34	25.4	1.4	87
50% HF x Fogera	18.3	40.46	36.8	1.54	151
75% Fresian 25% Zebu	15.3	33.6	23.1	1.29	150
62.5% HF x 37.5% Boran	14.87	41	28	2.7	135
75% HF x 25 % Boran	14.77	40	28	2.2	142
87.5% HF x 12.5% Boran	14.1	39	28	2.1	134

Source: Kefyalew and Checha, 2014 (unpublished review work)

*AFS: age at first service; *AFC: age at first calving; *CI: Calving Interval; *NSC: number of services per conception; *DO : days open

Risks: the indigenous animal breeds are now replaced by exotic and their crosses due to low reproductive performances and the crossbreed animals show reduction in performances after 3rd generation and show low performances than the indigenous breeds.

Risks in the Management of Animal Breeds and Breeding System at Refugee Camps in Africa

Africa (in spite of its huge livestock resource) produces the lowest animal protein from livestock farming. Livestock production systems in Ethiopia for example are generally subsistence oriented and productivity is very low, 8 kg of beef is produced annually per head of cattle compared to 10.7 kg in the Sudan, 14 kg in Kenya, 51 kg in Australia and Argentina and 79 kg in the USA (FAO, 2008). Livestock play a crucial part in people's livelihoods throughout the world and when humanitarian emergencies arise, rapid assistance is needed to protect and rebuild the livestock assets of affected communities (LEGS, 2009).

During recent decades, many of the events that provoked refugee migrations took place in semi-arid and arid areas. Most of the refugees who fled from Afghanistan, Eritrea, Ethiopia, Mali, Niger, Rwanda, Somalia, Sudan and other countries belonged to pastoral groups whose household economy was traditionally based totally or predominantly on mobile animal production, of different breeds and whose cultural and social values centred on sheep, goats, cattle (UNHCR—IUCN, 2005). Temporary shelters are amongst the most common measures employed in disasters to protect the lives of migrants and their assets. The wise management of animals and their respective breeds—whether as an individual draught animal, a household flock of poultry or a larger herd of grazing animals — would therefore seem to be an appropriate and systematic step to take in terms of generating or maintaining livelihood security in all refugee and returnee operations. In many of the relief operations which grew around these situations, a strong interdependence emerged between these displaced populations and the livestock they kept — to the extent that the latter have on occasion turned out to be the coping strategy most favoured by refugees, at the individual and family levels in particular. Livestock/animals are often also a fundamental consideration in repatriation programmes, many of which may involve the provision of livestock as draught or breeding animals, as sources of potential cash income, or as a more direct means of survival.

Although, the importance of livestock in food security and disaster coping is understood and acknowledged by experts and animal welfare organizations, livestock-keeping in many refugee camps faces implementation problems both from the host country and the humanitarian organizations. An evaluation report by Action against Hunger (AAH, 2007) revealed that a large proportion of people in the country in the refuge camps owned livestock, but that disease was a major cause for livestock loss as animals were managed in very close quarters. An assessment by FAO in IDP (internally displaced People) camps in Darfur in 2004 reported that 75% of donkeys in the IDP camps died during the pre- rains season from a lack of feed and water, and from stress. In human migrant environments (especially in pastoralist communities) the number of animals requiring attention can be significant and yet management is neither effectively delivered nor integrated in the existing human shelters (refugee camps).

At present there appear to be no best practices in managing livestock in human shelters (refugee camps). Therefore, investigating the scale and type of problems occurring with animal breeding and breeding system in human shelters (refuge camps) and matching available practical solutions from other areas of animal management, breeding and veterinary sciences would mean a significant improvement in the tools that humanitarian agencies have available for the care of livestock in camps.

Problems encountered in Animal Breed Management in Shelters

Animal production and particularly animal breeding can play an integral part in the welfare of many families and communities in the refuge camps. While the basic characteristics of keeping and caring for animals should not vary much between a stable community and people living in a refugee or returnee context, what can be expected to differ is the conditions that allow, or prevent, the keeping of livestock, especially larger animals. Space allocation alone will determine if any animal breed can be maintained around a homestead. The availability of forage and water too will determine what, if any, form of livestock- keeping might be practised. Added to this, however, may be local restrictions on keeping livestock, perhaps for a range of reasons such as a fear of disease outbreaks, or cultural taboos and loss of the breed is inevitable. The presence of additional livestock may also lead to excessive use of forage sprouting after the rains, thus reducing the availability of dry season forage for local community use. Additional concentrations of livestock also require more water and local sites of high biological diversity can be put under pressure if herd sizes suddenly increase. Some of the possible impacts/risks or challenges of keeping different animal breeds in the refuges include:

- **Depletion of water resources:** in refugee settlements, water resources are often limited. Without timely and strict control, the presence of large animal herds can contribute to the depletion and pollution of these resources;
- **Disruption of traditional livestock production patterns:** in most parts of Africa and Asia, people have developed well adapted patterns of land-use. In situations where people migrate with their livestock to other countries, continuation of this type of production becomes unviable. The consequent loss of herds implies a strong psychological dilemma for refugees who lose possibly the only economic base they are familiar with and, perhaps more seriously, the focus of their family life and culture;
- **Competition for rangelands:** refugee livestock compete with local herds for limited resources. With an increased overall density of grazing animals the production of local herds may decline and indigenous breeds can be exposed to feed shortage and starvation;
- **Conflicts with local population:** competition for rangeland and the destruction of crops is a relatively frequent reason for conflicts between refugees and the local population. If land tenure and grazing rights are violated, traditional grazing systems will be affected and imbalanced and again the local breeds can be exposed to different problems;
- **Impacts on Public Health:** uncontrolled watering of animals' bears the risk of transmission of diseases from animals to animals and from animals to humans, through water pollution with animal faeces. If veterinary drugs are provided to refugees, control over their application has to be ensured. Many drugs used for prophylactic and clinical treatment of livestock may have negative impacts on the health of humans. For example: externally applied solutions of acaricides (drugs used to eliminate external parasites) may contaminate the soil, food and food storage containers; and most drugs are stored in the body tissue of the animals treated (i.e. in the fat and meat), and are partly excreted with the animal's milk. People consuming the meat or milk of treated animals within a certain period of time after application — which is specific for each drug — also ingest a small amount of these drugs, which can produce unwanted and potentially serious side-effects. In refugee settlements, the transmission of zoonotic diseases from animals to humans is nurtured by the closeness of animals and humans. Malnourishment, stress and diseases that weaken the human immune system aggravate the impact of zoonoses. At the same time, a number of other diseases — some of which can reach epidemic proportions if not controlled in time — are transmitted directly from animal to animal or via a separate vector such as ticks or biting flies. Increased prevalence of livestock diseases: - The spread of diseases from one animal to another with the same or different breeds is one of the main risks when livestock from different areas mix. Animals brought in from other regions tend to have hardly any resistance to local diseases, if not vaccinated. Diseases may be of an epidemic nature, or may be vector or soil borne.

Animal Movement Among Refugees and its Associated Risk

Food assistance, remittances, petty-trading and animal husbandry are the main sources of the livelihoods in the refugee camps. Sudan refugees or their ancestors were pastoralists and agro-pastoralists. The pastoralists depend primarily on livestock or livestock products for income and food, while the agro-pastoralists derive their income from both livestock and non-livestock sources. For example, the Ethiopian government does not have regulations that protect the entrance of animals with refugees. Following culture of their ancestors and their experiences, some Sudanese refugees have brought their animals. Even though the animal population size entering with the refugees are not known, in all the visited camps the refugees have managed different kinds of animals around the refugee camps. Some have brought them from their origin of country and others restocked it in the host country, Ethiopia. The main livestock species found in the refugee camps were cattle, goats, sheep and dogs. There is interest also in gardening and poultry rising in refugee camps. Although, there are no accurate data on the number they owned in the camp, almost all refugee households in Sherkole refugee camp have some goats, sheep, and chickens (ducks).

Animal Management Problems in Refugee Camps

There are unsafe conditions of animal management in and around refugee camps both to the refugees and the host community in Ethiopian refuge camps. Animal veterinary experts in most of the refuges have expressed their discontent that the animals are entering to Ethiopia without quarantine service at the border. The animals are causing a new drug resistant disease for the host communities' cattle. It is reported that approximately 2000 individuals, along with an estimated 8000 livestock are living amongst the local community in a refuge (UNHCR, 2012) that may have a disastrous effect for host community as well as the refugee livestock. There is no a separate animal veterinary service program for the refugee camps.

The refuges on the other hand express the problem of animal management services such as lack of drugs and grazing areas. The UNHCR (2012) report indicated that many of the refugees opted out of the relocation because of a lack of grazing land in Bambasi of Ethiopia. Some livestock owners confirmed they are using indigenous (herbal) medicines and sometimes buy drugs from drug shops and strongly expressed the importance of regular vaccination and animal service program for their livestock.

Regarding the issues of animal management in the refuges, the veterinary experts forwarded the following recommendations to protect animal breeds from disaster:

- To protect trans-boundary and zoonotic diseases, animals should be quarantined and inspected at the entrance point before entering into the host country;
- Animals should get veterinary services after entering into the hosting country even not affect animal breeds of the hosting countries;
- So as to produce and reproduce animals sufficiently, animal management system of the refugee camps should be supported by animal production and breeding experts;
- Since the refuges are using the regional agricultural budget, e.g. of the Ethiopian government, vaccinations and other animal management issues should be handled by the budget of refugee affairs;
- There must be a control mechanism for protection from diseases of animal entering into the country and genetic resources going out of the country during repatriation;
- It is not only animal disease but admixture of genes from Sudanese breed with Ethiopia animal breed is common and are living in the same refuge camp and grazing together. The refugees stressed that there is no any organization responsible for the management of domestic animals in the refugee camps.

Avoiding risks, the refuge communities have requested the following conditions to be fulfilled:

- Grating lands and intensive professional management for their animals;
- They need animal feeds with integrated forage production, so as to manage their animals intensively;
- The shelter for animals should be in a place specially for winter periods (rainy seasons);
- They need to have their own veterinary and artificial insemination services at the refugee camps.

Therefore, the domestic animal genetic resources of Ethiopia are in question because they are mixed with the Sudanese animals. Therefore:

- There must be domestic animal management unit for the refugee camps;
- There must be quarantine and health inspection services at the border before animals entering into the hosting community.

In general a fundamental concern relating to livestock keeping and animal husbandry is the impact that these animals have on the environment and related social and economic issues for both the host and the refugee community. A decision on whether to allow livestock in or around refugee settlements has to be made by weighing positive and negative effectsby taking into consideration certain rules and regulations. Such decision can be used to develop effective anima management guidelines in and around refugee camps.

There is also a concern among humanitarian organizations for animal management in the refugee camps to include in emergency contingency plans and intervention activities. However, the livestock emergency response intervention such as health, feed, water, shelter, breeding mechanisms like Artificial Insemination and other conditions of animal management is not practiced and documented. As a result, the animals coming with refugees or restocked in the host country are facing many challenges. The critical problems encountered animal in the refuges was infectious disease control of animals. To be effective, emergency responses for refugee camps should include livestock interventions and must involve new partnerships between humanitarian organizations and animal welfare organisations.

Refugee camps are administered by Sphere Handbook — the Humanitarian Charter and Minimum Standards in Disaster Response, the UNHCR, standards and the host country's disaster risk management policies. In line with the humanitarian response guidelines, different animal management policies, guidelines and standards are produced internationally. Such policies and guidelines include policy and guidelines of the World Society for Protection of Animals (WSPA), Livestock Emergency Guidelines (LEGS), Livestock-Keeping and Animal Husbandry in Refugee and Returnee Situations (UNHCR/IUCN) and UNHCR Environmental Guideline Livestock in Refugee Situations. For example, LEGS provides guidance on identification of appropriate livestock responses with standards, key indicators, guidance notes and decision-making tools. The guideline also presents detailed information on various intervention possibilities, including restocking, destocking, veterinary services, the provision of feed and water and arrangement of livestock shelter.

However, these guidelines are not practiced in the study refugee camps, to the extent that the guidelines are not well known by the government and the humanitarian actors. Developing animal management policies and guidelines is not an ultimate goal. The objectives of the policies and guidelines should be known by donors, humanitarian organizations, animal risk reduction managers, technical experts, refugee stakeholders and the beneficiary community itself.

Currently, Ethiopia does not have policies and regulations that forbid the entrance of animals with refugees. Though, the number of animals entering to Ethiopia is not known, large numbers of livestock are reportedly gathering in Adamazin transit center, which have no areas for grazing and are thus, living around the camp. This poses a great hygiene and sanitation risk, particularly for the refugees themselves. Because of the absence of well organized quarantine at the border, different livestock diseases such as sheep-pox have been simply transferred to the host livestock population, as reported by the experts.

To bring to a close, refugee management and administration is mostly uncertain and unpredictable event. Ethiopia with its partners are using a preparedness contingency refugee management plan in anticipating the influx of refugees from conflict stricken neighbouring countries. There is therefore; a conducive environment to integrate animal management programs and activities with the contingency plan with humanitarian emergency response programs. Following these facts, animal welfare guidelines and standards could be pilot-tested in Ethiopia, just to show how the different animal risk reduction and management guidelines and standards can be practiced on the ground.

Case Studies

The chapter includes three Case Studies (Box 8.1-8.3) from two African countries (Ethiopia and the Republic of Mauritius, as tools for readers to see the realistic situations of how the farm animals, in particular the indigenous, the exotic and their crosses has responded to the challenges of animal management and gene segregation can create impacts on productivity of production these breeds.

The case studies aim at enhancing and equipping readers with the ability to balance theory with practice, to study the various perspectives of animal breeding on the African continent, and to be able to adapt easily to real work situations in their country.

The case studies do not aim to provide perfect solutions to the reader, but rather to put them in the problem-solving situation and decision making ability either as farmer, entrepreneur, research scientist or policy-maker. It allows raising questions and key issues, and working through the problem and finding his /her solution and enabling strategy to meet the challenges.

Box 8.1: Comparative study on Productive and Reproductive Performances of Crossbred and Local Cows in Ethiopia

Introduction

Increased genetic diversity in African cattle is believed to be a result of high levels of genetic introgression of *B. indicus* and *B. taurus.* According to Zerabruk *et al.* (2012), North Ethiopian cattle for example, are highly introgressed by the Zebu cattle from Indian zebu, and African, European and the Near-Eastern taurine ancestry.Estimates for Age at First Service (AFS) in Ethiopian cattle were reported to be longer for Zebu (Mukasa-Mugerwa, 1989) than for crossbreds (Mekonnen and Goshu, 1996). An earlier age at puberty is observed for F1 Friesian crosses than for indigenous zebu breeds. Different factors advance or delay AFS. Substantial evidence exists that dietary supplementation and the breed of heifers will reduce the interval from birth to first service (Azage, 1989). During periods of adequate nutrition and good breed selection, fertility rates were satisfactory even for Zebu cows. According to (Azage, 1989) when there was good rain, pregnancy rates in Boran cows ranged from 80 to 94% in four breeding units.

Objectives of this Case Study are:

- To help the readers to analyze the possible causes of reducing the performances of crossbred cattle as the blood level increases;
- To aware the readers to invent critically the causes of the risks of extinction of indigenous cattle through cross breeding.

Overview / Analyses

Comparative assessment on indigenous and crossbred cattle was conducted related to productive and reproductive performances in Ethiopia. Estimated for Age at First Calving (AFC) in Ethiopian cattle is found to be longer (35-62 months) than for crossbreds (29-42 months) (Mekonnen and Goshu, 1996). However, (Asimwe and Kifaro, 2007) in Tanzania reported that age at first calving increases with the level of exotic blood level. The F1 Arsi crosses heifers (F1 Arsi x Jersey and F1 Arsi xFriesian), had attain AFC significantly earlier than indigenous Arsi heifers but increases as the blood level increases (Negussie *et al.,* 1998). The apparent superiority of F1 crosses over indigenous heifers could be due to heterosis exhibited by the F1 crosses and the additive genetic effect from the exotic blood for faster growth rates at early ages (Negussie *et al.,* 1998). On the other hand, crosses with 75% Friesian and Jersey inheritances had age at first calving of 38.52 and 39.72 months, respectively. However the second generation of Friesian and Jersey crosses had long AFC of 49.80 and 48.24 months, respectively (Kefena, 2004).

Status Report

- There is a decrease in milk yield of high grade (3/4 Holstein Friesian and above) compared with the F1 crosses (Million and Tadelle, 2003). The superiority of F1 crosses over higher grades of both production and reproduction traits in low input production systems prevalent in the tropics (Rege, 1998).
- Study conducted in Amhara region, Ethiopia indicated that there is no significance differences the milk yield for 75 % exotic and 25 % indigenous crosses (6.27 ± 2.7 liter of milk/day) and 50% exotic and 50% indigenous cattle, which is 6.9 ± 2.5) litter of milk per day (Kefyalew and Getnet (2013), unpublished).

Case Problem

Many of the world's indigenous livestock breeds are *in danger of dying out as commercial* breeds take over, according to a worldwide inventory of animal diversity. Their extinction would mean the losses of genetic resources that help animals overcome disease and drought, particularly in the developing world, says livestock experts. Since the Indigenous cattle of Ethiopia are not producing the desired milk products and known with low reproductive performances, they are in the way to be replaced by exotic breeds through crossbreeding process. Reasons to say this is that superiority of F1 crosses over higher grades of both production and reproduction traits in low input production systems prevalent in the tropics, including Ethiopia (Rege, 1998). But the milk yield of high grade (3/4 Holstein Friesian and % of indigenous cattle) was less as compared with the F1 crosses might (Million and Tadelle, 2003). It is also reported that there is no significant difference in productive and reproductive performances in 75% exotic and 25% indigenous with 50% exotic and 50% indigenous cattle.

Questions

On one hand, we are crossbreeding our indigenous cattle with exotic to get more products and simultaneously, replacing indigenous breeds with exotics and crossbreeds; on the other hand, as the blood level increases, the crossbreed do not cope to produce the desired milk and related products. What might be the basic reasons for these situations and recommended solutions?

Box 8.2: Resistance of broiler chickens to *Salmonella* infections

The website of an industrial producer of chicken meat in the Republic of Mauritius indicated that "... *When experience serves quality - quality is at the very heart of our activities through strict hygiene-code standards at all production stages. We cover all operations associated with the production of chicken meat, all under strict quality standards"*.

Commercial broiler chicken lines have a limited genetic diversity and this may be the reason for epizootics of *Salmonella* infections in poultry, forcing the industry to use a range of wide-spectrum disinfectants, to reduce the risks of food safety hazards.

Questions

- In your opinion, what will be the economic advantages to the industrial producers to use commercial broiler chicken lines that are resistant to *Salmonella* infections?
- What will be the role of indigenous poultry breeds in the breeding programmes for chicken resistant to *Salmonella?*
- Propose a breeding programme that aims at the utilization of local chicken breeds by focusing on the conservation and genetic characterization of the indigenous local breeds.
- State how the evidence of your data can influence the policy of a "Conservation Programme" for the maintenance of genetic conservation and bio-diversity for indigenous breeds of poultry in Africa.

Conclusions

Disaster risk management in animal breeding is a systematic approach of preventing, mitigating and coping of risks in farm animal breeds and breeding systems against risks for emergency response, recovery and restocking. Hence, the objectives of this chapter were to identify and assess disaster risks facing African farm animal breeds, enhance early warning systems and strengthen disaster preparedness so as to reduce the risk factors facing indigenous farm animal breeds. Further objectives were to use knowledge, innovation and education to build a culture of safety and resilience of sustainable utilization of indigenous farm animal breeds genetic resources at all levels. The chapter discussed the concepts, risks and risk management directions of breeding polices and strategies, farm animal recording systems, breeding systems, conservation strategy/ system, trans-boundary disease in the refuges and its consequence as well as admixture of unrecognized breeds at refuges and climate change. In an increasingly globalised market, the absence of breeding policies and regulations, as well as the absence of gene bank for animal genetic resource conservation could put indigenous breeds at risk and endanger the future generations. Measuring and keeping records of important traits, and also predicting breeding values without bias and with a high precision, is fundamental for a functioning selection program. Therefore, if there is no record, it is impossible to predict breeding values of animals. The estimation of the effective population size offers the possibility to use one indicator for monitoring and planning purposes. Hence, small populations with low effective population size are at risk if no measures are taken. Risks of extinction due to loss of genetic diversity among populations occur due to high rate of gene flow from other populations, breeding processes, genetic introgression, inbreeding and climate change. The indigenous animal breeds are now replaced by exotic and their crosses due to their low reproductive performances. The crossbreed animals are also showing reduction in performances after the third generation than the indigenous breeds. Therefore, the chance of losing both the crossbred and indigenous is inevitable.

Questions for Discussion

1. What type of breeding policies need Africa so as to produce desired products from farm animals and conserve their indigenous breeds not replaced through crossbreeding?
2. The crossbred animals are with blood level of % and above not performing well in African environment at low input production systems. What are the recommended solutions for these prevalent problems?
3. If Africans need to develop their own breeds with the desired level of products, which breeding system must be followed and why?

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Section 3

Food and Environmental Safety in Agricultural Risks Management

Section 3: Introduction

Risk and uncertainty are inherent in agriculture and commodity supply chains. These risks arise from a wide range of factors within the farm level or within supply chains. The risks are numerous and varied and are specific to the country, climate, and local agricultural production systems. Managing risks in agriculture is particularly challenging, as many risks are highly correlated. Risk management therefore plays a key role at the beginning of the risk analysis process in identifying food safety problems and considering the best ways to manage them.

Food and environmental safety are of critical importance to Africa because of their impact on public health and economic development. In recent times considerable approaches has been made to strengthen food safety systems in order to reduce and prevent food borne diseases.

This section focuses on: (i) food safety in Africa with application of risk analysis; (ii) food safety practices along the food chain and (iii) food safety risk detection. The chapters have designed different case studies on how food and environmental risks can be managed along the agricultural chain.

9

Food Safety in Africa - Applications Of Risk Analysis

A.O. Obadina and I. O. Olotu

Summary

Food safety is of critical importance to Africa because of its impact on public health and economic development. In recent times considerable effort has been made to strengthen food safety systems in order to reduce and prevent food borne diseases. Risk analysis is a structured approach to strengthen food safety. With changes in the consumption pattern of Africans, urbanisation, intensification of agriculture, globalisation and increases in the complexity of food supply, it is essential not only to manufacture the highest quality foods to ensure safety and protect public health, but also to comply with international and national standards and market regulations. There is also need for a paradigm shift from the traditional food systems in Africa. With risk analysis, food safety systems in Africa can be modernised and strengthened. Foodborne illnesses can be reduced and food that will match both national and international standards can be produced. This chapter focuses on risk analysis as a strategy that can be applied consistently to strengthen food safety in Africa.

Resume

Securite Alimentaire en Afrique : Application a I'Analyse de Risques

La securite alimentaire est dune importance capitale pour l'Afrique a cause de son impact sur la sante des populations et le developpement economique. Plus recemment, des efforts considerables ont ete consentis pour en vue de renforcer le systeme de securite alimentaire dans l'optique de reduire et de prevenir les maladies nutritionnelles. L'analyse des risques est une approche structurelle de renforcement de la securite alimentaire. Avec les changements dans les habitudes des consommateurs Africains, l'urbanisation, l'intensification de l'agriculture, la globalisation et l'accroissement dans la complexite de l'approvisionnement en nourriture, il est essentiel, non seulement de produire une qualite superieure de nourriture pour asurer la securite et proteger la sante des populations, mais egalement se conformer aux standards nationaux et internationaux et les regles du marche. Il est egalement necessaire d'operer un basculement paradigme de systemes traditionnels africains a des systemes plus modernes. Avec les analyses de risques, les systemes de securite alimentaires en Afrique peuvent etre modernises et renforces. Les maladies liees a l'alimentation peuvent etre reduites et les aliments qui respectent les normes nationales et internationales peuvent etre produites. Ce chapitre met l'accent sur l'analyse des risques comme une strategie applicable de fa^on soutenue afin de renforcer la securite alimentaire en Afrique.

Introduction

Food provides nourishment to the body and it serves as a major determinant of the social well being and health of humans, communities, soieties and nations and if they are impropery handled, they could facilitate the transmision of diseases. (Mensah *et al.,* 2012). Foodborne illnesses continue to be a major threat to the health of people in Africa, especially vulnerable groups such as children, the elderly and people with underlying diseases such as HIV/AIDS. Several devastating outbreaks of foodborne diseases such as cholera, salmonellosis, hepatitis A and acute aflatoxicosis have occurred in a number of African countries. A worrying development is the presence of chemical contaminants in food. The misuse of drugs in health care and animal husbandry is leading to the development of multi-drug resistant strains of the causative agents of foodborne diseases (Mensah *et al.*, 2012). Furthermore, there are emerging and re-emerging threats to the food chain from zoonotic and other diseases. It is important for food safety systems to be effective and efficient in order to sustain the confidence of consumers and deliver regulations that are sound for both international and domestic food trades which reinforce the development of economies (CAC, 2003). Risk analysis is a structured approach to strengthen food safety. It is a science based process consisting of three components: risk assessment, risk management and risk communication (CAC, 2003). The importance of the use of risk analysis to strengthen food safety system in Africa is a way of bridging the gaps observed in the current food safety issues in African countries. Its application will also provide opportunities for innovation and flexibility, promote fair trade practices, reduce food losses, improve decision making process and in overall contribute to continuous improvement in food safety.

Learning objectives

The objectives of this chapter are to:

- Provide information on the present status of Africa in terms of food safety, food consumption and food control systems;
- Improve the knowledge and understanding of stakeholders (food regulators, governments, industries, academia etc.) on risk analysis as a tool that can be applied to food systems in Africa;
- Provide important background dataand non-theoretical information on the utilization of food risk analysis forstakeholders;
- Provide examples of internationally agreed and established principles of risk analysis which can serve as a structure and guide for its application in Africa food systems.

Learning outcomes

At the end of this chapter, learners and stakeholders are expected to have achieved the following learning outcomes:

- Have knowledge of the history of foodborne illness outbreaks, infrastructures and regulations in selected African countries;
- Explain the principles, concepts, philosophy and mechanism of the components of risk analysis;
- Appraise the need for implementation of risk analysis into food systems of African countries;
- Identify the essential requirements and preliminary activities that are necessary for the successful implementation of risk analysis.

Indigenous Crops and Foods Consumed in Africa

Africa has more native crops than any other continent which are diverse and grouped as grain crops, fruit and vegetable crops. They are indigenous because they are truly native to Africa. Theier Wild forms can be found in the African regions; Southern Africa, Northern Africa, Central Africa, Eastern Africa and Western Africa. They are different from what could be called traditional foods, which initially were foreign to Africa but were introduced and have been grown and consumed by early Africans from one generation to another. These crops are produced and found growing in the different regions under various weather conditions and they vary in specie, variety, shape, colour and size. They are mostly produced within the rural farming communities on small scale and are mainly for subsistence purposes. Indigenous grain crops can be defined as any crop yielding starch and protein enriched seeds suitable for food. These crops are further subdivided into cereals and pulses. Cereals such as pearl millet *(Pennisetum* *glaucum)* and grain sorghum *(Sorghum bicolor)* which are used for making porridge, cookies, cakes and beverages are important in Southern Africa (World Watch Institute, 2011). Pulses such as bambara groundnuts *(Vigna subterranean)* and mung bean *(Vigna radiata)* are also indigenous in Southern and Central Africa. Cowpea originated from central Africa and it is one of the continent's oldest known crops and the second most widely grown legume in Africa. For the Dogon people of Mali, fonio is the seed of the universe. The terminology is appropriate given its high nutritional value and adaptability to the region's soil and climate (World Watch Institute, 2011). Most people think of rice as an exclusively Asian crop, but farmers have grown native rice *(Oryza glaberrima)* in parts of West Africa for at least 1,500 years. Locust bean's name might seem deceiving. Whilst only distantly related to beans, this plant is actually a tree, It is indigenous to the savannah regions of Africa and it is most commonly found in the band of terrain stretching from Senegal to Uganda. Other crops include teff, safou, potato, pigeon pea, moringa, monkey orange etc. Despite their nutritional and economic value, most of these crops are still harvested in the wild, lesser known, underutilised, locally produced and only meant for immediate consumption. The potential of these crops for commercialisation and foreign exchange earnings has not been exploited.

Africa being the domain of several people of diverse ethnicity and cultures exhibit its diversity in thier food choices interms of ingredient selection, preparation style and tehniques of cooking. A usual African food is usually hearty and posesses components of starch, spices, meat as well as flavours. A wide range of food are consumed in different regions examples are fufu, asida, babute, amala, attieke, cachupa, chiyoko, tempeh, foutou, nyemba, tuwo, kenkey, chakalaka, frejon,himbasha, lahoh, mandazi, natoke, ndole, tahini, tajin, seswa, couscous, pounded yam, yassa etc. Dishes containing rice are also vastly consumed particularly in dry Sahel belt inland; some of these dishes are jollof rice; a rice dish prepared in West Africa identical to Arab Kabsah which is of Ghanian origin, benachin is also consumed in Gambia. In the past, the consumption of meats was reduced and indigenous oils like palm oil were used more in dish preparations but African diets today are much heavier in salts, fats and meats.

Several dishes incorporate meat and sea foods due to their nutritional value and availability but fish is not a major staple food in the savanna and highland zones of Africa, where there is a relative abundance of livestock as a source of protein. Fruits consumed include cherry, mango, pineapple, pawpaw, orange, water melon, banana, grape, tangerine, cashew, avocado, guava etc. In relation to beverages, a wellknown example is palm wine which is the fermented sap of different types of palm trees (Obadina *et al.,* 2008), other beverages are; pito, soy milk, kunu and burukutu e.t.c.

Another important group of indigenous foods consumed in different African regions are fermented foods, where both plant and animal based raw materials are used. For example, Africa indigenous fermented foods are produced in homes, villages and small scale cottage industries and are derived from substrates like roots, legumes, cereals, oilseeds, nuts, meat, fish, milk, palm tree, sap etc. (Obadina *et al.,* 2008). Some fermented foods common to Africans are dawadawa, gari, banku, ogi, injera, kaffir beer, merissa etc. The fermentation techniques vary from the very simple spontaneous fermentation that is complete within a few hours to a day, to the very complex and sometimes long fermentation, which can take anything from a few days to several months. Banku is fermented dough and staple indigenous to Ghana. Its substrate is predominantly maize and cassava. On the other hand, dawadawa (also known as uri, kpalugu, kinda, iru) is peculiar to West Africa, with the substrate being African locust beans. *Saccharomyces spp* is responsible for the fermentation of sorghum into Melissa, which is commonly consumed in Sudan.

Food Safety Status in Africa

Food security is the access to adequate, secured and nourishing food to retain hearty and energetic life. On the other hand, food safety is the confidence that the consumption or preparation of food will not lead to any harm in relation to its intendend use. Food safety in a broader view could also mean:

- the alteration of the trading of foods that are unsuitable for consumption
- the interception of the trading of food items to which any unsuitable inclusion or from which an important component has been eliminated, which is not of the anticipated substance nature or quality
- the prohibition of the importation of substandard foods and
- the supervision of enviroments where foods are produced, handled, stored, sold and processed.

Food safety is a growing global concern, not only for its continuing importance to public health, but also because of its impact on international trade. Ensuring food safety to protect public health remains a significant challenge in Africa. In many countries, a significant advancment in building up food safety systems has been made while some African nations are are still lacking behind. Arranged sytems for overseeing foodborne outbreaks are lacking and a signifiant number of these are not investigated, not reported and not regosnised (Taege, 2015). Therefore, these factors makes the determination of actual food borne incidence burdensome. In addition, diseases such as diarrhea, dysentery, cholera and thyphoid are customary in Africa and these is due to situations like poverty, high reliance on street foods, mycotoxins etc.

Street foods are cheap, convinient and atrractive foods that serves as an alternative to home made meals and they are widely consumed in communities. They also serve as a major source of income especially amongt women and a means of employment because of its low capital requirement (WHO, 2002). Food vending has significantly increased in Africa due to these factor but their link to food borne illnesses outweighs these as they have been identified to pose risks to public health. Thier food borne illness causing route is usually through the use of inappropiate food additives, inappropiate and improper handling due to lack of food safety education/awareness, exposure to enviromental contaminants, weak regulations and laws on food vending amongst others (Abdussalam and Kaferstein, 1993).

Toxins from fungi known as mycotoxins also pose a great challenge to the safety of African foods, they impair human health when inhaled, absorbed or ingested and these can lead to sickness or death in human (Bankole and Adebanjo, 2003). Toxigenic fungi affect various agriultural produce before and after harvest and their growth/mycotoxin prodution is favoured by the tropical conditions of some Afrian countries. Poor harvesting, storage, transport, processing and marketing conditions favours fungi growth and increase the risk of mycotoxins prodution. Agriculturally important mycotoxins are fumonisins, deoxynivanelol, aflatoxins, zearalenone and ochratoxin (IARC, 1993). There are findings that reveals that people in Africa are exposed to foodborne mycotoxins espeially fumonisins and aflatoxins (Miller, 1996) with serious impact on their health.

The increased number and extent of humanitarian emergencies in diffrent African Region in recent times have considerably affeted the safety of food. During the occuurence of natural epidemics such as drought, floods, border conflicts or civil wars, flood are often damaged or seriously contaminated. For example in refugee camps, surviors health is at risk and food diseases are common because of the unsanitary atmosphere, poor food handling pratices, presene of enviromental contaminants. A huge outbreak of cholera occured with over 700,000 cases in 1994 with a high fatality rate in Rwandese refugee camps close to Goma, Zaire (Democratic Republic of the Congo). The economic impact of foodborne illnesses cannot be underestimated, a outbreak which occured in Tanzania in 1998 costed USD 36 million. Also, in Nigeria the Food and Drug Administration damaged food contaminated with aflatoxin which was worth more than USD 200,000. The World Health Organization (WHO) and the FAO have documented several food quality and safety related issues that have affected the importation and exportation of foods jointly (FAO /WHO, 2003). Table 9.1 reports the incidence of some foodborne illnesses in Nigeria (Okike *et al.,* 2011).

The uttermost responsibility of food control is to enact food laws inorder to safeguard consumers against foods that are not safe and other fraudulent practices. It is important for consumers to have confidence on the integrity and safety of foods that is been supplied in a region/country.

Table 9.1: Incidence of some foodborne illnesses reported in Nigeria

Foodborne illnesses	Prevalence / incidence
Acute diarrhoea (Adults)	*E. coli* 3%; *Klebsiella* 9%; *S. aureus* 4%; *Salmonella typhi* 2%; *Pseudomonas* 3%; *Entamoeba histolytica* 35%
Acute diarrhoea (Children)	*Rotavirus* 24%; *E. coli* 15% ; *Salmonella* 11%; Klebsiella 11%; *Shigella* 5%; *Campylobacter* 3%; *Yersinia enterocolitica* 3%; *Giardia lamblia* 3%
Acute diarrhoea	*E. coli* 46%; *Shigella* 21%; *Salmonella* 17%; *Klebsiella* 9%; *Aeromonas* 4%; *Plesiomonas* 3%
Paragonimiasis	16.8%
Taeniasis	8.6%
Helminthiasis	*Ascaris lumbricoides* 54%; *Trichuris trichiura* 43.7% ; *Necator americanus* 42.7%
Cryptosporidiosis	2.3%
Gastroenteritis	21%
Cryptosporidiosis	13.5%
Salmonellosis	20 people died
Brucellosis	31.8%

Source : Okike et al., 2011

Food Control Systems in Africa

Food control systems should cover all food produced, processed and marketed within the country including imported food. While the components and priorities of a food control system will vary from country to country, most systems will typically comprise of the following components; food law and regulations, food control management, inspection services, laboratory services, information, education, communication and training. In 2002, the WHO conducted an assessment of the status of food safety programs in the African region (WHO, 2002 ; 2010), the following information were collected and analysed: labelling and conformance to safety and quality requirements, accuracy of labelling and consumer information contained therein, food inspection systems, mechanisms for monitoring of food exports and imports, surveillance systems for foodborne diseases and microbiological monitoring, human resource development and public education. The findings from 28 responding countries in the WHO African Region revealed significant gaps in the national food legislation. Furthermore, the study showed that there were inadequate linkages between strategies implemented to ensure food safety. The studies further showed that existing laws were often outdated, overly prescriptive and failed to adequately address the whole range of food safety concerns.

Food Safety Systems

Food safety system is broadly classified into two systems (FAO/WHO, 2003), namely: traditional food safety system and science (risk) based food safety system.

Traditional Food Safety Systems

The traditional food safety system defines unsafe food, prescribes the enforcement tools for removing unsafe food from sale and punishes the parties responsible. This indicates that the system is reactive rather than preventive. Some African countries possess an operational food control system which is established for adulteration/fraud inspection as well as hygiene. Irrespetive of some variations in the system, regulations and laws on food, laboratory services, inspection and food control managent are involed. In some cases, the systems constitute of information mechanism, communication, education and food supply monitoring. Although traditional food safety systems have been efficient to some extent relative to food hazard redution in the past, the system does not have the capacity to identify and rectify many current challenges or deal with evolving food safety challenges which are constitent, complex and pervasive (Institute of Medicine, National Research Council of National Academies, 2003).

Science (Risk)-Based Food Safety System

The science-based approach to food safety system is linked to activities including good agricultural practices, Hazard Analysis and Critical Control Point system (HACCP), good manufacturing practices and good hygienic practices. These techniques are in plae in several countries (Henok et al., 2013). Governments of African countries are already engaging in actions that will strengthen, impact and improve the food safety management systems. There has been a considerable shift from the traditonal approach, steady end product control closer to the science based approach by many countries. It is noteworthy that some regulators of food safety are executing various science oriented activities and making decisions in their daily activities. Table 9.2 captures the differences between the traditional and science-based food safety systems.

Table 9-2: Differences between traditional and science-based food safety systems

Traditional food safety system	Science-based food safety system
Approach is reactive	Approach is preventive
Government is solely responsible	Responsibilities are shared
Risk analysis is not structured	Risk analysis is structured
Expert based	Science based
Qualitative	Quantitative
Command and Control	HACCP-based
Depends on end-product inspection and testing	Depends on process control
Unsatisfactory levels of risk reduction	Improved level of risk reduction
Unstated regulatory goals	Quantitative performance-based criteria

Examples of Science-based Activities

Examples of science-based activities include:

- Hazard Analysis and Critical Control Point (HACCP) systems implementation;
- Acceptable daily intakes (ADIs) for veterinary drugs, additives (chemical) and pesticide residues;
- Establishment of tolerable intakes for chemical contaminants, inclusive of natural toxins;
- Development of risk warning labels through science.

The capacity of traditional food safety system is strenghtened through a science based approach in order to contribute solution to currnt challenges and increase accesibility to risk free food. The occurrence of hazards and risks (food-borne) can be reduced and managed through science based eveidence, also these can also facilitate decision making outcomes. An approach which is science driven facilitates and enables food safety regulators to: recognise hazards, categorise the extent and nature of hazards, analyse the level of exposure of the identified hazard and predict the magnitude and likelihood of the risks that results from the hazard and its effect on the health of people (Henok *et al.*, 2013).

Risk Analysis and Modern Food Safety Systems

A food safety system that is science based is not new but what is recent is the employment of risk analysis as a system to look into and provide solutions to challenges of food safety in an organised, patterned, sequential and scientific way so as to improve decision making processes in the food chain. This system is modern and ensures that problems are targeted at, evidence driven and effectively diagnosed. In additon, the use of a science based strategy improves food safety sytems and provides an opportunity to energize the capability of traditional food safety systems to combat thier present problems. It also provides a structure of productive management, communication and acceptance of risk in collaboration with other involved parties.

In order to build a structure of science basked risk analysis framework, there is need for public health and modern food safety institutions and infrastructure and also a conducive enviroment which can support the development and improvement of food safety system components which include food legislation, food inspection, laboratory analysis, monitoring systems for contaminations in foods, epidemological surveilance of food borne diseases and policies of food safety. The science-based approach will also help in the development and implementation of intervention developed for specific high risk areas to enhance food safety and lower the occurrence and burden of food borne diseases.

The Risk Analysis Process

Risk simply refers to the chance of an undesirable outcome: a loss (fire, flood, illness, death, lost product, financial setback, or any sort of hazard), or a potential gain that is not realised (new product did not catch on as hoped, investment did not produce expected benefits, health did not improve, new trade was not established, or any sort of opportunity missed).

Risk is often described as Probability x Consequence. It is important to note that:

- Risk is everywhere;
- Some risks are more serious than others;
- Zero risk is not an option (risk is unavoidable);
- Risks can be mitigated/managed but not absolutely eliminated.

In relation to food, risk is a function of the probability of an adverse health effect and the severity of that effect, consequential to a hazard(s) in food. Uncontrolled and abusive applications of agricultural chemicals, environmental contaminations, use of unauthorised additives, improper food quality control and handling practices during food processing and other abuses of food along the food chain can all contribute to the introduction of hazards, or the failure to reduce hazards related to food. The effects on human health of hazards associated with food, the increasing importance and rapid growth of world food trade and the demand by consumers for a safe food supply make the analysis of the risks associated with food more important today than ever before. Box 9.1 shows the risk of using pesticide.

Box 9.1: Risks associated with use of pesticides

The impact made by agricultural chemicals on ground and surface water quality is an increasing area of concern and the risk linked with a chosen pesticide or pesticide product is dependent on the compounds toxicity and well as the probability of exposure. In this regard, environmental protection agencies are responsible for the protection of the quality of the ground water of a nation/country as well as the regulation of the use and availability of pesticide products. There are risks that are peculiar to each pesticide product and potential impacts of pesticides that are detrimental are:

- Acute poisoning as aresult of a short-term or single exposure which can result into death;
- Chronic impacts of long-term exposure to pesticides for example through food can also lead to death;
- Degradadation of natural resources nwhen they come in contact with ground water, storm water, surface runoffs which contains pesticide residues;
- Pesticides that deviate from application sites can kill or harm birds, fish, non target plants and other animals;
- Improper handling of pesticides in mixing ares, storage facilities, loading areas etc. can contibute to water and soil contamination;

Questions

- Analyse the risk be associated with the use of agricultural produce contaminated with mycotoxins.
- Identify how these risks can be reduced or eliminated.

Food Hazards

It is important to recognise the difference between 'hazard' and 'risk'. A hazard is a biological, chemical or physical agent in (or condition) food, with the potential of causing harm. In contrast, risk is the estimated probability and severity of adverse health effects in exposed populations, consequential to hazards in food. Understanding the association between, a reduction in hazards that may be associated with a food and the reduction in the risk of adverse health effects to consumers is of particular importance in the development of appropriate food safety controls. Food hazards can be classified into three categories: chemical, microbiological and physical.

Chemical Hazards

Hazards which are chemical in nature include agricultural chemicals such as rodenticides, pesticides, insecticides, herbicides, antibiotics, fertilizers, cleaning residues, food additives, naturally occuring toxins e.t.c. Any material that is included to a food indirectly or directly through processing, storage, packaging or production is a food additive. They play a significant number of roles, they serve as stabilizers, flavouring agents, preservatives, foaming agents, emulsifiers, colouring agents e.t.c. Despite the fact that food additives undergo extensive laboratory testing before they are put into commercial food products, the use of additives in foods has facilitated great controversy and widespread public concern. The inappropiate use of animal drugs may lead to the formation of resideus in the tissues of animals which are slaughterd and these can be hazardous to consumers.

Diverse group of chemicals which are synthetic or naturally occuring that are used used to control undesirable activities of insects/target organisms are known as pesticides, being a broad term it includes insecrticides; used for controlling insects, fungicides; used for controlling moulds, fungi and mildew, herbicides; used for controlling weeds, rodenticides; used for controlling rodents and disinfectants; used for controlling bacteria and viruses. Three-quarters of pesticide are used for agricultural purposes majorly on the field and they are also used when produce are being transported and stored to shield them from moulds and insects. Humans may be harmed by pesticides in two ways: they may be poisoned or injured. Examples of classes of pesticides that has been found in foods are organonitrogen, phenoxy acid, n-methyl carbamate e.t.c. Additionally, naturally occuring toxins are also present in food supplies as animals and plants also produce substances which are toxic as protection against microrganisms, insects, grazing animals e.t.c. Gossypol in cotton seed, solanine in potatoes, caffeine in cofee and hydrogen cyanide in casssava are all examples of toxins that occur naturally.

Microbiological Hazards

These include disease causing microrganisms, some of which are ubiquitous, water borne, food borne or animal borne and include : bacteria, viruses and protozoa.

- Bacteria: some bacteria are beneficial and are used in making foods such as yoghurt, cheese and beer while others cause food to spoil, but do not cause human sickness. This difference between spoilage bacteria and pathogenic bacteria is important in the prevention of foodborne illness. Since pathogenic bacteria generally cannot be detected by looks, smell, or taste, we rely on spoilage bacteria to indicate that a food should not be eaten.
- Viruses: foodborne illness causing viruses are diffrent from bacteria in that they are smaller and need an host to reproduce and grow .They do not increase in foods and are incomplete cells and the ingestion of a few viral particles is sufficient to lead to infection. They are transmitted through sewage of water that is contaminated by feacal matter or via direct association with feacal materials of human origin. Undercooked and raw mollusc shellfish such as oysters, mussels, scallops, clams are examples of food that are mostly associated with foodbrone viral diseases.

- Protozoa and parasites: a number of parasites also cause foodborne illnesses. They must live on or inside a living host to survive. The most common foodborne parasites are: *Anisakis simplex, Cryptosporidium parvum, Cryptosporidium,* and *Toxoplasma.*

Physical Hazards

These are foreign objects such as dirts, insects, machine fillings, metal pieces, fillings etc. They inadvertently get into food and could cause harm to someone eating that food. There are established maximum levels of natural or unavoidable defects in foods for substances that present no major human health hazard. These are called Food Defect Action Levels and this is the maximum amount of unavoidable defects that might be expected to be in food when handled under good manufacturing and sanitation practices. They are allowed because it is economically impractical, and sometimes impossible, to grow, harvest, or process raw products that are totally free of natural defects. Unavoidable defects include insect fragments, larvae, and eggs; animal hair and excreta; mold, mildew, and rot; shells, stems, and pits; sand and grit (Roberts, 2001).

Physical hazards are most likely to be understood by people. Far more complex and less understood is the nature of the impact of chemical and biological hazards on human health because of the complexities of the interaction between the hazard and human biochemistry and the absence of empirical data to confirm the theories. By understanding how to eliminate or reduce hazards in foods, possibilities exist to establish food safety controls. The controls will lower risks to consumers and these actions constitute an important critical part of risk analysis. Box 9.2 gives examples of food hazards that have occurred as outbreaks in selected African countries while Box 9.3 reports a case study of microbial hazards associted with vegetables.

Box 9.2 : Examples of food hazards that have occurred as outbreaks in some African countries

Chemical hazards

- Pyrolizidine alkaloids outbreak in South Africa in 1920	Kakar, 2010
- Acute aflatoxicosis outbreak in Kenya in 2004	Azziz *et al.,* 2005
- Chemical intoxication due to consumption of beans and maize in Nigeria in 2008	WHO, 2014
- Pesticide residues outbreak from cabbage and other vegetables in Senegal	WHO, 2014
- Scombroid fish poisoning outbreak occurred in Dakar, Senegal in 2010	Demoncheaux et al., 2012
- Bromide poisoning in Angola in 2008	WHO, 2014
- Mushroom poisoning in Algeria in 2008	WHO, 2014
Microbiological hazards	
- Salmonellosis outbreak in Kwazulu-Natal, South Africa in 2011	Neil et al., 2012
- Typhoid fever outbreak in Uganda, between 2008-2009	Neil et al., 2012
- Botulism outbreak in Uganda between 2008-2009	Neil et al., 2012

Questions

- As a learner, evaluate the impact of outreaks through food hazards on the economy using your country as a case study.

Box 9.3: Study of microbial hazards in fresh cabbage and lettuce sold in Abeokuta Metropolis, Nigeria West Africa

Foodborne illness outbreaks associated with fresh fruits and vegetables continue to be a significant concern for the produce industry and a number of these have been linked to fresh produce contamination with microbial pathogens originating from human faeces of animal feaces. In some cases, this feacal contamination occurs via poor practices, such as fertilizing produce fields with untreated manure or inappropriately treated compost.

A study was conducted on cabbage and lettuce in Abeokuta a city in Southwest Nigeria by Oyinlola *et al.* (2014) with the aim of finding the effect of manure application to the microbial safety of vegetables. Samples were collected from farmers using manure from different sources in cultivating vegetables. The samples were analysed microbiologically using standard laboratory procedures. Coliforms, *E.coli, Salmonella spp*. which are feacal contaminants and could be from the manure in the soil on the farm were found to be present. This also support the findings of other researchers such as Ameko *et al.* (2012) who identified *Salmonella spp.* from contaminated manure as a source of contamination for vegetables.

Questions

- As a learner, list and discuss the other ways by which these microorganisms could have contaminated the vegetables.
- What should be done to prevent these microorganisms from getting into the final food products, e.g. salads?
- Identify other hazards and coressponsding sources that can be found in vegetables.

Risk Analysis

Risk analysis is a systematic way of gathering and evaluating data related to a hazard, and then using that knowledge to develop and implement programs to manage the risks associated with the hazard. According to the Codex Alimentarius Commission (CAC), risk analysis is a procedure that involves three constituents: risk management, risk assessment and risk communication (CAC, 2003). Risk analysis should be:

- Established on all statistics that are scientific;
- Implemented regularly;
- Open, unenclosed and written down;
- Assessed and analysed when due on the basis of recent scientific information;
- Established by taking into clear consideratiion variations and uncertainty.

A food safety risk analysis directs time and attention to greatest safety concerns in a facility.

Important Features of Risk Analysis

The following constitute important features of Risk Analysis:

- It is a frequent and continious process where steps can be restated if needed;
- It is a process that is throughly interactive, that needs extensive communication both internally and externally.

Conditions Necessary for Risk Analysis

Some factors that are expedient in order to implement successful risk analysis are outlined below:

- There must be an operational food safety system which will be characterised by sufficient laws and regulations on food, a national aproach to food ccontrol, efficient laboratory and inspection system, systematic and specialized capacity, establishments, clinical data, means of education and information transcmission;

- The knowledge on risk analysis must be sufficient. Most importantly, stakeholders including decision makers, regulators of food safety, officials of the government, food industries, academias, scientist and consumers must have a knowledge of risk analysis and it benefits to the health of the public;
- The support and commitment of key stakeholders who knows the value and participate in the risk analysis process must be optimal.

Risk analysis deals with three outstanding but closely knitted elements:

- Risk assessment;
- Risk management;
- Risk communication.

Risk Assessment

Risk assessment is the central scientific component of risk analysis and was developed primarily because of the need to make decisions to protect health in the face of scientific uncertainty. Different world organisations (World Organization for Animal Health — OIE; Environmental Protection Agency — EPA; Codex Alimentarius Commission — CAC; International Plant Protection Convention - IPPC), define risk assessment in different ways. The differences are based partly on what they are primarily examining. According to the OIE, risk assessment is the evaluation of the likelihood and the biological and economic consequences of entry, establishment, or spread of a pathogenic agent within the territory of an importing country. Risk assessment consists of the following steps: release assessment, exposure assessment, consequence assessment and risk estimation. However, CAC defines risk assessment as a scientifically based process consisting of the following four (4) steps: hazard identification, hazard characterisation, exposure assessment and risk characterisation. According to the EPA, step 3 is replaced with dose response assessment (CAC, 2003).

Characteristics of Risk Assessment

Risk assessment involves the folowing characteristics:

- It is a systematic and science-based process;
- It explicitly addresses uncertainty in an open, realistic and organised manner;

It can be descriptive or narrative, qualitative, semi-quantitative or quantitative.

Qualitative risk assessment is the system of arranging, filling and demonstration of evidence to back up a risk statement. Analysis and data which are numeric in nature can be a part of the contribution made into qualitative risk characterisation but the estimation of the final risk does not compulsorily results from efforts to create a computational or mathemeatical illustration of the risk producing system.

Quantitative risk assessment is established on numerical analysis and data, It can be probabilistic (e.g microbial risk assessment; see Case Study) or deterministic (e.g. safety assessment of food additives). A quantitative risk assessment describes doubts numerically with uncertainty distributions evaluated by various statistical methods (Vose, 2002). A quantitative risk assessment can tackle risk management problems better than qualitative risk assessment. The latter is often carried out when issues that could have direct effect/impact on food safety occur. For example, a qualitative risk assessment will be carried out in the following circumstances: use of a new food additive; changes in a food production process that may affect food safety or food supply chain; assessment of existing facilities; procedures, processes and polices to improve existing risk prevention etc.

Components of Risk Assessment Hazard Identification

This is the identification of biological, chemical, and physical agents capable of causing adverse health effects and which may be present in a particular food or group of foods. Diffrent physical, chemical and biological hazards are the causes of food safety risk. In a case when an hazard needs to be evaluated and primed based on evidence that are scientifically proven, assesors of risk give scientific assistance to risks managers to assist them in seleccting the hazard with the greatest apprehension (CAC, 2003). On the other hand, in situations where risk managers have discovered the hazard, risk assessors will shed more light into the scientific nature of the hazard.

Hazard Characterisation

Hazard characterisation is the qualitative and/or quantitative evaluation of the nature of the adverse health effects associated with biological, chemical and physical agents which may be present in food. During this process risk assesors come up with an absolute profile of the extent and nature of the negative health concerns accrued with the identified hazard. The results of altering the quantity of the hazardous substance/material on the health of humans can be looked into quantitatively or qualitatively in a narrative manner. For chemical agents, a dose-response assessment is usually carried out if data can be acquired.

Exposure Assessment

Exposure assessment is the qualitative and/or quantitative evaluation of the likely intake of biological, chemical, and physical agents via food as well as exposures from other sources if relevant. It merges particulars on the quantity and presence of hazardous substances in the enviroment and food supply of consumers and the probability that consumers will be introduced to several levels of this substances in thier food. Information on hazard presence and quantity can involve an evaluation of the number of pathogens in a food serving or the quantity of an additive that is consumed daily by a consumer. Based on the nature of the difficulty, exposure assessment consider important storage, production and handling practices along the food chain. Box 10.6 documents the hazard identification technique involved in the processing of fufu (an indigenous African meal often made from starchy roots such as yam, cocoyam, cassava and other cereal grains) (Obadina *et al.* 2008). Use information given in Box 9.4 to answer the questions which follow.

Box 9.4 : Hazard identification technique involved in the processing of *fufu* (an indigenous african meal often made from starchy roots such as yams, cocoyam, cassava and from cereal grains)

Table 9.3 outlines all the techniques involved in the processing of *fufu*. Study all the processes involved, the hazards and the sources of hazard(s), and answer the questions that follow.

Table 9.3: Hazard identification technique involved in the processing of *fufu*

Process step	Hazard	Source
Harvesting/ sorting of cassava	Chemical; cyanide	Root
	Pesticides	Farm
	Heavy metals	Water by processors
	Chlorine	Water
	Physical; stones	Processors
	Microbiological; vegetative pathogens *(E.coli, S.aureus, Salmonella)*	Processors
Peeling	Physical: peels	Incompletely peeled roots
	Microbiological; vegetative pathogens *(E.coli, S.aureus, Salmonella)*	Processors and equipments

Washing	Chemical: heavy metals Physical: stones and clay Micro biological; vegetative Pathogens	Well water Well water, soil Handlers, water
Steeping	Microbial; vegetative Pathogens Physical: metals and stones	Handlers, environment Equipment and environment
Sieving	Microbiological; vegetative Pathogens	Water, equipment's handlers
Settling	Microbiological; vegetative Pathogens	Handlers Tap and well water
Pressing	Chemical: heavy metals Physical: metals and stones Microbiological: vegetative pathogens	Equipment's handlers

- Refer to Table 9.3 and identify the hazards involved and their possible sources in the processing of fufu.
- Use the Hazard Identification Technique to identify the hazards of three food products obtainable in your community.
- How can these hazards be minimised?

Risk Characterization

The quantitative and/or qualitative evaluation of the chance of an event and its severity in an identified population based on exposure assessment, identification and characterization of a hazard is known as risk characterization (Umoh and Odoba, 1999). Usually, it doesn't give more than a realistic estimation or a detailed view of the actual risk.

Food Safety Risk Analysis: Case Study

Microbial Risk Assessment

A microbial risk assessment assesses the probability of the occurrence of human health effect upon exposure to a pathogenic organism or its occurrence medium. Because microorganisms are ubiquitous, this assessment often involves a farm to fork approach. The figure below (Figure 9.1.) indicates the microbial risk assessment clearly showing the four constitiutent of risk assessment.

Statement of purpose

The reasons(s) behind the assessment.

Hazard Identification

This involves establishing microbes of concerns and information can be obtained from surveillance of outbreaks, clinical studies, laboratory animal studies, epidemiological data etc.

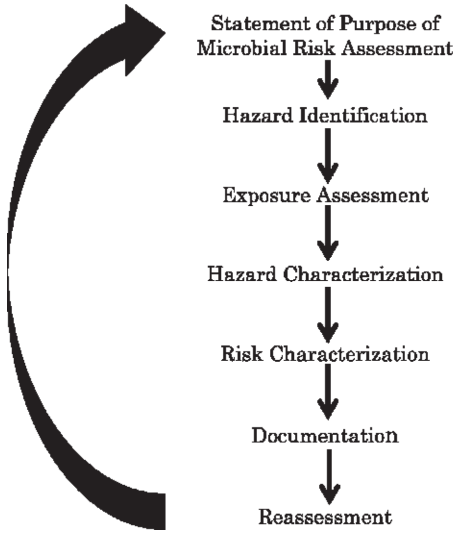

Figure 9.1: Microbial risk assessment process (Source: C

Exposure Assessment

Factors for exposure assessment of microbial risk are; feautures of pathogenic organism, initial contamination level of raw materials, micloflora of the food, production, storage, processing, transportation conditions, mode of consumption etc.

Hazard Characterization

Factors that impact hazard characterization for microbial risk are; replication of microganisms, pathogenicity, genetics factors, age, nutrition, pregnancy, medical history, population immunity etc. (CAC, 2003).

Risk Characterization

For microbial risk, this stage will involve the accumulation of all the quamtitative and qualitative information that has been developed in the previous steps and this will give information on the propability and expected severity of the adverse health effect which could occur in a group of people.

Documentation

The totality of the process will be recorded and communicated to mangers of risk and other interested parties.

Reassessment

The microbial risk identified will continually be reassessed and monitored to ensure that the chosen management option continuously produce the best result.

Risk Management

The process of evaluating policy options, uninaminousy with all stakeholders in consideration of risk assessment and other determinants for healthy protection of consumers, for the advancement of trade practices that are fair and choosing suitable control and prevention option is known as risk management. The process considers the best way to manage identified food safety problems (CAC, 2003). Evaluating policy options is significant in risk management and this involves the scientific side of the risk and any affiliated legal, environmental e.g. effect of identified food safety problem on climate change, economic e.g. cost- benefit analysis, political and social subjects that are expedient to people. Risk management must be carried out in collaboration with committed stakeholders and with risk communication tasks (FAO/WHO, 1995; 1997).

Risk management is not a straight process like other components but an iterative one, putting this into consideration, risk management models have to be flexible as the processes might not occur in similar manner (CAC, 2003). After risk assessment, different options to mange risk has to be choosen, evaluated and reviewed. This is usually done by risk managers but they can employ the experstise of risk assessors and other stakeholders to do this.

Risk Communication

The interactive reciprocation of ideas, facts and information on risks, hazards, risk discernment, risk related component among stakeholders during the risk analysis process is known as risk communication. It serves as a requirement for effective risk assessment and management (Fischoff, 1995) and provides accurate and useful information to the risk analysis team as well as external stakeholders so as to provide insight on the effect and nature of a specific food safety risk. It comprises of external and internal risk communication. The communication that occurs amidst diverse groups of team involved in risk analysis e.g. risk managers, communicators and assessors is internal while external risk communication is based on that which occurs between the team and stakeholders that are not within the risk analysis team including the general public. In addition, risk communication has models, in the first model; a member of the team is accountable for coordinating all risk communication activities which is carried out by others while in the second model one or more experts in risk communication is accountable for coordinating all the activities. Irrespective of the model that is adopted, it is critical that the roles and responsibility of each communicator is defined and there should be feedbacks (CAC, 2003).

Risk Communication Principles

- Audience should be known.
- Scientific experts should be involved.
- Expertise should be established in communication.
- Information sources must be credible.
- Responibilities should be shared.
- Value and scientific jugement should be diffrentiated.
- Transparency should be assured.
- Risk should be put into perspective.

Conclusion

Reports of foodborne illnesses and outbreaks, emerging pathogens, mycotoxins, inadequate infrastructures and weak regulations illustrate the challenges of weak food safety systems in Africa. Thus, there is need to expediently apply risk analysis into food systems to address these challenges that have major impact on public health. However, the rationale, concept, principles, requirements, preliminary activities, components and mechanisms of risk analysis need to be well understood before they can be integrated into the food systems to solve these challenges.

Questions for Discussion

1. Discuss how food safety risks can be managed at home via senses, science and technology.
2. Why should risk analysis be done?
3. What are the challenges of effective risk communication?

4. Evaluate other approaches by which food safety can be achieved in Africa.
5. The management of food safety risk be it physical, chemical or biological is everyones responsibility, discuss.

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10

Food Safety Practices along the Food Chain

A.O. Obadina and I. Olotu

Summary

Food safety is of growing global concern, not only for its importance to public health, but also because of its impact on international trade. Ensuring food safety to protect public health remains a significant challenge in Africa. Even though considerable progress to strengthen food safety systems has been achieved in many countries, some African countries are still lacking behind. The resultant effect of ensuring that hygienic practices and principle are put in place along the food chain is the consumption of contaminated food which is hazardous to health. Therefore, some measures and practices can be adopted between the point of processing and consumption that can drastically reduce contamination and the risk of foodborne illness. This chapter is intended for use by every individuals either trained in agriculture or not who are interested in learning about these practices and measures and concerned with the safety of their products as well as prevention of foodborne disease during the processing.

Resume

Securite Alimentaire le long de la Chaine des Valeurs

La securite alimentaire est une preoccupation mondiale croissante, non pas pour son importance sur la sante publique, mais egalement a cause de son impact sur le commerce international. Assurer la securite alimentaire pour la protection de la sante des populations reste un defi majeur en Afrique. Bien que des progres considerables pour renforcer les systemes de securite alimentaires aient ete obtenus dans beaucoup de pays, certains pays Africains sont toujours a la traine. L'effet induit assurant que les pratiques et principes d'hygiene qui sont mises en place le long de la chaine alimentaire sont la consommation des aliments contamines, qui constituent un risque pour la sante. Ainsi, des mesures et pratiques peuvent etre adoptees entre le point de traitement et de consommation qui peut reduire drastiquement la contamination et le risque de maladies liees a l'alimentation. Ce chapitre est destine auxpersonnes ayant une experience ou non en agriculture, interesses a apprendre ces pratiques et mesures et preoccupes par la securite de leurs produits, ainsi que la prevention des maladies liees aux aliments durant le traitement.

Introduction

The expectation for affordable, high quality and safe food materials is on increase and efforts needs to be made along the food chain in order to ensure that these expectations are met. Food safety is the assurance that a food product will not cause harm when is prepared or consumed. Ensuring that food is safe from farm to fork is a shared responsibility and it depends on the people involved in the food chain (harvesting, processing, packaging, storage, transportation, distribution etc.). In order to achieve these, some food safety management systems have been introduced such as such as hazard analysis and critical control points (HACCP), good manufacturing practice (GMP), good agricultural practice (GAP) and good hygienic practices (GHP). These systems are often supported by pre-requisite programs such as employee training, allergen controls, ongoing monitoring, pest control etc (Stier, 2012). Consumers also need to know of and food safety practices that can be adopted into their everyday lives e.g. the importance of checking expiry dates, following labelling, storage and cooking instructions and good hygienic practices. Food safety practices needs to be improved through the utilization of both regulatory and non-regulatory measures (e.g. training programmes, technical support) (WHO, 2002).

When appropriate food safety practices are not carried out along the food chain, the food can become hazardous. There are three types of hazards namely: physical, chemical and microbiological hazards. Microbiological hazards results into food borne illnesses and this could be in form of food poisoning or intoxication. The most potent agents of food borne illnesses are disease-causing pathogens of animal and human origin though cases from chemical hazards are also fatal. Recent studies have concluded that about 20 % of food poisoning cases are caused by mishandling of food in homes (Meat and Livestock Australia, 2015). Cholera cases have been reported in several African countries in recent time's e.g. Mozambique, Nigeria, Kenya, Ghana and Malawi. Also, 18 people were reported to have been killed due to methanol poisoning in Nigeria (Safe Food International, 2015) due the consumption of contaminated distilled spirit. Surveys over the last decade also show that food safety practices are poorly understood by individuals and the improvement of food quality and safety needs intervention at various segments of the food chain (Meat and Livestock Australia, 2015). Therefore, it is expedient to provide information that will help the public to have understanding and knowledge on inspection, food hazards, pest control, personal hygiene, food storage among others headings which will be addressed in this chapter. The implementation of these safety practices will help to safeguard the wellbeing and health of individuals and improve the productivity of food industries.

Learning objectives

The objective of this chapter is to discuss measures for controlling and managing hazards from farm to fork in order to ensure the safety of food.

Learning outcomes

At the end of this chapter, learners are expected to have achieved the following learning outcomes and gain knowledge of,

- Practical hygienic practices;
- Food safety risk factors;
- Basic food safety principles;
- Foodborne diseases;
- Influenceof food safety in trade;
- The purpose of food safety studies;
- Terminology related to food safety practices.

Good Personal Hygiene Practices Definitions

Cross contamination: refers to actions, areas and equipment in a high-risk area that can contaminate a low risk manufacturing area.

Food or beverage safety: refers to all practices and procedures that will ensure that food or beverage is safe for consumption by human beings. These practices and procedures are applied throughout the food chain from 'farm to fork': from raw material receiving, handling and storing until the final product is manufactured, stored and sold to the customer.

Food or beverage manufacturing environment: This indicate raw and final product storage enviroment, work area surrounding the equipments, building structures, equipments and the processing section. refers to storage of raw and final products, work area around equipment, processing line, equipment and building structure.

High risk area: these are areas where products are liable to contamination e.g microbial contamination etc.

Standard operating Procedure (SoP): these is made up of the procedures of organisations, procedures prescribed by manufacturers, food safety guidelines, good manufatuting practices, menus, specifications, applicable legislation and best practices.

Insights on Sanitation and Hygienic Practices

Hygiene and sanitation practices refer to the practices we execute to protect ourselves and our foods and include:

- Wahing of hands;
- Wearing clean uniforms;
- Putting work instructions into consideration;
- Washing, sanitising and disinfecting of production plant before and after use.

Sanitation and hygiene are basically focuses on the production of safe foods and all the people along the food chain including the people who work at the farm are responsible for the production of safet foods. The expectation of consumer is to be able to consume food products without them leading to sicknesses and diseases.

Through the execution of proper sanitation and hygienic procedures that the achievement of food safety is feasible which make the prescription of food safety law a neccessity in order for them to be followed.

Professional Hygiene and Appearance

Impressions are said to be formed within 30 seconds of meeting an individual and this is also how a workplace or an organisation is percieved including its staff. The desire to uphold a high personal hygiene standards depicts respect and value.

Tables 10.1 and 10.2 outline simple steps to improve professional appearance and personal hygiene. For example, the wearing of uniforms is mandatory in some organisation and the purpose is for the protection of employee, product and workplace.

Table 10.1: Tips on how to improve professional appearance

Step 1	Uniforms should be worn based on company standards but it should be tidy and neat
Step 2	Only covered safety shoes / water booths should be worn
Step 3	Hair must be trim, tidy, or pulled to the Facial hair is not encouraged, although it should be kept clean and covered everytime in food preparation areas
Step 4	Badges or tags, which are means of employee identification should be displayed prominently and neatly
Step 5	Nails of employees should not be long but short and neat without nail polish
Step 6	Studs should be disallowed on employees with piercings during working hours
Step 7	The use of jewellery in large quantity should be disallowed

Table 10.2 : Tips on how to improve personal hygiene

Step 8	The hands of employees much be washed after body contacts
Step 9	Employees should sanitize there hand throughly after using the rest rooms and under other circumstances.
Step 10	Employees should wash thier hands frequently with warm water and soap.
Step 11	Employee should take thier bath, wash thier teeth and change their underwear daily
Step 12	Uniforms must be clean at all times

Peculiar Challenges of Hygiene Encountered in the Agricultural Industry

There are different types of employment within the agricultural industry which are often physically demainding and due to these there are chances that employees in this industry will get sweaty and hot while working and this can lead to foul body odour which can be uncomfortable for other co-workers. Personal hygiene involves keeping the body under an healthy condition and it is important to prevent and avoid contamination from microganisms which can be present as a reult of contact with body fluids such as sweat.

What actions to take when you or other staff are sick ? The actions to be taken in cases of sickness of a member of staff are outlined below:

Give details of illness to the manager or foreman who will make the decision if the employee will continue to work or not. In an instance where by the condition is critical, employees may addrees the issue with the human resource manager who will act upon it by taken it up to the production manager. A doctors certificate needs to be obtained if the employee has an ailment which exclude him/her from working.

Box 10.1 reports the impact of hygiene of food processors on the safety of food. Work in groups and discuss the questions that follow.

Box 10.1: Impact of hygiene of food processors on the safety of food

People are the key to preventing/reducing the risks of foodborne illness. People can be carriers of disease-causing microorganisms, whilst not showing symptoms of illness. Thus, they may pass on the illness to other people. One half of all healthy people carry a type of *Staphylococcus,* either without symptoms, in a pimple, acne or skin wound.

Tortoe *et al.,* (2013) reported a studey that was conducted in year by the Natural Resources Institute (NRI, UK) and the Food Research Institute (FRI, Ghana) on the hygiene of street-vended food. It was observed that for waakye (rice and beans) in particular, bacteriological counts of *Escherichia coli, Staphylococcus aureus, Bacillus cereus* and *Clostridium perfringens* were higher than the earlier survey funded by FAO between 1994 and 1997 (Tortoe *et al.*, 2013). This was attributed to mishandling by infected foodservice workers. Hands, which can never be totally free of bacteria, are in constant contact with cooked and uncooked food items. Limiting hand contact with all food items is one of the first lines of defence in reducing foodborne illness.

Questions

- Discuss the various diseases that the bacteria *(Escherichia coli, Staphylococcus aureus, Bacillus cereus* and *Clostridium perfringens)* can cause if contaminated food is ingested.
- Discuss the economic impact of such food contaminations.
- Explain how the implementation of hygiene practices can improve the safety of food.
- Refer to any street food-vended activity in your village/ town/ city.
- Write the procedures for hygiene practices that you will recommend for implementation.

Risk Factors in Food Contamination

Learners should be able to establish an level of understanding on risk factors in relation to food contamination.

Three division of factors that could determine the safety of food and the causes of contamination are : 3 types of factors that could influence food safety and cause contamination, namely:

– Physical factors;
– Chemical factors;
– Microbiological factors.

Physical Factors

Physical factors will affect food safety throughout the food chain. The section which follows documents the risks associated with physical factors. Strategies to control the impact of the physical factors on food safety are discussed, and the crtical inspection points are highlighted.

Handling

Food product which are in the storage environment can encounter contamination if:

- They are dropped on the floor;
- They make contact with surfaces which are unhygienic such as walls; The parties responsible for product handling does practice good personal hygiene.

Storage

Temeparature is one of the main tool that can be used to control the growth of bacteria in foods. Food products should be placed into freezers and chillers quickly. The chance of bacteria contamination is reduced as temperature of storage reduces below gets below 4 °C.

Chilled air will be unable to circulate if food materials are tightly packed in the chiller and this can lead to the formation of hot air pockets. Under this condition, product temperature does not drop quickly and the chance of bacteria multiplication increases and this can negatively affect the product shelf life.

Food temperatures should be observed regularly and packaging materials such as cardboard boxes with plastic liners should be used to protect bacterial food contamination.

Inspection is expedient during the receipt of raw materials in the processing area, and the following aspect of inpection should be attended to:

- Vehicles used to transport materials should be inspected for irregularities which could cause contamination;
- The incoming materials should be inspected to check if the specifications of the factory are met before they are being introduced into the process;
- All raw materials for each production batch must be accompanied by a certificate of analysis upon delivery from the supplier;
- It should be ensured that the packaging materials are appropriate and intact with a proof that they have not been tampered with;
- Entry of unauthorised personnel should be prevented from the areas where raw materials are stored;
- All incoming materials must be passed through the quality assurance department to ensure they are suitable for processing;
- Expired materials should be rejected and the expiry date of all materials should be clearly stated.

When storing materials, they must be stored away from the wall and off the floor to avoid dampening of materials, on shelves, in a safe way and according to set guidelines and in dedicated areas or bins.

Handling Materials

- Leakages, spillages and waste in the industry must be disposed properly;
- Labelling of materials should be done corretly and damaged labels should be immediately replaced;
- Products that do not confrom to set specification must be kept away from the materials used in production.

The Floor

Any food/beverage/raw materials that come in contact with the floor must be discarded and not put back into the production line. Contact between the floor (and other dirty surfaces), and packaging materials must be avoided and they must not be left in places where they can be contaminated.

Thermometers

A suitable thermometer which cannot break or contaminate food or beverage product should be used to measure temperature of products. Thermometers such as mecury thermometers should be avoided and alcohol thermometer may be used except if the thermometer is to be used in a tank or pipeline system.

Another thermometer can be used to calibrate the thermometers that are in use in the laboratory and should be left under the care of the laboratory head.

Pest Control

Pests are major impediments to the safety of food products, some examples are cockroached, flies which are known to be carriers of microrganisms and diseases. Rodents like rats and mice assail packaging materiasl, devour foods, spread contamination, leave droppings and also destroy electical insulators and wires. The prsence of birds on production floor and storgae rooms are rare but the presence of birds nests around food processing facilities is common. Bird droppings affects the stock and contaminates the processing enviroment. This problem can be prevented by netting but getting rid of birds once they are established is a tasking procedure.

Pest Controlling Measures

An effective pest control program should be in place in food areas and littering the enviroment with scraps should be avoided to reduce the attraction of pests. Food enviroment should be tidy and orderly in other to avoid pest crevices. It is important to immediately report signs of pests to the supervisors for remedial actions. The operating licence of an operation may be threated if an auditors sees signs of pest infestation such as chewed packaging meterials and paper, droppings, leakages e.t.c. The perception of pest infestation in a processing facility may also lead to the shrinkage of the rganisations market share.

Rodents and insect baits should be kept away from food processing area, food contact surfaces and food products as these can harm people. Split and broken bait boxes should be cleaned and disposed appropiately according to industry guidelines. Draft curtains should be used to keep flies away from processsing areas and these areas should be fogged perodically to restrict insects such as flies and cockroaches.

Expired or Contaminated Raw Materials

Contaminated and expired products/raw materials should neot be used unless they are marked as suitable by the laboratory. Raw materials/products or ingredients that doo not meet company guidelines that have been returned or rejected may not be stored together with apprced products. Raw materials and/ or ingredients may not be placed in the same place withprocessed final products. Raw materials and/or ingredients storage should be 15 cm above ground level, preferably on palettes and 30 cm (minimum) away from the wall.

Chemical Factors

The following shoud be known about the chemicals to be used:

- Appropiate storage condition of chemicals;
- Properties and use of the chemicals;
- Information about its health hazards;
- Precautions for use;
- Requirements for safe handling;
- Insecticides, fumigating and cleaning agents;
- Fumigants, insecticides and cleaning agents must be kept away from the contact surfaces of products;
- Fumigants, insecticides and cleaning agents must not be stored in the same location as food/ beverages and/or raw materials.

Box 10.2 documents the food and human health hazards associated with chemical contaminants. Work in groups and discuss the questions that follow.

Box 10.2: Food and human health hazards associated with chemical contaminants

Chemicals constitue significant health hazards, although the cause and effect relationships are difficult to demonstrate. Chemical contaminants in food include : natural toxicants such as mycotoxins and marine toxins ; environmental contaminants such as mercury, lead, radionuclides and dioxins; naturally occurring chemicals in plants, such as glycoalkaloids in potatoes. Chemical contamination of food can affect health after a single exposure or, more often, after long term exposure. However, the health consequences of exposure to chemicals in food are often inadequately understood.

In 1988, some primary school pupils died and this was traced to their consumption of aflatoxin-contaminated ground nut cake called 'kulikuli' in south western Nigeria (...). Furthermore, posthumous autopsy of some children suffering from kwashiorkor revealed significant levels of aflatoxin in their brains (Oyelami *et al.*, 1996). This was equally traced to the consumption of contaminated maize-based gruel regularly fed to infants in Nigeria.

Questions

- Propose strategies that can be implemented in your country to reduce the risks of food and human health hazards associated with chemical contaminants.
- Illustrate your answer by referring to the food chain supply of a named food product, from 'farm to fork.'

Microbiological Factors

Diffrent microrganisms threaten food safety and the most important of these organisms are grouped into:

- Bacteria;
- Yeast;
- Moulds;
- Viruses.

Microrganisms have nuritient and enviromental requirements and there are several factors that controls the presence of microganisms in foods such as moisture content, water activity, temperature e.t.c. their presence in foods beyond permissble level leads to food borne illnesses in form of intoxification and poisoning with symptoms ranging from simple illnesses such as headache to more complex ones such as cancer. Examples of bacteria that pose hazards to food safety are *Escherichia coli, Staphylococcus aureus, Salmonella, Clostriduim botulinum etc.* Moulds are usually asscoiated with dry foods and have been reportedly found in food products such as maize, peanut etc. Moulds have been found to produce toxic secondary metabolites known as mycotoxonin. Examples of toxigenic producing moulds are *Aspergillus flavus, Aspergillus parasiticus* etc.

Preventative Measures Against Food Contamination

After studying this chapter you should be able to:

- Apply preventative measures against the contamination of food;
- Recognise and adhere to warning signs relating to product safety.

Table 10.3 outlines simple preventative procedures that will contribute to food safety practices and avert contamination

Table 10.3 : Outline of simple preventative measures to avert contamination and enhance food safety

1. Waste disposal	Dispose unneccessary materials
2. Chemical containers	Store separately and correctly and dipose when empty
3. Working areas	Tidy upworking areas
4. Open wounds	Open wounds should be dressed appropiately and additional gloves should be worn. If there is liklihood of exposure of the wound to food product, the employee should be placed on light duty
5. Hand washing	Wash hands as previously discussed

What will happen if we do not apply preventative food safety practices? The impact on food safety, and associated economic implications, is summarised below:

- Food could become contaminated;
- Consumers could become ill or sick from consuming it;
- Trading licenses could be lost;
- Facing payment of fines and court cases;
- Loss of market share;
- Business facing bankruptcy proceedings.

Harvest Intervals and Withholding Periods

Pre-harvest Intervals

Pre-harvest must be carried out and pre-harvest interval should not be ignored under any circumstances. A crop protection plan must be in place for crops that have been harvested continuoulsy over a period of time sin order not to compromise food safety. These plan should incorporate the engagement of field markers to clearly select crops that are ready to be harvested.

Withholding Periods

Details on chemical application and specific-witholding protocols for a spraying program can be found on the chemical label. Spray program must be balanced with harvest schedule so as to avoid clashes between both programs.

The farmer can show that pre-harvest intervals have been observed for crop protection products applied to the crops. Objective evidence include the use of clear documented guidelinessuch as, product application records, crop protection and harvesting dates from treated locations.

Conclusion

In order for food not to pose any threat to the health of individuals, various food safety principles and measures needs to be put in place, understood, considered and implemented along the food chain. Food safety systems need to be strengthened with focus on the whole spectrum of the food chain (regarding supply and production), from farm to fork. Considerable progress has yet to be achieved in African countries.

Questions for Discussion

1. Discuss the negative impacts of the absence of food safety measures in a home, industry and country.
2. Discuss GHP, GMP, HACCP as related to food safety practices along the food chain. Illustrate your answer by making reference to named food chains.

Suggested Readings

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11

Food Safety Risk Detection, Management and Communication in Agriculture

M.O. Edema, A.O. Obadina and I.O. Olotu

Summary

Risk is everywhere and the food chain is not an exception. Agricultural activities are a risky means of livelihood and smallholders are constantly being confronted, on a daily basis, with uncertain economic, environmental, social and climatic outcomes. The management of agricultural risk is of great challenge. It is expedient to identify and adequately assess the level, and nature of agricultural risks before effective risk management strategies can be put in place. The exchange of information to stakeholders on the nature and level of agricultural risks also helps to reduce these risks. This chapter is developed for use by students and development practitioners who are motivated in obtaining information on how agricultural risks can be detected, managed and communicated.

Resume

Detection de Risque en Securite Alimentaire, Gestion et Communication en Agriculture

Le risque estpartout et la chaine alimentaire n'estpas une exception. Les activites agricoles representent des moyens de survie et les petits exploitants en sont constamment confrontes tous les jours avec des resultats au plan economique, environnementaux, incertains. La gestion du risque en agriculture est un defi majeur. Il est expedient d'identifier et evaluer normalement le niveau et la nature du risque agricole avant que les strategies de gestion effective puissent etre mises en place. L'echange d'information au niveau des acteurs sur la nature et le niveau de risque agricole peuvent egalement aider a reduire ces risques. Ce chapitre est congu pour usage par les etudiants et les praticiens qui sont motives envers l'obtention d'information sur la fagon dont des risques peuvent etre detectes gerer et diffuse.

Introduction

Risk and uncertainty are inherent in agriculture and commodity supply chains. These risks arise from a wide range of factors. Risks arise at the farm level or within supply chains. The risks that farmers face are many, specific and vary in terms of climate, agricultural system of production and country (Jaffee *et al.,* 2010). Given the pervasiveness of risks, farmers, agro-enterprises, international agencies, and governments are increasingly seeking effective and sustainable strategies and approaches to mitigate, transfer, or cope with these inherent risks. Agricultural risk management is specifically filled with challenges because the risks involved are connected to one another.

From a broader view, the totality of the risk of agribuisness firms and farm face as well as operational and strategic risk are much more pervasive and complex than the perceptions about them. With increased exhibition of the model of industrial characteristics, the kind of risk that will be encountered will also differ.

Learning objectives

The objective of this chapter is to introduce the reader to rapid methods of detecting, managing and communicating risks associated with agricultural productivity from "farm to fork".

Learning outcomes

At the end of this chapter, it is expected that the reader shall be able to:

- Understand effective methods for detecting risks;
- Have information on the approaches to risk management;
- Have the knowledge of the strategies, components and channels of risk communication.

Agricultural Risk and Human Health

The agricultural sector has been found to pose significant hazrds to health globally and this is based on a report by International Labour Organisation (ILO). Agricultural work that are risky for health include exposure to the weather, close contact with animals and plants, extensive use of chemical and biological products, difficult working postures and lengthy working hours, and use of hazardous agricultural tools and machinery. Health problems which this hazards are accountable for varies from simple ailments e.g exhaustation due to heat to complex health problems such as cancer. Specific figures on the prevalence of asssociated diseases and exposure levels in developing countries are few. Illnesses caused by pesticides for example is commonly underreported even though it has been stated that 2-5 million people are victims of acute poisoning and 40 thousand die yearly. Yearly, million of impairment happen and about 170,000 are devastating for workers in the agriculture sector. These injuries are due to dangerous equipments and working conditions, limited number and low usage of protective equipments and inadequate training amongst others (Cole, 2006). Box 11.1 reports elements of incidences of agricultural related injury. Study the data and information contained therein, and answer the question set.

Box 11.1: Incidence of agricultural related injury

A research on the epidemiology of agriculture related injuries amongst African American farm workers was studied by McGwin *et al.* (2000). The injury rates and prospective risk factors among 1,246 subjects were evaluated. Subjects were contacted biannually over a four-year period to ascertain the occurrence of agriculture related injury. An increased frequency of agricultural injury was reported among the farm workers due to some factors such as reduced use of farm safety equipments, such as seat belts on farm machinery: over 40% of the injuries reported were associated with machineries and approximately 15% of the injuries were associated with equipment failure. Lack of training on food safety also increased the susceptibility of farm workers to injuries. The study identified possible ways of reducing this risk of agricultural related injury.

Question

- What do you think are the other possible ways of reducing or preventing agricultural related injury?

What are the Risks?

Risk is defined as uncertainty that affects an individual's welfare and it is often associated with adversity and loss. Harwood *et al.* (1999) simply describe risk as the possibility of adversity and refer to it as ''uncertainty that matters". Among the many definitions of risk in literature, three properties emerge as common factors. They are (1) the chance of a bad outcome (2) the variability of outcomes and (3) the uncertainty of outcomes. Distinguishing the different types of risk that an agricultural stakeholder confronts is useful to explore the different actions required for managing them. Risk may be encountered during production, processing, storage and distributions of agricultural produce occurring before and after harvesting

Some common agricultural risks are listed below:

- Risks of pesticides and related chemical use;
- Weather: rainfall or temperature variability or extreme events;
- Production or risk yield risk;
- production seasons and market revolutions;
- Geographical distribution of production and end users;
- Unique and unpredictable political economy of food;
- Low prices, market supply and demand, volatility;
- Changes in regulations, political instability and market disruption of markets;
- Illness, death, injury.

Box 11.2 : Risk of pesticide use

The influence of agricultural chemicals on ground and surface water standard continues to be a major area of concern and the dangers affiliated with a specific pesticide or related product is dependent on how toxic the compound is and its likelihood of exposure. However, it is the responsibility of the environmental protection agencies to see that the country's ground water is safe and they are also responsible for regulating the use and availability of pesticides. Each pesticide items possess risks.

Impacts of pesticides which are detrimental are:

- Severe poisoning due to a short-term or singular exposure can lead to death;
- Persistent impacts of exposure to pesticides and pesticide residues in food over a long period of time can also lead to death;
- Degradation of natural resources due to pesticide residues from storm water runoffs which leaches into groundwater or enters the stream;
- Pesticides that migrate from application sites can damage or kill non- target animals and plants;
- Improper handling of pesticides in storage facilities and loading and mixing areas can contaminate soil and water.

From a study by PAN UK on hazardous pesticides and health impact in Africa it was discovered that farmers who are growers of cowpea, vegetable, cotton, cereals, legumes and pineapple in Ghana, Senegal, Benin and Ethiopia handled, applied, stored and disposed pesticide in a manner that exposes the farmers consumers and their families to intense pesticide risks. At least one WHO (World Health Organisation) Class Ia termed as being extremely hazardous or 1b class termed as being highly hazardous pesticides or toxic fumigants were found to be in use in all their cropping systems except from pineapples from Ghana. The class Ib and Ia product were found to be mostly associated with vegetables as farmers spray them few days before they are harvested

(PAN UK, 2007). Example of class 1a pesticides are calcium cyanide, captafol, hexachloro-benzene, parathion, parathion-methyl, phosphamidon and phenyl mercury acetate and class 1b are 3-chloro-2,3-propanediol, carbofuran and fluoroacetamide (WHO, 2004).

Also, cases of pesticide poisoning were reported in a study by Mbakhaya *et al.* (1994) in East Africa between 1989 and 1990, the use of organo-chlorine pesticides on food was found to have led to 456 and 736 poisoning cases in Kenya and Tanzania.

The United Nations also stated that the potential cost that will be incurred on illnesses related to pesticide poisoning in Sub- Saharan Africa from 2005-2020 can be up to $90 billion (UNEP, 2012) based on the growing environmental and health hazards of the chemicals.

Questions

- What practical steps can be taken detect and reduce the risk of pesticide use locally, nationally and globally?
- What are the possible health effects of pesticide exposure?

Risk Awareness

It is very important to identify and adequately assess agricultural risks before effective risk management strategies can be put in place. Risk identification is therefore the basis for risk management. Risks (and their impacts) are evaluated through the quantification of 3 main factors: vulnerability, hazard and exposure.

Hazard

Hazard is the categorisation of the considered risk type for example pest,weather, price, market or policy. The azard then quantified through the assessment of 3 subvariables namely,

- Frequency: how often will/does the risk occur?
- Severity: what are the possible consequences of the risk, if it occurs?
- Spatial extent: What will be the widespread impact of the risk ? one person? onecompany? One village?

Vulnerability

Vulnerability is an approximation of the influence of the percieved risk in relation to the assets that is affected by the event as well as the consideration of the current capacity to regulate the impact.

Exposure

Exposure is the discovery of the location of livestocks, crop and farm holding that may be affected by the hazard.

Risk Detection Strategy

Risk detection strategy encompasses four steps: mapping, verification, record keeping and process improvement.

Mapping

Mapping a procedure is an important step in any risk assessment. It involves itemising each step in the agricultural process and evaluating possible areas where a safety proble can occur. A good map creation denotes the inclusion of a team of employees with diffrent areas of specilaization. In planning an effective agricultural risk detection program, there is a need to first identify, select and empower a team of internal, field-level manpower which is knowledgeble about the operations involved. Hence, the mapping process can be accurately defined.

Verification

Measurable activities must be built into a risk detection and assessment program because immeasurable risks cannot be managed effectively. Measurable activities generate data that verify that the risk management plan is being followed. The statics can also help to detect areas where improvement could be made. As an example, if a map selects irrigation water obtained from a well as a risk factor, then the quantifiable programs could be to inspect the well physically on a weekly bases and to conduct test for pathogenic *E.Coli* once in a month.

It is important to consider the consequence of a test result that is positive and have a process in place inorder to rectify such situation. Great tools in this types of situations are decision trees which assist in mapping out an interprter of generated data as well as determine who will dispose the product or work in the field as the case may be. in advance the ramifications of a positive test result and have a plan in place to handle such a situation. Decision trees are great tools in such circumstances and will assist in drawing out who will interpret the data and who will make the decision to ship or destroy products or to harvest or walk- by a field. Duties and responsibilities are clearly laid down. These decisions can be costly due to of their impacts (bottom-line). Having a prepared solution also helps to diminish negative impact and confusion.

Record Keeping

Records are critical to the to the prosperity or collapse of a risk assessment program. In addition to this, keeping agricultural data safe may be the first way of depicting conformance to written program to customers or regulators. The movement of a food safety event to a complete, legal, accurate, and properly evaluated statistics could build or destroy the case. Therefore, it is important to have a store and catalogue that contains these data:

- Firstly, data must be obtained and stored accurately in a secure manner. Checks and balances must be in place to ensure the maintanance of the integrity of the data;
- Secondly, policies in written forms that decribes data handling, verification, storage and review should be in place. Safety professionals should serve as the only body authorised to collect, store and verify safety data;
- Thirdly, both long and short term storgae option (off-site and both on site), to avoid data loss incase of the occurrence of a disater should be considered.

Process Improvement

There are continuous changes based on risks, hence risk management and assesment is never finished. All agricultural enterprise need to constantly re-evaluate and re-equip its related risk management and assesment plans. For example, as a new ranch is added, a cooler needs to be organised, a new processing line is needed, a new transportation company needs to be contracted etc. The risk management program needs also to be evaluated to ensure that it is still correct.

Risk Management

A supply chain that is agriculturally based is made up of all supply input, post- harvest, production, food service, distribution, processing, storage, marketing and consumption functions together with the 'farm to fork' continuum for a particular product. Based on the awareness of risk and its assessment, the next point of call is to determine how the parties which are involved with the risk can manage it. It is important to note that the management of risks need to be planned before the discovery of the event. There are 4 major perspectives to risk management which are outlined below.

Risk Avoidance or Risk Prevention

This is scarcely possible in the area agricultural production, particularly in developing countries which are characterised with few alternative means of non- agricultural based employments.

Mitigation

Mitigation is reducing the adverse effect of hazards and related mishaps. The ptions of mitigating risks varies and are many e.g diversifivation of livestock and crops, drainage of soil, diversification of income, resistant seeds utilization, mulching, crop calenders and risky practices avaoidance.

Transfer

Transfer means the movement of prospective financial consequences of a specific risk from one alliance to another in developing countries, insurance is the best known method of risk transfer and the utilization of informal methods of risk transfer within communities and families is very important.

Coping

Coping refers to improving the resilience to withstand and manage events, through *ex-ante* preparation and making use of informal and formal mechanisms in order to sustain production and livelihoods following an event. Although we have noted that coping is an ex-post activity, it is possible to plan and to prepare for coping activities on an ex-ante basis. This is often fiscally beneficial, as the ability to quickly respond to events often reduces losses.

Risk Management Regulations for Food Safety Assurance

Another risk which is strategic innature that have increased in recent times is regulatory risk. Increased regulations in several aspects of business dealings are being faced by farm firms. In addition to traditional areas of regulations, concerns about transportation, food safety, taxes, enviroments and labour are rapidly growing. Strategic risk analyses would ask a question in this regardwhat if my waste disposal and handling system does not conform to the new regulations. In order for many farm buisnesses to survive, the development of a contigency plans is extremely important.

Food Safety Risk Communication

Risk communication is the method in which decision-makers exchange information with variousparties of intrest on the level and nature of risks as well as risk reduction stategies

An effective risk communication should achieve the following:

- Respond to and deduce the concerns of communites;
- Reduce pressure between staff of agencies and communities of concern and agency staff;
- Give effective insights on health risk to communities.

The aim of communicationg risk is to facilitate risk assesment plans and to relay risk assesment results in a manner that efficiently aid risk management decisions ; this is in order for the risk management decisions to satisfy the project objectives and give some safety levels to stakeholders

The strategies of an appreciable risk communication are critical aspects of building trusts among several stakeholders and the community are considered first before executing te risk assesment. Community involvement as well connecting with other stakeholders (e.g. organizations, agencies, media, and officials) and maintaining relationships are key factors in the strategy of risk communication. Channelling communications to the cultural arrayof the community is expedient because it can facilitate the establishment of trust which is imperative to complete a risk assesment that will meet the needs of the community and stakeholders.

- A positve mind-set with no room for impossibility is needed for communication. It involves a science-based two-way method of exchanging opinions and information amongst stakeholders in order to enhance understanding, elucidate misconceptions and clarify myths. Risk communication is a two-way process (iterative): message sent and feedback received;

- Feedback ensures that the the concerns of stakeholders are identified and addressed and that Information obtained is analysed for improved communication.

Risk communication strategic plan should have three main components: science strategy, capacity strategy and policy strategy.

Risk Communication Strategy

Generally, planning a strategy for risk communication involves the following steps,

- Determination of the communication effort goals;
- Identification of communication barriers;
- Identification of the the audience(s);
- Identification of the concerns of the audience(s);
- Obatianing of the audience existing knowledge about the issue at hand;
- Designing the message(s) to be relayed to the community;
- Designing the best communication channels to reach people;
- Preparing to present the message;
- Anticipatation of communication problems;
- Evaluation of the program;
- Modification of the program where necessary.

Risk Communication Channels

Channels of delivering messages include the following:

- Presentations: making speeches to groups in public. Benefit: it provides the audience with the opputunity to ask questions and reaches many people at the same time. Limitations: if presentation is poor it can disrupt the perception of the community, it cannot satisfactorily adress concerns of individuals, and can become confrontational;
- Availability Sessions/Open Houses: informal meeting where members of the public can interact with staff individually. Benefit: it allows individual convesation and help to develop rapport and trust;
- Small Group Meetings: this involves the sharing of information with intrested stakeholdes/ community members. Benefit: it facilitates two- way interaction with the community;
- Limitations: it may be time-consuming to reach a few people; it may be interpreted by community groups as a means to reduce attendance; communicators must ensure that information is similar or there is a chance of being accused of telling different groups, different stories;
- Briefings: this can be held together with key officials, leaders of the community and media representatives and it is not absolutely open to the public. Benefit: it facilitates the questioning of risk assessors by key individuals before public information is released. Limitation: it should not be the only means of communicating to the community as a negative feeling may be developed by someone who has been left uninvited;
- Community mailings: Information is sent by mails to concerned members and key members of the community. Benefit: information is deliveredquickly and it may require less planning compared to a meeting. Limitation: there are no feedback opportunities;
- Exhibits: illustrations on health issues and intermediate interventions are displayed visually. Benefits: creates visual impact. Limitations: there is no opportunity for feedback since it is a one-way communication tool;

- Fact Sheets: theses are used to provide information on things. Benefit: the summary ofacts and issues are given, gives an overview of information that was delibrated upon in meetings. Limitations: facts sheets needs to be written properly in an understandable manner, it is also a one-way communication tool;
- Newsletters: it informs community of the findings and activities that are on-going in the community. Benefit: it provides basic information and shed light on findingsLimitations: it can backfire if memebers of the community misinterpret the information;
- News Release: staements issued by the media to transmit information to a large number of community members. Benefit: information gets to the audience in a cheap and quick manner. Limitations: it may exclude important details and can focus on subjects that do not need attention.

Conclusion

Agricultural risks need to be identified before they can be effectively managed through the quantification of their hazard, vulnerability and exposure. Also, the strategies, components and channels of risk management and communication need to be known before agricultural risks can be reduced/eliminated.

Questions for Discussion

1. Differentiate between acute, sub-chronic and chronic toxicity or poisoning. Give examples of each.
2. Outline other agricultural risks that were not stated in this chapter.
3. What are the physical, chemical and biological risks faced by agriculture workers and how can each be mitigated.

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Section 4

Managing Risks Associated with Climate Change for Increased Resilience

Section 4: Introduction

It has currently become more challenging to grow enough food in the developing nations due to the erratic climate changes. Existing crops and livestock breeds are exposed to unpredictable climate changes that affect their biochemistry and physiological functions leading to poor productivity or death. Studies have reported a strong negative correlation between heat stress and feed intake in pigs, poultry and dairy cows. In order to lower the heat production, farm animals reduce their physical activity, spend less time eating, which obviously compromise the production parameters like decline in milk yield, retarded growth and increased risk of diseases.

New pest and diseases have emerged in different part of sub-Sahara Africa as a consequence of the changing climate. Existing crop cultivars and animal breeds are no longer as resilient as they were before the advent of climate change. The susceptibility of the existing crop cultivars and animal breeds to the emerging pest and diseases have obviously necessitated the need for crop and animal breeding, evaluation and selection from local pools of crops and animals that have putative genes for tolerance/ resistance to the emerging pests and diseases.

This section has five chapters. Each chapter discusses practical ways to increase resilience against climate change and documents case studies on increasing resilience.

12

Effective Crop Evaluation And Sustainable Crop Management For Mitigating Climate Change Risks

K.P. Baiyeri, and S.C. Aba

Summary

Changes in atmospheric weather variables are obvious all over the world. These changes have devastating impact on agriculture particularly in the developing countries. Available measures to minimize the impact are either adaptive or mitigating. Both local and exotic germplasm pools have putative genes for adaptation to the erratic weather changes. Identification of new crop varieties adapted to the changing climate is a major strategy to avert total crop failure among subsistence farmers. Crop evaluation involves testing crop varieties, genotypes or accessions across temporal and/or spatial environments; this allows identification of pattern of adaptation and thus permits recommendation of crop type(s) for specific agricultural niches. Appropriate evaluation strategy would allow identification of crop plants possessing putative genes for abiotic and biotic stresses. Different crop evaluation strategies involving time (year, season), location, agronomic systems and statistical modelling of genotype x environment interaction are discussed. Also discussed are crop management strategies to minimize the impact of changing global climate. This chapter equips readers with appropriate skills for crop evaluation and recommendation, as well as sustainable crop management options for most suitable environment. These would ultimately enhance agricultural risk aversion. Case studies are included to prove the practicability of the methods discussed.

Resume

Evaluation effective des cultures et gestion durable des cultures pour I'attenuation des risques lies aux changements climatiques

Des changements au niveau des variables atmospheriques sont observes a travers le monde. Ces changements ont un impact tres negatif sur l'agriculture, particulierement dans les pays en developpement. Des mesures disponibles destinees a reduire l'impact sont soit adaptatives ou de reduction/attenuation. Le a la banque de genes locale et exotique possede des genes putatifs pour l'adaptation au changement erratique du climat. L'identification dune nouvelle variete de plante adaptee au changement climatique est une strategie majeure pour eviter les pertes importantes de recolte au niveau I'agriculture de subsistance desplanteurs ruraux. L'evaluation des cultures implique revaluation des varietes de plantes, des genotypes et des ou des accessions a travers un environnement temporel et ou spatial. Cecipermet d'identifier des tendances/schemas d'adaptation etpermettre ainsi la recommandation de culture type pour des niches agricole specifiques. Une strategie devaluation appropriee permettrait d'identifier les plantes qui possedent des genes putatifs pour faire face au stress biotique et abiotique. De differentes de strategie s devaluation qui concerne le temps (annee, saison), site, systemes agricoles et modelisations statistiques des genotypes x interactions environnementales sont discutes. En outre, les techniques de gestion des cultures visant a minimiser/ reduire l'impact du changement climatique sont egalement abordees. Le chapitre donne au *lecteur les outils d'evaluation et de recommandation, ainsi que les options d'amenagement des cultures dans un environnement convenable. Ce quipermettra d'accroitre la prevention des risques. Des etudes de cas y sont incluses pour justifier l'applicabilite des methodes proposees.*

Introduction

Nature made it that climatic conditions vary on daily, seasonal and inter- annual time-scales. In addition to this natural climate variability, accumulating evidence (Fischer *et al.,* 1994; Booij, 2002; Uguru *et al.,* 2010) suggests that average climatic conditions measured over extended time periods (conventionally 30 years or longer) are also changing, over and above the natural variation observed on decadal or century time scales.

Climate change refers to a long-term shift in the climatic pattern of a specific location, region or planet measured by changes in features associated with average weather components, such as temperature, wind patterns and precipitations (Warrick and Barrow, 1991); effects of which are erratic behavior of nature, such as rising global temperature, intensified drought, flooding, cyclone, etc. These changes, according to the report of the United Nations' Intergovernmental Panel on Climate Change (IPCC, 2001) could be caused by natural processes like volcanic eruptions, variations in the sun's intensity, or very slow changes in ocean circulation or land surfaces which occur on time scales of decades, centuries or longer. Nevertheless, human activities are by far the major cause of climate change through the continuous release of greenhouse gases (carbon-dioxide, methane, water vapour, sulfuric and nitrous oxides) and aerosols into the atmosphere, by changing land surfaces through urbanization and indiscriminate waste disposal, and by depleting the stratospheric ozone layer.

Global warming and the consequent climate change, and weather instability are among the key environmental issues facing the world today. Extreme weather events, such as drought and forest fire devastations in Kenya and Ethiopia or floods that rendered more than 100, 000 people homeless in Mozambique,

Botswana, South Africa and China, and recently in Nigeria are discernable indicators of changing climate. Climate change is increasingly emerging as one of the most serious global problems affecting many sectors of economic growth in the world (Lema and Majule, 2009). Such sectors widely affected by the impacts of climate-related hazards and calamities include agriculture, freshwater sources, fisheries, forestry and other land-use. Others are wildlife, energy use, industrial processes and product use, waste management, human health, and the sustainable livelihood of rural and urban communities.

It has become more challenging in the recent years to grow enough food in the developing nations due to the erratic changes in the world climate. Existing crop varieties and animal breeds are exposed to unpredictable changes that affect their biochemistry and physiological functions; the consequences of which are malfunctions of their genetic codes which may lead to death or extremely poor performance (productivity). It is therefore imperative to adopt climate smart farming practices with important synergies between sustained productivity, adaptation and mitigation strategies.

Identification of resilient crop varieties that could adapt to the changing climate is a major milestone to averting total crop failure particularly among the resource-poor farmers. This is achievable through concerted crop evaluation and management strategies. Crop evaluation involves testing crop varieties, genotypes or accessions across temporal, spatial or agronomic environments. This allows the identification of patterns of adaptation and thus permits recommendation of crop(s) or cropping systems for specific agricultural niches. The causes of climate change are global, but the impacts are local. Appropriate evaluation strategy across locations would allow identification of crop plant(s) possessing putative genes for abiotic and biotic stress tolerance.

Learning objectives

This chapter provides information on how to sustain crop yields in the emerging precarious global climate through conscientious crop evaluation and management strategies. More specifically, the fundamental of sustainable crop evaluation strategy are discussed. Besides, case studies on crop evaluation, cropping systems and crop management strategies that support risk aversion are presented.

Learning outcomes

At the end of this chapter the learners will:

1. know the consequences of changing global climate on agriculture, especially among resource poor farmers in Africa;
2. be equipped with the methods of adapting or mitigating the effects of climate change on crop production;
3. know effective crop evaluation strategies leading to the identification of crops with putative gene for tolerance to changing climate are known;
4. know how to avert crop failures through some practicable management strategies

Minimizing the impact of Global Climate Change

Climate change impacts on agriculture can be roughly divided into two groups (FAO, 2007): biophysical and socio-economic impacts.

Biophysical impacts include:

- physiological effects on crops, pasture, forests and livestock (quantity, quality);
- changes in landforms, soil and water resources (quantity, quality);
- increased weed and pest challenges;
- shifts in spatial and temporal distribution of impacts;
- sea level rise, changes to ocean salinity;
- sea temperature rise causing fish to inhabit different ranges.

Socio-Economic impacts are as follows:

- decline in yields and production;
- reduced marginal GDP from agriculture;
- fluctuations in world market prices;
- changes in geographical distribution of trade regimes;
- increased number of people at risk of hunger and food insecurity; - migration and civil unrest.

Numerous stress scenarios have also been identified with climate change by Ajaero *et al.,* (2009) with respect to the Nigerian environment. This include frequent and extreme weather events of rainfall, drought, flooding, erosion and destructive storms; general increase in annual temperatures and heat waves; erratic changes in on-set and length of seasons, making hitherto established cropping patterns unreliable and unpredictable and resulting in attendant crop failures; increase in total annual rainfall resulting in erosion, flooding and landslides, and general loss of topsoil and soil fertility; more frequent dry spells associated with crop failures and famine; higher incidence of pests and diseases; desertification, deforestation and loss of soil cover and general reduction of cultivable land area.

These climate change events adversely affect the country's crop and animal agriculture wherever they exist particularly on food security of the nation. It would be timely and most desirable that various approaches should be sought through research to finding ways of adapting, mitigating and coping with the climate change effects, and even in some cases, taking advantage of the new development for good. For instance, through the introduction of new crops to suit the emerging climate, and screening for stability of performance.

It is obvious that climate change is inseparable from agriculture owing to its implications on food security and sustainable livelihood. The emerging new climate requires development of new crops, new production techniques and technologies, new copping strategies for successful adaptation and risk mitigation at each agro ecology.

Explaining Mitigation and Adaptation in Context (of this Chapter)

Mitigation and adaptation are the two principal ways of dealing with the threat of global climate change (Ozor *et al.,* 2010). Climate change mitigation approaches are aimed at reducing or minimizing the root-causes of climate change like reduction in greenhouse gas emission and the burning of fossil fuels, efficient waste management, and the use of clean and climate-benign energy sources (solar, wind and hydro-power). We can mitigate by reducing the greenhouse gas emission into the atmosphere and enhanced sequestration through plantation and perennial grassland development. Adaptation strategies involve manipulating agricultural practices, landforms, crop cultivars and crop growth environment to suit the prevailing climate.

Adaptation strategies are multifarious. Adjustments in this direction would include enhancing biodiversity through breeding efforts to produce new crops with innate elasticity to tolerate the changing climate, use of certified seeds, adjustment in planting/sowing dates, conservation tillage to further conserve soil carbon, contour cropping, bunding and terracing. Other strategies include use of organic sources of plant nutrients, crop intensification (through mixed cropping, alley cropping, crop mixtures with arable and perennial tree species in multi- storey arrangement and cover cropping) to optimize resource use, and water stress management options like screening for resistance/tolerance, use of soil amendments including mulching, compost and potash fertilizer. An example of differential resource utilization and genotype adaptation pattern to different cropping environment is shown in Box 12.1.

Box 12.1: Alley Cropping as a Sustainable Musa spp. Production System: Lesson From IITA-Plantain and Banana Improvement Program at Onne, Nigeria

Identification of the most appropriate crop environment for existing crop cultivars or emerging new genotypes will ensure full expression of genetic potential, as a consequence, there will be a low risk of crop failure in spite of climate change. Thirty Musa genotypes (comprising of six genomic groups: AAA, AAB, ABB, AAAA, AAAB and AABB) were evaluated under alley cropping and sole cropping systems for two crop cycles. Comparatively, crops under alley cropping combined earliness with high yield (in some cases producing more than 50% higher yield than the sole cropping system). The alley system was characterized by high organic matter build-up from pruning of the hedgerows resulting to perennial mulch cover throughout the crop growth cycle, which improved the soil environment. The ratoon crop also produced significantly higher yield than the plant crop, which was attributed to longer duration of biomass accumulation and crop growth factors. The adaptation pattern of the 36 genotypes across the four environments (cropping system x cropping cycle) was established using the additive main effect and multiplicative interaction (AMMI) model; but in most cases, genotypes adapted to sole cropping were similarly adapted to alley cropping (depicting a non-crossover genotype-by-environment interaction). Alley cropping was a more sustainable cropping system than sole cropping in Musa species production (Baiyeri *et al.,* 2004). Therefore, under budget constraints, selection of putative cultivars for both cropping systems could be made under sole cropping. Would you think a repeat of this study in different countries and different agro ecologies might produce similar results?

Plant breeding programs aim to develop and deploy improved varieties that consistently display distinct phenotypic superiority in cultivation or utilization when compared to existing varieties across their cropping range in farmers' fields. The environment of evaluation influences the phenotypic expression of crops. This gave rise to the concept of genotype-by-environment (GxE) interaction, which is the differential or inconsistent performance of crop genotype(s) in diverse evaluation environments that could be spatial, temporal or cultural. Measuring GxE interaction is important for determination of an optimum breeding strategy for releasing genotypes with specific adaptation to target environments. Germplasm evaluation is therefore a key element in cultivar recommendation; it allows selection for specific adaptation and utility. Multi-location evaluation trials (MET) constitute an important step in the evaluation of breeding lines, in order to assess their adaptation and stability patterns across environments, and to ensure optimal targeting of putative lines. Thus, germplasm evaluation assures predictable (reliable) recommendation of genotype(s) or cultivar(s) for specific agro- ecological niches and production option or crop management systems amenable to the recent seemingly precarious climate.

Conventionally, agronomic interventions are designed to complement breeding efforts in optimizing crop yields in any target environment; this is because the expressivity of putative genes depends largely on the resourcefulness of the prevailing environment. In a recent study (Aba *et al.,* 2009), bunch trimming and manuring were used to optimize the fruit filling capacity of a recently selected high yielding, micronutrient fortified and biotic stress tolerant 'PITA 24' plantain hybrid. Baiyeri *et al.,* (2010) also established the efficacy of bunch trimming treatment in enhancing bunch and fruit yield in 'PITA 24' plantain (through the improvement of individual fruit size); but maintained that bunch trimming should not be delayed beyond three weeks after bunch anthesis.

The Concept of Sustainable Crop Management

Sustainable crop management takes the concepts from sustainability, which has three components: the environment, the needs of present and future generations, and the economy. Considering these components, sustainable management is the ability to keep a system running indefinitely without depleting resources, maintaining economic viability, and also nourishing the needs of the present and future generations (FAO, 1989).

Sustainable crop management could therefore be defined as the production of crop plants (to satisfy man's needs) in a system that is socially acceptable, agronomically viable, economically profitable and environmentally sound over an intergenerational time horizon (FAO, 2010). Sustainable crop management centres on an array of crop management practices aimed at improving crop yields and ensuring food security, sustaining farmers' income and livelihoods, and at the same time conserving the environment for the continuous use by present and future generations. Sustainable crop management practices should therefore provide for the needs of current and future generations, while conserving natural resources.

The concept of sustainable crop management therefore hinges on the following principles (FAO, 1989):

- It must be agronomically viable and practicable;
- It should improve or sustain crop yields in short and long run;
- It should improve farmers' income and livelihoods — there must be clear evidence of profit margin to the practicing farmers;
- It must be environmentally safe and friendly — must minimize pollution and conserve soil productivity and maximize resource use;
- The practices must be socially acceptable to the target community.

Sustainable agriculture addresses a number of problems that afflict conventional agriculture such as pollution from pesticides and fertilizers, depletion of fossil resources, loss of biodiversity and soil productivity, dwindling crop yields, low farm income, risks to human health and wildlife habitats, and recently climate change.

Sustainable crop management practices include but not limited to conservation/minimum tillage, right choice of crop varieties, permanent organic soil cover on croplands in form of fallow or mulch and use of crop residues, diversification/intensification of crop species grown in sequence and associations (crop rotation, alley cropping, multi-storey crop mixtures), building soil and water conservation structures (like contours, terraces, bunds, drains and embankments), organic agriculture (use of organic sources of plant nutrients) and integrated plant nutrient management. Also of great importance is precision farming where the optimum doses of required inputs are used at the right time, and in the right manner to maximize resource use, minimize pollution and spillage to surface and underground water.

Historically, Musa cultivations particularly on compound farms have benefited from regular organic matter input in the form of compound sweepings, livestock and kitchen wastes including miscellaneous waste water and wood ash thrown around the plantain and banana cultivation (Robinson, 1996). Mulching just like the use of organic sources of plant nutrients has been very beneficial to the productivity of crop plants. A high level of organic matter in the soil is beneficial; it stimulates root development, improves soil drainage, minimizes soil temperature fluctuations, and increases soil porosity and biological life, and at the same time holds nutrients in readily available but stable forms preventing leaching and eutrophication of adjacent water bodies. Research evidence has shown that a combination of organic and inorganic fertilizers is much more sustainable for plantain production in Nigeria, as shown in Box 12.2.

Box 12.2. Evaluation of Combined Effect of Organic and Inorganic Fertilizers on Yield of Some Plantain Genotypes in Sub-Humid Environment of Nsukka, Southeast Nigeria

Subsistence farmers rarely apply fertilizer of any type to banana and plantain farms, but due to declining soil fertility leading to rapidly declining yields in many plantations, farmers are encouraged to apply either or both organic and inorganic fertilizers. Concept of sustainable soil fertility management suggests combination of both organic and inorganic fertilizers. The yield of Agbagba, the most prevalent landrace plantain (Musa sp. AAB) cultivar in Nigeria was evaluated alongside three other maternally related plantain genotypes (Mbi-Egome, PITA

14 and PITA 24) across five nutrient management options — including organic (poultry manure applied at 20 t/ha/yr), inorganic (400 kgN + 600 kg K O per hectare per year), a complementary dose of organic and inorganic sources thereof, a Moringa alley plot and a sole control plot which had no additional nutrient input throughout the three-year study duration. Bunch yield was found highest in PITA 24 plantain hybrid, but the fruits were rather poor in size and quality. Cycling, i.e., the duration of consecutive harvests was fastest in PITA 14 hybrid resulting to highest cumulative yield over the three-year cropping seasons. The landrace genotypes particularly Agbagba had the least bunch yield but produced the most attractive fruits. Besides, the landrace genotypes were the most tolerant to the transient drought prevalent in Nsukka from November through March each year. The hybrid genotypes (PITA 14 and PITA 24) were more susceptible to logging caused by the weakening of the pseudostem tissues following the transient moisture stress. Cumulative bunch yield was somewhat at for plots that received sole application of organic or inorganic fertilizer nutrients; but the inorganic plots flowered late, with fruit bulking protracting through the dry season to the early rains causing severe pseudostem breakage of the bearing plants. Highest bunch yield was recorded in plots that received complementary doses of organic and inorganic fertilizer nutrients. These plots also recorded the earliest harvests, and shortest duration of consecutive harvests.

Crop Evaluation as an Adaptive Mechanism

The environment of evaluation influences the phenotypic expression of crops. Understanding the relationship between crop performance and the evaluation environment (genotype x environment interaction) has long been a key issue for plant breeders and geneticists. Crop performance - the observed phenotype, is a holistic function of genotype (variety or cultivar), environment, and the genotype x environment interaction (GEI) term (equation 1).

Thus, P = G + E + GEI .... (1)

Where: P = Phenotype (morphology/growth behaviour, farm-gate yield, postharvest, processing and biochemical qualities, etc.); G = Gene (genetic make-up, its durability, plasticity and potential); E = Environment (edaphic, biotic, climatic, agronomic, resource potential and availability); and GEI = Expressivity of G within the available E.

Genotype-by-environment interaction (GEI) is said to occur when different cultivars or genotypes respond differently to diverse environments. For GEI to be detected via statistical procedures, at least two genotypes (cultivars) must be evaluated in at least two environments. Breeders and agronomists usually test a diverse array of genotypes in diverse environments, which implies that GEIs are to be expected. GEI can be grouped into two categories: crossover (qualitative) and non-crossover (quantitative) interactions. Differential response of cultivars to diverse environments is referred to as crossover interaction when cultivar ranks change across environments. Non- crossover interactions represent changes in magnitude of genotype performance (quantitative), but rank order of genotypes across environments remains unchanged; i.e. genotypes that are superior in one environment maintain their superiority in other environments. The later may mean that cultivars are genetically heterogeneous but test environments are homogeneous, or genotypes are genetically homogeneous but environments are heterogeneous. All identical genotypes grown in constant (ideal) environments would perform consistently; any variance from the ideal environment leads to GEI. According to Baker (1990), the crossover interaction is more important than non-crossover interaction in crop cultivar development programs.

Researchers agree that GEI is important only when it is significant and causes significant change in genotype ranking in different environments, i.e., when different genotypes are superior (in quality of interest) in specific environments (Haldane, 1946). GEI has a negative impact on heritability; the lower the heritability of a trait, the greater the difficulty in improving that trait via selection. Understanding the structure and nature of GEI is important in plant breeding programs because significant GEI can seriously impair efforts in s e lecting s uperior genotypes relative to new crop introductions and cultivar development programs (Shafii and Price, 1998). Information on the structure and nature of GEI is particularly useful to breeders as a guide in developing cultivar(s) for all environments of interest or specific cultivar(s) for specific target environment(s) (Bridges, 1989).

According to Gauch and Zobel (1996), «where there are no interactions, a single variety of wheat (Triticum aestivu L.) or corn (Zea mays L.) or any other crop would yield the most the world over, and furthermore the variety trial need be conducted at only one location to provide universal results. And where there is no noise, experimental results would be exact, identifying the best variety without error, and there would be no need for replication. So, one replicate at one location would identify that one best wheat variety that flourishes worldwide». Measuring GxE interaction is therefore very important for the determination of an optimum breeding strategy for releasing genotypes with adequate adaptation to target environments. Typically, superior genotypes are identified and selected in experimental fields that only marginally represent the range of target environments. To ensure that the selected varieties have a reliable and predictable performance in the farmers' fields, multi-locational evaluation trials (MET) are often conducted, with the primary goal of matching superior cultivars to target environment(s) best suited to them (Yan *et al.,* 2001). Thereafter, deploying the improved cultivar(s) on a large scale in matching region(s) constitutes one powerful environmentally benign and cost-efficient means of enhancing crop productivity and farmers' income (Kueneman, 2002). Therefore, crop evaluation in terms of new crop introductions and/or evaluation of new and existing varieties or cultivars in diverse environments aimed at matching superior cultivars to target environment(s) is ultimately an adaptive mechanism to both present and emerging climates. Box 12.3 below revealed differential adaptation patterns of some sweet potato genotypes in Nigeria.

Box 12.3. Evaluation of Sweet potato (*Impomea batatas*) Genotypes for Yield Stability at Umudike, Southeast Nigeria.

Yield reliability from year to year has greater significance to the subsistence farmers than wide spatial adaptation (Evans, 1993), which is more desirable to the breeders. Baiyeri and Nwokocha (2001) evaluated the stability (consistency of performance) of total and marketable root (tuber weight e» 100g) yields of 10 sweet potato genotypes for three consecutive years using the Mean-CV model of Francis and Kannenbberg (1978) and Gauch and Furna's AMMI model (1991). The analysis of variance results showed that effects due to genotype, year, and genotype-by-year interaction were all significant; with the genotypic variance accounting for about 65% of the total variation, while genotype x year interaction accounted for only 7%. This suggested similarity in the resource availability to the crops during the three years of evaluation. The two stability models revealed that 'TIS8164' and 'TIS2532' were high yielding and stable sweet potato genotypes well adapted to Umudike agro-ecology. In contrast, 'AK/83/7' and 'TIS2498' (previously selected in the 1980s for high yield) were classified as low yielding and unstable meaning that the yield potential probably degenerated over time owing to some environmental changes related to soil, climatic or biotic stress or the interactions thereof. This scenario of changing stability pattern over time suggested the need for periodic crop evaluation to avert cultivar failure. Do you agree? If you disagree, do you have any evident-based reason for your disagreement?

Germplasm evaluation assures predictable (reliable) recommendation of genotypes (cultivars or varieties) for specific agro-ecological niches and production option or crop management system. Crop performance trials normally involve testing of promising genotypes in several environments to ensure that genotypes are recommended for cultivation in the areas of ecological advantage (i.e., where they are likely to perform best) particularly when there are strong interactions between cultivars and environments (Gauch, 1992). The occurrence of significant GxE interaction indicates inconsistent phenotypic performance of the tested genotypes across temporal and/or spatial environments, which may cause selections made in one environment to perform poorly in another environment. A large GEI reflects the need for testing cultivars in numerous environments (locations and /or years) to obtain reliable results. If the weather patterns and/or management practices differ in target areas, testing must be done at several sites representative of the target areas.

A proper dissection of the GxE interaction often leads to identification of genotypes possessing either specific or broad adaptation. Besides, this ensures that genotypes are recommended for where they are best suited, thereby minimizing unpredictable performance. A breeding program should therefore be designed to identify individual genotypes that would not only have superior performance but also display stable performance across the target environments.

Aspects of Crop Evaluation Strategies

As earlier mentioned, crop evaluation environment could be spatial (in space and location, i.e., multi-locational), temporal (in time and season to work out niche periods for the production of specific crops and to identify crops or systems possessing durable stability) or agronomic, in which case crop genotypes are evaluated across diverse management options to optimize resource potential and availability. Specific cultivars could be better adapted to particular soil type, specific prevailing climate and periodicity, and or specific agronomic interventions or tolerant to some existing biotic stresses. Our experience with bananas and plantains shows clearly specific adaptation of putative genotypes to specific environments predicated on resource availability relating to moisture availability, prevailing temperature, soil nutrients, and disease load (particularly the black sigatoka leaf fungal disease caused by *Mycosphaerella fijiensis). In* other words, genotype x environment interaction may cause discrepancies between expected and observed performance of crop species both spatially and temporally. Spatial variations have often been attributed to differences in climate (rainfall pattern and temperature), soil quality (biophysical and physicochemical characteristics), and cultural practices. Changes over time (relating to climate, soil quality and cultural practices) cause the same factors to explain temporal variations. Both types of variations have been widely reported in Nigeria for Musa species (see Box 12.4), and genotypes that produced heavy bunches and demonstrated consistent performances across cropping cycles, cropping systems and locations were identified (Baiyeri *et al.,* 2000a & b; Baiyeri *et al.,* 2004; Tenkouano and Baiyeri, 2007).

Box 12.4.: Musa Germplasm Evaluation in Nigeria

Germplasm evaluation is a global agricultural practice to ensure new crop cultivars are available for various agro-ecologies to avert crop failure due to climate change and damaging effects of emerging pest and diseases, to increase existing yield plateaus, and in some cases for improved nutrition.

Several studies (De Cauwer *et al.,* 1995; Baiyeri and Ortiz, 2000; Baiyeri *et al.,* 2004; Tenkouano and Baiyeri, 2007) have demonstrated the occurrence of significant genotype x environment interaction in Musa species performance in Nigeria owing to the distinct variability in biophysical resource potential across the country's vast landmass. For instance, Tenkouano and Baiyeri (2007) evaluated seven Musa genotypes comprising five plantain hybrids (PITA 14, PITA 21, PITA 22, PITA 23 and PITA 25), one cooking banana hybrid (BITA 7) and a local check 'Agbagba' for stability of performance and adaptation in three agro-ecologies of southern Nigeria (delineated by rainfall); including Onne (rainforest ecology), Ibadan (forest-savannah transition zone) and Nsukka (derived savannah ecology), for two crop cycles. The adaptation patterns of the genotypes and their yield stability were examined with four stability statistics; thus, the additive main effect and multiplicative interaction (AMMI) model (Gauch, 1992), genotype plus genotype by environment interaction (GGE) biplot model (Yan, 2001), simultaneous selection for yield and stability (YSi) model (Kang, 1993), and linear regression model (Eberhart and Russel, 1966). The stability analyses captured PITA 23 and PITA 25 as high yielders but differed in adaptation depicting a cross-over type of interaction. PITA 25 was specifically adapted to the derived savannah ecology of Nsukka, whereas PITA 23 performed better at Onne and Ibadan. Also, BITA 7, PITA 21 and PITA 22 produced below average yield but were stable, whereas PITA 14 produced above average yield and was the most stable genotype across the six environments (i.e., site x cropping cycle); hence was recommended for broad adoption. The four stability models showed that the local check 'Agbagba' was unstable and had the lowest mean yield.

In a similar study (Baiyeri and Ortiz, 2000) involving 75 plantain landraces and 17 banana cultivars in two locations (Onne and Ibadan), most of the quantitative growth and yield characters were significantly influenced by genotype-by-location interaction. Phenotypic characteristics most influenced by GEI was the average fruit weight, while the most stable characters were the number of fruits per bunch and the number of fruits in the first and second proximal hands, which were more or less genotype specific. Analytic procedures used to estimate and dissect GEI to different components as documented in publications cited in this case study are amenable for use on other crops.

The clonal phenotype, which corresponds to a specific genotype, can vary from year to year in the same location and or from location to location within an agro-ecology in the same year. This phenomenon, which affects genotype ranking in different environments, is known as genotype-by-environment interaction. Breeding programs aim to identify genotypes, which have high and stable yield in a range of environments across a targeted region. A genotype is considered to be stable if its response in all environments is relatively constant (Kempton, 1984).

Musa germplasm evaluation studies in Nigeria had identified a good number of high yielding and disease resistant hybrids that are adapted to some specific agro-ecological niches (Baiyeri *et al.,* 2004 & 2005; Tenkouano and Baiyeri, 2007). A study by Baiyeri and Ortese (2007) observed significant genotypic differences in nitrogen and potassium mining capacity by the landrace and hybrid genotypes suggesting differential nutrient demand by the genotypes. Nitrogen and potassium concentration also varied with tissue, genotype and plant age at sampling, implying that nutrient uptake and consequently nutrient demand varies with genotype, plant part and plant growth stage. Supplemental application of essential plant nutrients would, therefore, vary accordingly as the hybrid genotypes that have high nutrient demand would impoverish the soil faster, hence requiring more nutrient input. Besides, the peak nutrient demand in bananas coincides with the transitory reproductive growth stage (Obiefuna, 1984).

In a similar study, genome variability and plant age significantly influenced the response and sensitivities of Musa plants to transient moisture stress (Baiyeri and Ortese, 2010). Adequate potassium uptake has been implicated for high water economy under water stressed conditions. Potassium improves water use efficiency via osmotic regulation of plant stomata by modulating transpiration of water and the penetration of atmospheric carbon dioxide into the leaf.

The cooking bananas (Musa ABB) and plantains (Musa AAB) were found to be more drought tolerant than the AAA-dessert bananas. Similarly, the landrace triploid genotypes were relatively more susceptible to water stress than the tetraploid hybrids. The effects of moisture stress were also severe in the older plants (plants at the reproductive transition phase) suggesting that Musa crops at the early vegetative growth stage are more likely to withstand moisture stress than plants at their reproductive growth phase. Thus, field planting and other cultural practices (like irrigation and mulching) should be conscientiously planned to avoid prolonged exposure of plants to drought during their reproductive growth phase.

Just like in bananas and plantains, multiples of hybrid genotypes have been developed by breeders for most of the common food crops grown in Nigeria including maize, cassava (see Box 14.5), yams, cowpea, tomatoes, pepper, watermelon, groundnut, etc.; there is an obvious need to aggressively embark on evaluation of the available gene pool in the face of changing climate. This would help identify in each agro-ecology cultivars with durable genes that would withstand the vagaries of the changing climate.

Box 12.5: Evaluation of Cassava (Manihot Esculenta Crantz) Genotypes in Nsukka Agro-Ecology of Southeastern Nigeria.

In the face of the changing climate, 15 new cassava genotypes (from the National Root Crops Research Institute, Umudike, Nigeria) and one local check 'Okwoko' were evaluated for adaptation to Nsukka agro-ecology (in Nigeria) for two cropping seasons (Baiyeri *et al.,* 2012). Variability in most growth and yield parameters of the 16 genotypes was significant in both cropping seasons. Root yield was consistently lowest with the local check (18.66 and 24.67 t/ha in 2008 and 2009, respectively) compared to the highest yielder 'TMS 98/2132' which recorded 42.04 and 43.50 t/ha, respectively.

The incidence of cassava mosaic disease (CMD) was mild among the improved genotypes, whereas root rot was totally absent. The local check was more susceptible to both CMD and root rot disease among the genotypes evaluated. Tuber yield of 'TMS98/2132' was consistently the highest in the two years of evaluation. All other genotypes demonstrated marked change-order interaction with respect to tuber yield. However, the tuber yields of CR12-45 and TMS01/1371 were high with slight rank-order change across the two years. The highest tuber yields (averaged over the two years) in order of importance were TMS98/2132, CR12-45, and TMS01/1371. These three genotypes were the most adaptable to Nsukka agro-ecology and were recommended for adoption by cassava farmers for reliability of yield. Selected genotypes will probably have high and consistent yield in similar agro-ecologies in sub-Saharan Africa.

The effect of climate change on agriculture is related to variability in local climates rather than global climate patterns. Climate change is therefore expected to affect crops differently from region to region. Consequently, breeders and agronomists consider that any assessment (varietal or cultural) has to be individually considered in each local environment or agro-ecological zone (Phil-Eze and Ubachukwu, 2009), preferably through farmer participatory approach. Adoption potential of a new technology is usually higher if farmers participated (even if partially) in decisions that led to the development of the technology. In other words, the effectiveness of crop/ cropping system evaluation is better achieved when conducted with the farmers in their own native fields. The temporal and spatial test environments must be associated with the agricultural niche or farmers' groups for which/ whom eventual crop recommendation is to be made. For instance, crops found adapted to humid environment will not likely have full genetic expression in the savannah environment; thus effective crop evaluation will require using specific agro-ecology targeted for crop recommendation.

Basic Skills for Crop evaluation and Recommendation

Multi-environments evaluation trial helps to identify adaptation pattern of crop genotypes based on the stability of the phenotypic expression of important agronomic traits (Kang, 1998). This information is used to make reliable recommendations for specific uses or targeted environment of the genotypes (Gauch, 1992).

Apart from the basic knowledge of experimental designs utilized in most agricultural and biological experimentations, germplasm evaluation requires such models that can handle multi-factor experimentation and ensure that interactions among/between factors are estimated. In the presence of a significant genotype- by-environment interaction, both the stratification of environments according to their agro-climatological similarities and the determination of stability parameters for genotypes across environments are important tools for the management of the interaction effect.

Several techniques have been developed to determine the most stable genotype in a set of replicated trials across years and locations or combinations of both environments. However, these postdictive models are not useful in the identification of which genotypes and environments contribute to the GxE interaction. Nevertheless, a breeder may be interested in identifying which genotypes are adapted to specific environments and or to predict their performance in a specific location. The additive main effects and multiplicative interaction (AMMI) model was developed to provide answers for such questions (Gauch, 1992). AMMI uses the analysis of variance (ANOVA) to study the main effects of genotypes and environments and principal component analysis (PCA) for the residual multiplicative interaction.

PCA is a multi-variate/mathematical model commonly used for visualization of genetic relatedness of collections of plant or animal materials. AMMI model and the Genotype-Genotype-environment (GGE) interaction model are biplot models for data visualization in multi-location yield trials and related experiments (Gabriel, 1971).

An AMMI1 biplot is a two-dimensional graph showing the main effects on the abscissa and the first axis IPCA scores on the ordinate and containing two kinds of points for genotypes and environments, hence the name biplot (Gauch, 1992). AMMI analysis gives graphical representation that summarizes information on the main effects and the first principal component scores of interaction (PCA1) of both genotypes and environments, simultaneously (Kempton, 1984).

Results from AMMI are useful for performing mega-environment analysis in which a crop growing region is subjected into homogeneous sub-regions that have similar interaction patterns and cultivars rankings simplifying cultivar recommendations (Gauch and Zobel, 1997).

Crop varietal trials are routinely conducted to compare multiple genotypes in multiple environments (years and locations) for multiple traits, resulting in genotype by environment by trait three-way data. Varietal trials provide essential information for selecting and recommending crop cultivars.

Prior to the advent of GGE biplot analysis, variety trial data were rarely utilized to their full capacity (Gabriel, 1971). Data may be collected on many traits, but analysis limited to single trait (mostly yield) and information on other traits left unexplored. Analyses of genotype by environment data were limited to genotype and environment main effects, while genotype-by- environment interaction was treated as noise or a confounding factor. Biplot analysis methodology has bridged this gap.

A GGE biplot is a scatter plot that approximates and graphically displays a two- way table by both its row and column factors such that relationships among the row factors and column factors, and the underlying interactions between the row and column factors can be visualized simultaneously.

The biplot graph offers a powerful tool for perceiving and communicating the patterns in varietal trials since it shows, at a glance, both main effects and interaction for both genotypes and environments. In essence, labeling genotype and environment points as informative as possible enhances agricultural interpretability of biplots.

Box 12.6: Polyethylene Color Nursery Shades Influenced Seedling Quality of Pawpaw in Sub-Humid Environment of Nsukka, Nigeria.

In this study (Baiyeri, 2006), two pawpaw morph types showed specific pattern of response to five different nursery shade polyethylene colors (blue, yellow, green, red, colorless), palm frond shade and a non-shaded (control) nursery. The green polyethylene nursery shade supported the highest percentage emergence and the best seedling qualities in the nursery and had a carryover effect on field re- establishment. These results were attributed to the variable micro-climates existing within each nursery shade with variable radiation patterns and distinct temperature variation in each shade color; suggesting that the immediate micro- environment in which nursery seedlings are raised influences the growth and development, as well as, future field re-establishment. The green polyethylene shade therefore had the best blend of light quality and temperature requirement needed for optimum performance of pawpaw seedlings. A similar result was observed in Musa plantlets initiation chamber (Baiyeri and Aba, 2007) using different color polyethylene shades. Different polyethylene colors used as shade reflect different spectra of the visible light and transmit some spectra of the visible light with consequent effect on physiological behavior of plants (Hart, 1988). This variable performance of crop plants under different spectra of the visible light could be manipulated in a host of vegetables and field grown crops for improved yield in the face of the changing climate; especially with the continuous depletion of the stratospheric protective ozone layer and the concomitant increase in ultra- violet radiation reaching the earth's surface.

Since crop evaluation serves the purpose of identification and recommendation of superior genotype(s) for targeted environment(s), it is timely to recommend aggressive evaluation of available gene pools of crop species in local environments to identify putative genotype(s) that would adapt to the new environment(s). As climate change continues to affect the productivity of existing crop varieties, there is need for new crop introductions through concerted breeding efforts. Emerging genotypes should be tried on farmers' fields across locations, seasons and cropping systems to match elite cultivar(s) to targeted agro-ecologies in other to sustain crop yields. Agronomic management strategies involving crop combinations, time of planting, manipulation of type and time of organic manure/inorganic fertilizer application, tillage methods, etc. are possible ways to avert crop failure in the changing climate. Plasticulture (see Box1.6), a high-tech agricultural method, involving the use of high tunnels and plastic mulches, have high potential in Africa especially for horticultural and peri-urban production. High tunnels ensure non-seasonal crop production, especially horticultural crops (small fruits, nurseries, vegetables, and ornamental plants) requiring precision production systems. In most cases, plasticulture enhances quality produce.

Study Questions

1. Identify and discuss compelling reasons for germplasm evaluation in the face of global climate change
2. Before embarking on national or sub-regional crop evaluation, what are the major considerations to ensure that eventual genotype selection(s) is/ are predictable/reliable?
3. Discuss the relative sensitivity of stability statistics and how are they amenable to dissection of GEI?

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13

Climate Change and Emerging Plant Diseases

B.C. Echezona and K.P. Baiyeri

Summary

It has become more challenging in recent times to grow enough food particularly in the developing nations due to the erratic changes in the world climate. Existing crop cultivars are exposed to unpredictable changes that affect their biochemistry and physiological functions leading to extremely poor productivity or death. New pest and diseases have emerged in different parts of sub-Sahara Africa as a consequence of the changing climate. Thus, existing crop cultivars are no longer as resilient as they were before the advent of climate change. However, once crop growth environment is properly harnessed to suit the changing climate, the resilience of the growing crops to emerging pests and diseases improves. Basic framework to understanding the conceptual causes of climate change, its impact on plant diseases and information on how pathogens adapt to seasonal environments and climate change are provided. Furthermore, this chapter will enable proper understanding of the ecological effects of seasonal drivers of climate change to plant diseases.

Resume

Changement climatique et emergence de maladies des plantes

Il devient de plus en plus difficile, ces derniers temps, de produire suffisamment de nourriture, en particulier dans les pays en developpement, en raison des changements erratiques du climat mondial. Les cultivars existants sont exposes a des changements imprevisibles qui affectent leurs proprietes biochimiques et les fonctions physiologiques, conduisant a une faible productivity ou a la mort. De nouveau ravageurs et maladies sont apparus dans differentes parties de l'Afrique sub-saharienne comme une consequence de revolution du climat. Ainsi, les cultivars existants ne sont plus aussi resistantes comme ils etaient avant l'avenement du changement climatique. Cependant, une fois les conditions de croissance des plantes sont bien reunies pour faire face a l'evolution du climat, la resilience des cultures en croissance face aux ravageurs et aux maladies emergentes s'ameliore. Ceci constitue une base pour la comprenhension des causes conceptuelles du changement climatique, de son impact sur les maladies des plantes et des informations sur la fagon dont les agentspathogenes s'adapternt a des environnements saisoniers et au changement climatique. En outre, ce chapitrepermettra une bonne comprehension des effets ecologiques des leviers saisoniers du changement climatique.

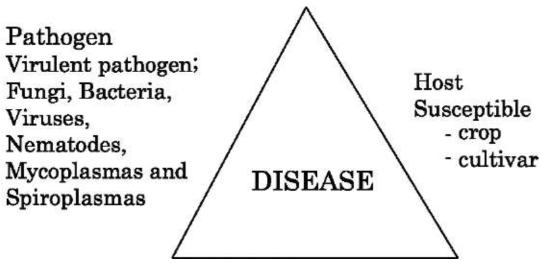
Introduction

Global climate has been changing since pre-industrial times. According to Chakraborty *et al.* (2000), atmospheric carbon dioxide (CO_2) a major greenhouse gas, has increased by nearly 30% and temperature has risen by 0.3 to 0.60C. From this report, the intergovernmental panel on climate change predicts that with the current emission scenario, global mean temperature would rise between 0.9 and 3.50C by the year 2100. There are, however, many uncertainties that influence these predictions.

Despite the significance of weather on plant diseases, comprehensive analysis of how climate change will influence plant diseases that impact primary production in agricultural systems are presently unavailable. Evaluation of the limited literature in this area suggests that the most likely impact of climate change will be felt in three areas: in losses from plant diseases, in the efficacy of disease management strategies and in the geographical distribution of plant diseases. Climate change however could have positive, negative or no impact on individual plant diseases. Results indicate that climate change could alter stages and rates of development of the pathogen, modify host resistance, and result in changes in the physiology of host- pathogen interactions (Coakley *et al.,* 1999).

According to Guro (2005) climate is the average of weather over time and space, while weather is basically the way the atmosphere is behaving, mainly with respect to its effects upon life and human activities. Weather consists of the short-term (minutes to months) changes in the atmosphere. It is thought generally in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure, as in high and low pressure. In most places, weather can change from minute-to-minute, hour-to-hour, day-to-day, and season-to-season. Climate is the description of the long-term pattern of weather in a particular area. Scientifically, climate is defined as the average weather for a particular region and time period, usually taken over 30-years. It's really an average pattern of weather for a particular region. The climate of a place refers to the average of precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail storms, and other measures of the weather that occur over a long period in a particular place (Coakley *et al.,* 1999).

A plant disease on the other hand, may be defined as a physiological disorder or structural abnormality that is deleterious to the plant or to any of its parts or produce or that reduces their economic value (Arene, 1999). Diseases are caused by various agents either acting singly or in combination with one another (Wheeler, 1969). The agents fall into seven groups. They are animate agents like bacteria, fungi, viruses, nematodes, some insects, some parasitic plants and inanimate agents like mineral deficiencies and excesses and unfavorable environmental conditions. The factors that interact to cause a disease are susceptible host, virulent pathogen and favorable environment. This is described as disease triangle represented as in Figure 13.1:



Air temperature	Soil fertility	Rainfall
Soil temperature	Soil type	relative humidity
	Soil pH	Soil moisture

Figure 13.1: Disease triangle (Source: Francl, 2001).

Recently, time and human were added as fourth and fifth factors respectively, which changed the concept to «disease pyramid» as represented in Figure 13.2:

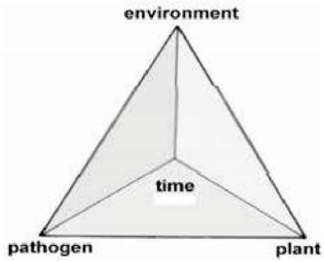


Figure 13.2: Disease pyramid showing the interaction of components of plant disease expanded to include time and humans (Francl, 2001).

The time as the fourth component together quantifies the amount of disease. The human equation affects the three components of the disease triangle and was considered as a fifth component in disease development. These later components changed the disease triangular shape to disease pyramid as shown in Figure 2. Plants can be considered hosts but can vary in their degree of susceptibilities to pathogen. The different levels of susceptibility include:

- Immune - cannot be infected,
- Susceptible - can be infected,
- Resistant - may or may not be infected, and is the plant able to prevent the pathogen from killing it. i.e. defense compounds.

Changes in host plants may therefore result in expectable alterations of disease incidence, depending on host plant growth stages and type of pathogen. The pathogen factor includes amount of inoculums present per unit time, pathogen genetics, and virulence of the pathogen, type of reproduction (monocyclic or polycyclic) and ecology and mode of spread (air, soil, seed and vector dependency). Environment such as moisture, temperature, effect of human culture practice (monoculture, amount of inoculums, introduction of new pathogens) can also modify the degree to which the relationship between a pathogen and its host is expressed. Changes in season length may affect the utility of management practices that depend on reducing inoculum load at a local level. When we look at some examples of plant disease epidemics from the published literature, we not only notice that the incidence or severity starts near zero and then increases dramatically, but we also can discern some distinct patterns of development with time. For example, in Phytophthora blight of pepper seedlings (*Phytophthora capsici)* and Fusarium kernel rot *(Fusarium moniliforme,* currently *F. verticilloides)* of maize, disease progress is roughly linear (Anon, 2014).

Learning objectives

This chapter provides:

1. Basic framework to understanding the conceptual causes of climate change and its impact on plant diseases.
2. Information on how pathogens adapt to their seasonal environments and to climate change.
3. Proper understanding of the ecological effects of seasonal drivers of climate change to plant disease.

Learning outcomes

1. There will be proper perception of the cause and effect of climate change particularly as it concerns plant disease development and management.
2. Farmers, research institutes and other stakeholders are empowered in their plant disease prognoses.
3. Stakeholders have improved understanding and management of plant diseases in the face of current and future climate.
4. Direction for future relevant research is known

Causes of Climate Change

The term 'climate change' is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather conditions, or in the distribution of weather around the average conditions (i.e., more or fewer extreme weather events). Climate change is caused by factors such as biotic processes, variations in solar radiation received by Earth, plate tectonics, and volcanic eruptions. Certain human activities have also been identified as significant causes of recent climate change, often referred to as «global warming».

Scientists agree that the main cause of climate change is human activities, which magnify the 'greenhouse effect' — a natural process in which gases in the atmosphere warm the earth by trapping heat that is radiating towards space (NASA, 2013). Factors that can shape climate are called climate forcings or «forcing mechanisms». These include processes such as variations in solar radiation, variations in the Earth's orbit, mountain- building and continental drift and changes in greenhouse gas concentrations. There are a variety of climate change feedbacks that can either amplify or diminish the initial forcing. Some parts of the climate system, such as the oceans and ice caps, respond slowly in reaction to climate forcing, while others respond more quickly

Manning (1995) recorded that continued world population growth results in increased emission of gases from agriculture, combustion of fossil fuels, and industrial processes. This causes changes in the chemical composition of the atmosphere. According to the report, increased solar Ultraviolet-B (UV-B) radiation is reaching the earth's atmosphere, due to stratospheric ozone depletion. Carbon dioxide (CO_2), ozone (O_3) and UV-B are individual climate change factors that have direct biological effects on plants. Such effects may directly or indirectly affect the incidence and severity of plant diseases, caused by biotic agents. Carbon dioxide may increase plant canopy size and density, resulting in a greater biomass of high nutritional quality, combined with a much higher microclimate relative humidity. This would likely promote plant diseases such as rusts, powdery mildews, leaf spots and blights. Inoculum potential from greater overwintering crop debris would also be increased.

A layer of greenhouse gases, including water vapour and smaller amounts of carbon dioxide, methane and nitrous oxide, act as a thermal blanket surrounding the Earth. This absorbs heat and warms the surface to a life- supporting average of 15°C. As energy slowly escapes out of our atmosphere, the greenhouses gases absorb some of it, which warms the Earth further. Although these gases are present naturally, human activity is increasing their concentrations, thereby exacerbating the greenhouse effect (NASA, 2013). Carbon dioxide (CO_2) has been recognized as the main greenhouse gas of concern. A finite amount of carbon is stored in fossil fuels, the sea, living matter and the atmosphere. Without human influence there is a fine balance in the amount of carbon in these stores, but when humans cut down trees or burn fossil fuels, they release extra carbon into the atmosphere (NASA, 2013).

Warming caused by man-made emissions of greenhouse gases also increases the amount of water vapour in the air by boosting the rate of evaporation from the oceans and elsewhere. This amplifies the warming effect, as well as the amount of rain and snow falling to Earth which can lead to extreme weather patterns (NASA, 2013).

The burning of fossil fuels was regarded as the greatest source of these man- made emissions (IPCC 2007)). As the world's population grows, more people are burning fossil fuels for energy. By driving cars, heating our homes with oil, gas, or electricity from coal-fired power stations, we release greenhouse gases into our atmosphere. In 2005, burning fossil fuels sent about 27 billion tons of carbon dioxide into the atmosphere (Directgov- Causes of climate change:http://www. direct.gov.uk/en/ Environmentandgreenerliving/Thewiderenvironment/ Climatechange/DG_072920). Food production also leads to the burning of fossil fuels. Land must be cleared for farming, which often contributes to deforestation. Food is also often transported across the world to reach distant markets, meaning fossil fuels are burnt in the process. Fertilizer production for crops and methane gas emitted by livestock also contributes to emissions.

Scientists estimate that forest loss and other changes to the use of land account for around 23 percent of current man-made carbon dioxide emissions. This is because forests are a natural 'sink' of carbon dioxide. By harnessing the sun's energy, plants absorb carbon dioxide from the air as they grow, turning the carbon molecules into the building blocks of their trunks, branches and leaves. But when forests are cleared or burned, their stored carbon is released back into the air, contributing to global warming.

The Earth's climate has changed throughout history. In the last 650,000 years there have been seven cycles of glacial advance and retreat. Most of these changes are attributed to very small changes in the Earth's orbit changing the amount of energy the Earth receives from the sun (NASA 2013). Chakraborty *et al.* (2000) reported that Global climate has changed since pre-industrial times with atmospheric CO_2 a major greenhouse gas, increased by nearly 30% and temperature risen by 0.3 to 0.6°C. They noted that intergovernmental panel on climate change predicts that with the current emission scenario, global mean temperature would rise between 0.9 and 3.5°C by the year 2100.

Changes in the modern climate show a discernable warming trend that can only be partly explained by natural causes (European Commission - Climate Change: http://www.ec.europa.eu/clima/sites/campaign/index_en.htm).

The overwhelming majority of scientists agree that this is due to rising concentrations of greenhouse gases in the atmosphere caused by human activities. The current human-induced warming trend is of particular significance as it is occurring at an unprecedented rate (Met Office - Climate Change: http://www.metoffice.gov.uk/climate-change/).

Evidence for the measured climate change on crops and their associated pests and pathogens is starting to be documented. Globally atmospheric carbon dioxide (CO2) has increased, and in northern latitudes mean temperature at many locations has increased by about 1.0-1. 4^{0}C with accompanying changes in pest and pathogen incidence and to farming practices (Coakley *et al.,* 1999). Many pests and pathogens exhibit considerable capacity for generating, recombining, and selecting fit combinations of variants in key pathogenicity, fitness, and aggressiveness traits that there is little doubt that any new opportunities resulting from climate change will be exploited by them (Gregory *et al.,* 2009).

Research on impacts of climate change on plant diseases has been limited, with most work concentrating on the effects of a single atmospheric constituent or meteorological variable on the host, pathogen, or the interaction of the two under controlled conditions. Results indicate that climate change could alter stages and rates of development of the pathogen, modify host resistance, and result in changes in the physiology of host- pathogen interactions (Coakley *et al.,* 1999). The most likely consequences are shifts in the geographical distribution of host and pathogen and altered crop losses, caused in part by changes in the efficacy of control strategies.

Climate Change impacts on Agriculture and Plant Diseases

Scientists observed that despite tremendous improvement in technology and crop yield potential, food production remains highly dependent on climate, because environmental factors like solar radiation, temperature and precipitation are the main drivers of crop growth (Dahlstein and Garcia, 1989). The sedentary nature of plants makes them particularly vulnerable to climate change. A prime example is the quiver tree from the Namib Desert in southern Africa, which is disappearing from northern parts of its range due to drought stress (IUCN, 2009). Plant diseases and pest infestations are influenced by climates. Altered weather pattern can increase crop vulnerability to infection, pest infestation and choking weeds. Ranges of crop weeds, insects and diseases are projected to expand to higher latitude (Sutherst, 1990). Sequential extremes can affect yields and diseases. Drought, followed by intense rains for example, can reduce soil water absorption and increase the potentials for flooding, thereby creating conditions favoring fungal infestations of leaf, root and tuber crops in run off areas (Rosenzweig *et al.,* 2001). An example of the effect of soil additives on nematode population dynamics is shown in Box 13.1.

Box 13.1: Plant Growth and Nematode Dynamics in Response to Soil Amendments With Neem Products, Urea and Compost

Environment as one of the principal epidemic requisites and a prime factor modulated by climate has been reported to have a great impact on the dynamics of pathogens in the soil. To illustrate this dynamics, Akhtar (1999) showed that when urea and compost manure were incorporated in field soil at different doses to alter the environment the populations of nematodes in the soil increased with increasing doses of the amendments. Suggesting that soil additives could influence nematode population dynamics. The consequence is that some seemingly good additives may end up portending danger to crop production. Note, however, that this observation might vary across ecological zones and soil types, giving room for experimental trials across Africa.

Many people throughout the world rely on rain-fed agriculture. As a result, it is highly vulnerable to changes in climate variability, seasonal shifts, and precipitation patterns. Any amount of warming will result in increased water stress. Roughly 70 percent of the population lives by farming, and 40 percent of all exports are agricultural products (WRI, 1996). One-third of the income in Africa is generated by agriculture. Crop production and livestock husbandry account for about half of household income. The poorest members of society are those who are most dependent on agriculture for jobs and income. (Odingo, 1990; FAO, 1999). Findings on the impact of climate change on plant diseases are often inconsistent and context dependent.

Climate change may have positive, negative or no impact on plant diseases. Manning (1995) reported that ozone (Og) is likely to have adverse effects on plant growth and that necrotrophic pathogens may colonize plants weakened by O_3 at an accelerated rate, while obligate biotroph infection may be lessened. According to this report, ozone is unlikely to have direct adverse effects on fungal pathogens. The report further suggested that ozone effects on plant diseases are host plant mediated. The principal effects of increased UV-B on plant diseases would be via alterations in host plants. Increased flavonoids could lead to increased diseased resistance. Reduced net photosynthesis and premature ripening and senescence could result in a decrease in diseases caused by biotrophs and an increase in those caused by necrotrophs. Manning (1996) noted that microbial plant pathogens are less likely to be adversely affected by CO_2, O_3 and UV-B than are their corresponding host plants. Given the importance of plant diseases in world food and fiber production, it is essential to begin studying the effects of increased CO_2, O_3 and UV-B (and other climate change factors) on plant disease. We know very little about the actual impacts of climate change factors on disease epidemiology. Epidemiologists should be encouraged to consider CO_2, O_3 and UV-B as factors in their field studies.

While climate change is the most serious threat to the survival of many species, some are benefiting from a changing climate. Warmer climates and changes in rainfall levels are opening up previously inhospitable habitats to many species, including those described as 'generalists'. But while most of these invasive species do no harm in their new environments, a small number do disproportionate harm and are thriving at the expense of those species adapted to a narrow range of environmental conditions, unable to quickly adapt to the changing climate.

Coakley *et al.* (1999) indicated that climate change could alter stages and rates of development of the pathogen, modify host resistance, and result in changes in the physiology of host-pathogen interactions. The most likely consequences are shifts in the geographical distribution of host and pathogen and altered crop losses, caused in part by changes in the efficacy of control strategies.

The susceptibility of a particular crop cultivar or variety to a particular plant disease in an environment where other cultivars and /or varieties are resistant lends credence to plant host as one of the factors that can influence disease outbreak. As change in climate could make a host to be susceptible/resistant to a disease, the host could respond to the action of the stressor by expressing this damage or tolerance in the form of low or high yield, respectively. Aba *et al.* (2011) demonstrated that two plantain genotypes similarly susceptible to a fungal disease varied significantly in their yields (See Box 13.2 for details).

Box 13.2: Impact of Poultry Manure on Growth Behaviour, Black Sigatoka Disease Response and Yield Attributes of two Plantain (Musa spp. AAB) Genotypes

The vulnerability of a host to disease outbreak is dependent on the genetic constitution of the host plant and its environment, which could be altered by climate change. Three rates of decomposed poultry manure 0, 10, and 20 t ha^{-1} were evaluated on growth, black Sigatoka disease response and yield attributes of "PITA 24" (a plantain hybrid) and its maternal grandparent 'Mbi-Egomi' (a landrace plantain) by Aba *et al.* (2011). The authors found that increasing manure rates reduced days to harvest by over 30 days; similarly, plant stature, suckering, leaf chlorophyll content, index of non-spotted leaves (index used in assessing Sigatoka disease incidence), crop cycling and total biomass increased with increasing manure rate. Notwithstanding the susceptibility of both genotypes to black sigatoka disease, the improved yield variables observed in 'PITA 24', according to the workers, suggests that it is somewhat tolerant to the virulent air-borne fungal leaf spot disease. The study suggests that the deleterious effect of pathogens even in the face of climate change can be ameliorated by some cultural practices like appropriate fertilizer management. A practical way to confirm this idea, or otherwise, is to set up experiments using different crops at different seasons and locations.

(Chakraborty, 2000) noted that by broadening the perspective beyond agriculture, this review integrates cross-disciplinary knowledge to show that at scales relevant to climate change, accelerated evolution and changing geographic distribution will be the main implications for pathogens. The report emphasized that new races may evolve rapidly under elevated temperature and CO_2, as evolutionary forces act on massive pathogen populations boosted by a combination of increased fecundity and infection cycles under favorable microclimate within enlarged canopy. Changing geographic distribution will bring together diverse lineages/genotypes that do not share common ecological niche, potentially increasing pathogen diversity. Mckenzie *et al.* (2013) acknowledged that climate change may not directly affect the abundance of an herbivore on above-ground habitat, however, if the abundance or impact of an associated antagonist is reduced then climate change may increase herbivore abundance indirectly.

Management of Plant Diseases through Climate Change

Majority of the global diseases are caused by environmental exposures, which can be averted. Well-targeted interventions can prevent much of this environmental risk. It is estimated that more than 33% of diseases is caused by environmental exposures.

By focusing on the environmental causes of diseases, and how various diseases are influenced by environmental factors, the analysis breaks new ground in understanding the interactions between environment and plant health. The environment has been reported to be a major abiotic factor affecting aphid's population dynamics (Liu and Perng, 1987; Kocourek, *et al.*, 1994). The environment of an organism comprises the totality of all the biotic and abiotic factors surrounding the organism. In crop production, some of these factors include the nutrient status of the soil. This is necessary at optimum level for proper growth of the crop. Below this level it becomes expedient to ameliorate it by modulating the environment through some cultural practices like addition of organic manure. Echezona and Nganwuchi, (2006) reported that application of some of these organic matters like poultry manure could somewhat predispose crops like cultivated pepper to pests and diseases. Box 13.3 illustrates this observation.

Box 13.3: Poultry Manure Application and Varietal Effects of Chilli Pepper (Capsicum Species) on Insect Pests and a Disease in Humid-Tropical Environment

Organic manure application could alter the crops environment and thereby affect the micro fauna load of the crops. The effect of poultry manure rates (0, 20, and 40 t ha-1) and three varieties of chilli pepper, Capsicum annum vars. tartashi and tarugu and Capsicum frutescens var. Birds eye chilli were therefore evaluated in relation to the infestation by major insect pests and a major disease of pepper by Echezona and Nganwuchi (2006). All the varieties were found to be susceptible to Pepper Veinal Mottle Virus (PVMV) with a disease incidence of between 37% and 45%. Records taken 100 days after transplanting showed that increasing rates of poultry manure significantly ($p<0.05$) increased incidences and severities of PVMV symptoms on the plant leaves compared to where no manure was applied. The different varieties were also found to significantly ($p<0.05$) affect the infestations by insect pests as well as the incidences and severities of PVMV symptoms, such that PVMV symptoms and insect pests were found more on tartashi and tarugu, exotic varieties, than any other given the same treatment. The study indicated that germplasm evaluation would be very important to mitigate the effects of emerging pathogens as a result of the changing climate.

The general principles of plant disease control according to Arene (1999) are based primarily on the understanding of the disease ecosystem. The disease ecosystem is a triangle comprising host, the pathogen and the environment each equidistant to one another and situated at the vertexes of the triangle, all the points interact. More recently, a fourth and fifth component were added which are time and human (Francl, 2001). The susceptible host has to be present, the disease inoculums has to come in contact with the host, and favorable environmental conditions have to prevail at the appropriate time and may be through human activities to predispose the host and pathogen for the development of the disease syndrome. Seasonal variation, which is a component of climate change, is a typical evidence of the effect of time component on the vulnerability of a host to disease infection. Fajinmi *et al.* (2011) demonstrated that seasonal fluctuation affects the distribution of aphid vectors of Pepper Veinal Mottle Virus (PVMV) on cultivated pepper in Nigeria. See Box 13.4 for further details.

Box 13.4: The Effect of Agro-Ecological Zones on the Incidence and Distribution of Aphid Vectors of Pepper Veinal Mottle Virus, on Cultivated Pepper (Capsicum annuum) in Nigeria

To study the impact of climate change on the incidence of aphid vectors of Pepper Veinal Mottle Virus (PVMV) in different ecological zones of Nigeria, the distribution of the vectors as well as the virus itself were studied on cultivated pepper in the major producing areas of the six agro-ecological zones in Nigeria by Fajinmi *et al.* (2011). Population of aphid vectors increased progressively in all the agro- ecological zones from March at the onset of rainy season reaching a peak in August and then declining from September at the onset of the dry season. The Humid forest and Derived Savanna agro-ecological zones recorded highest mean population of aphids per leaf and types of aphid's species compared with other agro-ecological zones. Fajinmi *et al.* (2011) finally concluded that the high incidence of aphid vectors on pepper plant in the Derived savanna and the humid forest agro-ecological zones compared with other agro-ecological zones might have been influenced by the climate and vegetation of these zones. These zones are characterized by thick vegetation and warm humid climate, coupled with the presence of many secondary host plants for the aphid vectors. This could have encouraged the rapid multiplication of the aphid and the virus itself and subsequent increase in the efficiency and the ability of the aphid species to successfully transmit the virus.

Control measures are therefore designed to secure at appropriate time crop varieties that are not susceptible to reduce the amount of inoculums from which the disease starts or to reduce the rate at which it increases; and to utilize environmental conditions that are unfavourable for the development of the disease. These could be achieved through regulations by human activities. These methods include (Maslin, 2004):

- encouraging climate regulation;
- encouraging disease regulation;
- encouraging plant biodiversity;

- encouraging insect biodiversity;
- encouraging microbial biodiversity and bio-control;
- encouraging use of resistant genes;
- encouraging water regulation;
- encouraging cultural method of pest control;
- encouraging judicious and limited use of pesticides;
- monitoring local environment conduciveness to disease during the season;
- ensuring the implementations of all the agreements reached in all the global climate summits held in Washington, New York, Pittsburgh, London, Bangkok, Copenhagen as well as the Kyoto protocol agreement to reduce greenhouse gasses.

Any change in climate may change everything. Climate change has a significant impact on biodiversity and therefore on ecosystem inhabiting pests and diseases. Therefore, substantial reductions of heat-trapping gas emissions in developed countries and adaptation strategies mapped out in the various global climate summits are crucial. For example, biodiversity must be managed to ensure that conservation is occurring at appropriate places, and that adequate habitat is preserved to enable species plants, animals and humans to migrate. Also efforts will be made by all stakeholders to reduce greenhouse gasses to the barest minimum. The conservation of biodiversity will ensure delivery of ecosystem goods and services necessary to human life support systems (soil health, water, air, etc.). An integrated approach to environmental management is therefore crucial to ensure sustainable benefits (Francl, 2001).

Conclusion

Many consequences of climate change include but not limited to alteration of disease status of plants. Mitigating the effects of climate change will reduce the catastrophic losses brought on plants. In agriculture, the effect of climate change on emerging plant diseases is currently a topical issue. The main cause of climate change is anthropogenic activities. The resistance or vulnerability of any host plant-to-plant disease is a function of the prevailing environmental factors, which impact the host and the host status at a particular point in time. These environmental factors tend to alter the biochemistry and physiological functions of the plant thereby influencing the disposition of the host plants to emerging diseases. Environmental factors are components of the climate (temperature, rainfall, wind velocity, *et* c.), which over the years affect the aggressivity or otherwise of pathogens to cause diseases. Therefore, to mitigate the impact of climate change on emerging plant diseases requires proper modulation of environmental (climatic) factors to enhance the resistance of the host plant at a particular time. This could be achieved by well-targeted interventions by man in order to ameliorate the risk factors of the climate.

Study Questions

1. Distinguish between weather and climate change.
2. What are the causes and effects of climate change?
3. Briefly discuss the impact of climate change on disease development.
4. Discuss the epidemiology of any plant disease using some key environmental factors.
5. What could a citizen do in an urban settlement to help mitigate climate change?

Suggested Further Readings

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14

Mitigating Effects of Climate Change Risks in The Smallholder Poultry Sector In Africa

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Summary

This chapter describes the characteristics of the smallholder poultry keeping in Africa. It assesses the contribution of the sector in chicken meat and hen eggs in Africa. The chapter provides a review of the potential impact of climate change on smallholder poultry keeping in Africa. It analyses the impact of climate change on the productivity of smallholder production systems, the risks and vulnerabilities of the sector and addresses the opportunities for increasing the resilience of smallholder poultry production systems in Africa.

The chapter further discusses the adaptation strategies to climate change and the coping methods for mitigating the effects on the sector in Africa, by recognising indigenous knowledge in adaptation and mitigation strategies to climate change. The chapter contains four Case Studies, aimed at preparing the students in proposing and validating local climate change mitigation and adaptation strategies, which focus on concrete local actions in their home country, whilst addressing the global challenges.

Resume

Attenuation des effets des risques lies au changement climatique chez les petits producteurs de poulets en Afrique

La majorite des elevages de volaille en Afrique sont conduits par de petits exploitants. Ce secteur d'activites est caracterise par des systemes de production extensifs vulnerables aux risques engendres par les changements climatiques dont les enjeux et cles sont identifies et presentes. Cela devrait aider les producteurs qui utilisent les ressources disponibles pour ameliorer la resilience de leurs moyens d'existence. Ainsi, ce chapitre met l'accent sur la contribution des petits exploitants et leur vulnerability, leur sensibilite aux changements climatiques et les strategies de lutte et d'adaptation. Par ailleurs, les savoir et savoir faires locaux pour le developpement et le renforcement des strategies d'adaptation aux changements climatiques sont consideres. Les etudes de cas traitees dans ce chapitre decrivent, entre autres, des situations qui permettront aux etudiants de refleter et d'explorer des strategies de lutte contre les effets des changements climatiques dans les petites exploitations d'elevage en Afrique. Ce chapitre concerne egalement les formateurs.

Introduction

The Food and Agricultural Organisation (FAO) has classified the poultry production system into four operational sectors. These are: sector 1 - industrial and integrated production; sectors 2 and 3 - commercial production and sector 4 — village and backyard production (FAO, 2004, 2006). The classification is given in Table 14.1. Four major criteria are used to classify the poultry sector, namely (i) level of bio-security (ii) housing (iii) market outputs and (iv) dependence on markets for inputs.

Table 14.1. Classification of the poultry production sector

Poultry production system	Sector 1	Sector 2	Sector 3	Sector 4
Criteria used	Industrial and Integrated	Commercial		Village / Back-yard
1. Bio-security	High	Medium	Low	Low
2. Housing	Closed	Closed	Closed/Open	Minimal
3. Market outputs	Export/Urban	Urban/Rural	Urban/Rural	Rural/None
4. Dependence on markets for inputs	High	High	High	Medium/Low

Source: FAO, 2004; 2006

In African countries, however, the majority of poultry are still kept by smallholders in less intensive systems, essentially in sector 3 and sector 4 (FAO, 2004; 2006). The advantages of these systems are the low levels of market inputs required and the unique products that they produce. The role played by the smallholder poultry production are pertinent and include (i) security of supply of animal- based protein sources coming from poultry meat and hen eggs and (ii) nutrition for health. Poultry and poultry products will continue to play an important social and cultural role in the life of rural livelihoods in Africa (FAO, 2010; Ojwang' *et al.,* 2010; Thornton *et al.,* 2013), with significant impact on development (Alders and Pym, 2009). Furthermore, the contribution of women and children to the smallholder production system in Africa has been reported in many studies (Neville *et al.,* 2008; IFPRI, 2009; FAO, 2013).

However, these poultry production systems are practised by smallholder communities whose livelihoods are vulnerable to the vagaries of climate change. The challenges and key issues arising from global climate change need to be identified and addressed. This is essential as rural communities must prepare themselves for the possibility of food shortages and make appropriate use of resources to enhance their resilience.

The questions that are addressed in this chapter are:

- What is the contribution of the smallholder poultry keeping to the supply of animal-based protein supply in Africa and the related nutrition issues?
- How sensitive is smallholder poultry keeping to risks arising from climate changes?
- What are the challenges arising from climate change, the security of food supply / nutrition, and resilience of the smallholder poultry production systems?
- How vulnerable are the smallholder poultry production systems?
- What are the strategies for mitigating and coping with climate change impacts?
- What are the gaps in knowledge?
- What is the key evidence required to inform, monitor and evaluate policy initiatives that increase resilience of smallholder poultry production systems?

Learning objectives

By the end of this chapter, students will:

- Navigate through FAOSTAT database and other databases, to retrieve data of production and consumption of chicken meat and eggs in different regions of Africa;
- Gain an understanding of the effects of climate change on smallholder production of chicken meat and eggs, and the risks on the security of supply in Africa;
- Study and analyse the impact of climate change and heat stress on the productivity of chicken;

- Explore, through Case Studies, strategies that can mitigate the effects of climate change in their country and other countries in the African region.

Learning outcomes

Having studied the chapter, the students will be able to:

- Use data from FAOSTAT and other recognised collections of statistical data to analyse the trends in poultry production and consumption in selected African countries;
- Employ analysis of trends to assess the contribution of smallholder poultry production to the demand for poultry meat and hen eggs;
- Identify the risks of climate change and their impact on the production parameters and immune responses of smallholder poultry production in Africa;
- Discuss how adaptive and mitigation strategies impact on the resilience of smallholder poultry production in Africa;
- Use the Case Studies in Boxes 14.1-14.4, to devise and describe in writing, coping mechanisms and adaptation options for increased resilience of vulnerable smallholder poultry production communities in selected countries in Africa.

Current Trends in Poultry Production and Consumption in Africa: Demand Analysis

Aggregated data of global poultry meat and hen egg production and consumption show that the growth of the two commodities has been very unbalanced over the past two decades (Table 14.2 and Table 14.3), both globally and between regions in Africa (FAOSTAT database, 2014).

The production of poultry meat has increased steadily in Africa over the period 1990 - 2012 (+ 6.9 % per year), with the slowest rate in Eastern (+ 3.3 %) and Western Africa (+ 4.5 %). In contrast, for the same period, the production of poultry meat has increased rapidly (+ 12 %) in Asian countries, as shown in Table 14.2. Asian countries surpassed African countries in their production volume for the period 1990 - 2012, and at present (FAOSTAT database, 2014) they contribute about 34 % to global poultry meat production, compared to a contribution of 5 % by African countries (Figure 14.1).

Table 14.2. Global contributions to poultry meat production between 1990 and 2012

	Poultry meat production (1,000 tonnes)					
Regions	Period 1990 - 2012				% change	
	1990	2000	2010	2012	Absolute	Per year
Africa*	1849	2778	4520	4647	+ 151	+ 6.9
Northern	669	1215	1839	1914	+ 186	+ 8.5
Eastern	272	327	476	471	+ 73	+ 3.3
Middle	53.5	58.7	120	128	+ 139	+ 6.3
Western	311	338	588	620	+ 99	+ 4.5
Southern	542	839	1496	1515	+ 180	+ 8.2
Asia	8590	18644	29240	31542	+ 267	+ 12.0
Americas	14362	27155	38676	40066	+ 179	+ 8.1
Europe	10162	9387	13778	15321	+ 51	+ 2.3
Oceania	454	732	1050	1235	+ 172	+ 7.8
World*	35416	58696	87263	92811	+ 162	+ 7.4

* Sum does not add because of rounding

(Source: Calculated from FAOSTAT database, 2014)

The global hen egg production has shown a major dynamic during the past two decades (period 1990 - 2009) (FAOSTAT database, 2014). The rapid global increase in egg production (Table 14.3) has been very unbalanced. Whereas production has shown a rapid increase in Asian countries (+ 8.6 % per year), the increase in volume of egg production in Africa has been restricted to 3.5 % per year, with countries in Eastern Africa showing an annual increase of 1.2 % annually. Corresponding value for southern Africa was at 6.1 % per year. Data available for 2009 indicate that Asia is the centre for egg production, contributing about 63 % of global egg volume. In contrast, the contribution of African countries to global egg production is about 3.7 %. The developed countries have shown stagnation in the production of poultry meat for the same period.

Table 14.3. Global contributions to hen egg production between 1990 and 2009

Hen egg production (1,000 tonnes)					
Regions	Period 1990 - 2009			% change	
	1990	2000	2009	Absolute	Per year
Africa*	1304	1618	2176	+ 67	+ 3.5
Northern	498	595	771	+ 55	+ 2.9
Eastern	221	233	271	+ 23	+ 1.2
Middle	19.8	26.7	33.8	+ 71	+ 3.7
Western	403	511	753	+ 87	+ 4.6
Southern	164	253	347	+ 116	+ 6.1
Asia	14038	29450	37071	+ 164	+ 8.6
Americas	6893	8754	10529	+ 53	+ 2.8
Europe	10702	8766	9334	- 13	- 0.68
Oceania	233	157	182	- 22	- 1.16
World*	33171	48745	59293	+ 79	+ 4.2

* Sum does not add because of rounding

(Source: Calculated from FAOSTAT database, 2014)

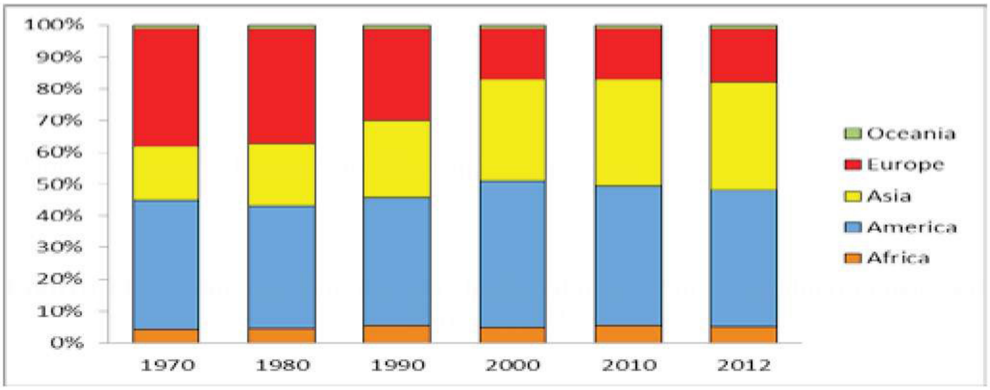

Figure 14.1: Changing contributions to global poultry meat production between 1970 and 2012 (Source: FAOSTAT database, 2014)

Data in Table 14.4 and Table 14.5 indicate the consumption of poultry meat and hen eggs on *a per capita* basis (kg / year) for Africa. Data given in Table 14.4 indicate that the consumption of poultry meat in Africa for 2009 (kg *per capita* / year) is 3-times less when compared to world data (5.5 kg *vs* 13.6 kg). However, there are large variations between regions of the African continent (range: 1.6 - 28.4 kg *per capita* / year), with Eastern Africa having the lowest intake. The consumption of poultry meat has increased slowly over the period 1990 - 2009, growing at a rate of 3.3 % per year. In contrast, the Asian countries have increased the *per capita* consumption at a rate of 8.4 % per year.

Table 14.4. Global consumption of poultry meat between 1990 and 2009

Region	Poultry meat consumption (kg per capita / year)				
	Period 1990 - 2009			% change	
	1990	2000	2009	Absolute	Per year
Africa*	3.4	4.2	5.5	+62	+3.3
Northern	5.1	7.6	9.3	+82	+4.3
Eastern	1.5	1.4	1.6	+6.7	+0.35
Middle	1.8	2.8	4.8	+167	+8.8
Western	1.8	1.9	2.6	+44	+2.3
Southern	13.7	18.3	28.4	+107	+5.6
Asia	3.4	6.7	8.8	+159	+8.4
Americas	21.9	31.8	35.9	+64	+3.4
Europe	14.6	16.0	21.9	+50	+2.6
Oceania	21.8	30.2	35.7	+64	+3.4
World*	7.7	11.1	13.6	+77	+4.1

* Sum does not add because of rounding

(Source: Calculated from FAOSTAT database, 2014)

The scenario for *per capita* egg consumption (kg / year) indicates the considerable differences in regional patterns of consumption, both globally and between regions of the African continent (Table 14.5). The average *per capita* egg consumption for the year 2009 for all African regions (range: 0.60 - 6.1 kg *per capita)* was below world average (8.9 kg *per capita).* Asian countries surpassed world average to achieve a *per capita* consumption of 9.2 kg in 2009.

The increase in the concentration of poultry meat and hen eggs in regions of Africa will depend on many driving forces (Windhorst, 2008; Jez *et al.,* 2011), and include:

- Climate change;
- Population development;
- Urbanisation of the society;
- Development of the gross national income;
- Outbreaks of highly infectious poultry diseases including the emergence of new diseases;
- Public policies and international regulations.

The most important variable seems to be the effects of climate change on the sustainability of smallholder poultry production, as highlighted by several reports and analyses on the resilience of smallholder poultry production and its associated impacts on food security (Naylor, 2008; McDermott *et al.,* 2010; IFAD Strategic Framework 2008 - 2010). Smallholder poultry production is sensitive to risks associated with climate change, thus jeopardising the security of protein supply from poultry meat and hen eggs (FAO, 2010).

Table 14.5. Global consumption of hen eggs between 1990 and 2009

Region	Period 1990 - 2009			% change	
	1990	2000	2009	Absolute	Per year
*Africa	2.2	2.1	2.3	+ 4.5	+ 0.24
Northern	3.4	3.4	3.8	+ 12	+ 0.63
Eastern	1.1	1.8	1.8	+ 64	+ 3.4
Middle	0.60	0.60	0.60	-	-
Western	4.4	4.4	7.5	+ 71	+ 3.7
Southern	7.8	9.8	6.1	- 22	- 1.2
Asia	4.5	8.0	9.2	+ 105	+ 5.5
Americas	19.2	21.2	22.8	+ 20	+ 1.1
Europe	13.6	12.1	12.7	- 6.6	- 0.35
Oceania	10.5	6.2	6.4	- 39	- 2.05
*World	6.3	8.1	8.9	+ 41	+ 2.2

* Sum does not add because of rounding

(Source: Calculated from FAOSTAT database, 2014)

Smallholder Poultry Sector in Africa and its Contribution to Security of Supply of Animal-based Protein and Nutrition

Although the contribution of the poultry sector from Africa to the global production is still low, the poultry sector has made substantial contributions to the protein supply from food of animal origin, thus alleviating protein insufficiency and strengthening the security of protein supply (Table 14.6).

The poultry sector in most African countries continues to be characterised by traditional and smallholder systems of production (FAO, 2010). The smallholder farms are operated predominantly by small and low-income farmers. The contribution to the supply of poultry meat and hen eggs are derived mainly from small and subsistence-type farms rather than from large commercial operations. However, there are some exceptions, e.g. South Africa and the Republic of Mauritius. In the Republic of Mauritius, 15 % of the total poultry meat consumed in 2010 was produced by smallholder production systems (5.3 kg *per capita),* and the rest (85 %) from industrial vertically-integrated systems of production (30.1 kg *per capita)* (Central Statistics Office - Republic of Mauritius, 2012).

Characteristics of the Smallholder Poultry Sector in Africa

The characteristics of the smallholder poultry sector are often defined in terms of its differences compared to the large-scale, commercial, vertically-integrated systems of production (FAO, 2004, 2006, 2010; Herrero *et al.,* 2010; African Technology Policy Studies Network, ATPS 2013).

Typically, the smallholder poultry sector is not,

- Large scale;
- Technology intensive;
- Bio-security intensive;
- Dependent on external market inputs;
- Dependent on outside labour;
- Export / urban market oriented.

However, the smallholder poultry sector is still vibrant in Africa and is of continued significance to the supply of protein from poultry meat and hen eggs. The smallholder poultry keeping in most regions of Africa contributes significantly to the income and internal household position of women (FAO, 2010) and contributes to households and livelihoods, highlighting the gender dimensions of smallholder production systems in most regions of Africa (FAO, 2010). Sonaiya (2007) and Gueye (1998) have reported that almost 80 % of poultry production in Africa is found in the rural and peri-urban areas, where birds are raised in small numbers by the traditional extensive or semi-intensive, low-input-low-output systems and mainly free-range systems.

However, the sustainability of the smallholder poultry production systems and their resilience with respect to the challenges of climate change should be addressed given that the concept of food security is closely linked to the concept of livelihoods. Analyses and assessments of the impact of climate change on the smallholder poultry production in Africa must include a livelihood perspective.

Contribution of the Smallholder Poultry Sector to the Security of Supply of Animal-based Protein - What do We Know?

The following definition of food security, formulated by the 2009 Declaration of the World Summit on Food Security, is widely used:

"Food security: Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food, which meets their dietary needs and food preferences for an active and healthy life." (FAO, 2009).

Food security is a complex process and it is affected by an interaction of factors including:

- Agro-ecological;
- Environmental;
- Socio-economic;
- Political and;
- Biological factors.

Of interest to smallholder poultry production in Africa is the contribution of poultry meat and hen eggs to the household food security including access to and utilisation of protein from the poultry meat and hen eggs (Table 14.6).

Table 14.6. Protein supply quantity from poultry meat and hen eggs (g per capita / day)

Protein supply quantity (g per capita / day) for period 1990 - 2009							
	Poultry meat		Hen eggs		Total protein supply from poultry		
	1990	2009	1990	2009	1990	2009	% change
Africa*	1.2	1.9	0.6	0.7	1.8	2.6	+ 44
Northern	1.7	3.2	1.0	1.1	2.7	4.3	+ 59
Eastern	0.5	0.5	0.3	0.2	0.8	0.7	- 14
Middle	0.6	1.6	0.2	0.2	0.8	1.8	+ 125
Western	0.6	0.9	0.6	0.7	1.2	1.6	+ 33
Southern	5.4	11.2	1.2	1.9	6.6	13.1	+ 98
Asia	1.2	3.0	1.4	2.9	2.6	5.9	+ 127
World*	2.8	4.7	1.9	2.7	4.7	7.4	+ 57

* Sum does not add because of rounding

(Source: Calculated from FAOSTAT database, 2014)

The recommended daily allowance (RDA) for adults per day is 56 g of protein from a mixed diet (Pimentel and Pimentel, 2003). However, it is easier to eat a balanced diet when it includes animal protein sources as they contain high-quality protein, and essential macro and micro elements and vitamins. It is estimated that about 20 g per day of edible animal-based protein would be sufficient for a complete human diet (Flachowsky, 2007). The contribution of poultry meat and hen eggs have contributed to the alleviation of protein insufficiency in many African regions, as illustrated by data shown in Table 14.6.

However, the risks of climate change facing the smallholder poultry production systems and the food security of the smallholder livelihoods must be assessed and evaluated. Enabling strategies to mitigate the effects of climate change must be devised. Enhanced food security and climate change adaptation are linked (FAO, 2013).

Concerns, Challenges and opportunities Facing the Smallholder Poultry Sector in Africa

The impact of climate change on the smallholder poultry sector is a global challenge. However, for sustainable results, the challenge must be tackled at the local level. In the face of climate change, all African regions and individual countries in Africa have to implement adaptation strategies and consider mitigation activities that will reduce the risks facing the sector.

Mitigation strategies involve taking *ex-ante* actions to reduce the magnitude of the impact of climate change in the medium and long-term.

Enabling adaptation mechanisms include all activities that help to reduce the sensitivity of smallholder livelihoods to adverse impacts of climate change.

There are no unique solutions neither for mitigation nor adaptation. The measures need to be tailored to specific contexts, as illustrated in the situations and challenges proposed in the Case Studies (Boxes 14.1 -14.4). Risk management will work best when tailored to local circumstances.

However, neither adaptation nor mitigation alone can alleviate all climate change impacts. To respond to the challenges and threats of climate change, it will be necessary to focus on both mitigations to reduce the level of emission of gases contributing to global warming, and adaptation, to support local communities deal with the impacts.

Climate change provides opportunities for the development of strategies that promote sustainable smallholder poultry production systems in Africa. It does so by reducing the underlying risks to food security through the application of good practices, processes and technologies for prevention, mitigation and strengthening of livelihood diversification and resilience (FAO, 2013). This combination of growing demand in the developing world and stagnant demand in industrialised countries represents a major opportunity for livestock keepers in developing countries, where most demand is met by local production, and this is likely to continue given the trends in production of poultry meat and hen eggs (Table 14.2 and Table 14.3).

At the same time, the expansion of agricultural production needs to take place in a way that empowers smallholder production systems so that they can benefit from anticipated increased demand, whilst at the same time moderating its impact of production on the environment. Activities aimed at increasing the resilience of smallholder livelihoods will be necessary to support their capacity to adapt and to manage risks. The challenges are enormous given the estimated and predicted increase in population in Africa (Table 14.7).

By 2050, it is predicted that Africa's population will rise to (2.39 billion, particularly in Middle, Eastern and Western Africa, coupled with growing urbanisation. These trends will have a considerable impact on the future of smallholder production systems. The enabling strategies that are implemented now can provide an important impetus to the development of the smallholder poultry production in Africa as market development drives supply.

Table 14.7. Total population (billion) in Africa

	Total population (billion)			in Africa (estimated and projected				
Year			Region			Total	Rural	Urban
	Northern	Eastern	Middle	Western	Southern			%
2000	0.176	0.254	0.094	0.234	0.052	0.810	64.2	35.8
2010	0.210	0.333	0.125	0.305	0.059	1.032	61.2	38.8
2020	0.235	0.451	0.164	0.400	0.063	1.310	57.3	42.7
2030	0.266	0.576	0.209	0.516	0.068	1.625	52.8	47.2
2040	0.294	0.717	0.261	0.655	0.072	2.009	47.5	52.5
2050	0.319	0.869	0.316	0.815	0.075	2.390	42.7	57.3
% change	+ 81	+ 242	+ 236	+ 248	+ 44	+ 195	-0.66	+60

(Source: Calculated from FAOSTAT database, 2014)

Impact of Climate Change on the Smallholder Poultry Sector in Africa

When poultry hatch, the comfort zone is 35 °C but then decreases to about 24 °C at 4 weeks of age (Daghir, 2008). As homeotherms, poultry can maintain their temperature within only a short range, and the optimal relative humidity (RH) for broilers when ambient temperature exceeds 28 °C is 60-65 % (Yahav, 2009). The lower and upper limits of the circadian rhythm in deep body temperature is around 40.5 and 41.5 °C respectively in well-nourished chickens that do not gain or lose heat to the environment (Daghir, 2008).

This situation illustrates the physiological effects of climate change, and associated heat stress on the productivity of birds. Heat stress is the most important environmental stressor challenging poultry production globally, with a greater impact on smallholder production.

Climate Change Projections in Africa

Climate can be defined as the prevailing weather conditions (precipitation, temperature, relative humidity and other meteorological elements) for a given location over a period of time (Patterson and Guerin, 2013). Evidence from the Intergovernmental Panel on Climate Change (IPCC, 2007) is overwhelmingly convincing that climate change is real.

Climate change will become worse and its impact will be more on the most vulnerable livelihoods. The International Fund for Agricultural Development (IFAD) acknowledges climate change as one of the factors affecting rural poverty and as one of the challenges it needs to address. While climate change is a global phenomenon, its negative impacts are more severely felt by poor people in developing countries who rely heavily on the natural resource base for their livelihoods. Agriculture and livestock keeping are amongst the most climate- sensitive economic sectors and rural poor communities are more exposed to the effects of climate change.

No continent will be struck as severely by the impacts of climate change as Africa (FAO, 2007). Given its geographical position, the continent will be particularly vulnerable due to the considerably limited adaptive capacity, exacerbated by widespread poverty and the existing low levels of development. The IPCC predicts that by 2100 the increase in global average surface temperature may be between 1.8 and 4.0 °C. With global average temperature increases of only 1.5 - 2.5 °C, approximately 20 - 30 % of plant and animal species are expected to be at risk of extinction (FAO, 2007).

Risks of Climate Change on Productivity of Smallholder Poultry Production Systems in Africa

The most obvious constraint on poultry production in regions of Africa is the climate, worsened by global climate change. High temperature, especially when coupled with high humidity, imposes severe heat stress on birds and leads to reduced performance (Daghir, 2008). Innovative strategies will have to be developed to mitigate the impact of climate change on smallholder poultry production. Adaptive mechanisms will have to be developed, implemented, and monitored to cope with climate change so as to increase the resilience of the smallholder livelihoods.

When faced with environmental challenges, all animal species will respond to alleviate the effects of heat stress and maintain their homeostatic integrity. However, poultry seems to be particularly sensitive to temperature-associated environmental challenges (Daghir, 2008). In the sections that follow, we review the impact of climate change and associated heat stress on the productivity of poultry, and the challenges to poultry production, in particular in the African region. Furthermore, climate change has an indirect impact on poultry production by affecting the yield of cereal crops that constitute the most important ingredient in poultry feeds. The effects of climate change on prolonged drought conditions have resulted in significant increases in the price of cereals on the world market, thus directly increasing the price of poultry feeds and reducing the profit margin of smallholder poultry producers (Wheeler and Reynolds, 2013).

Physiological Effects of Heat Stress on Poultry

Under high temperature conditions, poultry will alter their behavior in order to decrease body temperature and maintain thermoregulation and homeostasis. When subjected to long and continuous periods of heat stress conditions, poultry will engage in a number of physiological behaviour to reduce the heat load. The birds will spend less time feeding, more time drinking and panting, less time moving or walking, and more time resting (Mailfert, 2006; Daghir, 2008; Mailfert and Driver, 2008). Typically, poultry have an additional mechanism to promote heat exchange between their body and the environment, through panting. Panting promotes air circulation on surfaces contributing to increase gas exchanges with the air, and consequently, the evaporative loss of heat (Daghir, 2008).

Heat-shock proteins have an essential role in restoring normal functioning in endangered cells or organisms through their association with a number of proteins (Etches *et al.,* 1995), having thus a very important protective function. Cardiac output is also greatly increased showing the high involvement in heat dissipation of the cardiovascular system (Etches *et al.,* 1995). An impairment of N use occurs during heat stress, since more was shown to be excreted through urine (Belay *et al.,* 1993). According to Smith (1990), feed efficiency is maximised within the temperature range 21 - 26 °C, and a decrease in feed consumption and growth occurs above 21 °C for broilers of 3 -7 weeks of age, indicating the great pressure imposed on the bird's physiology.

However, increased panting under heat stress conditions leads to increased carbon dioxide levels and higher blood pH (alkalosis) (Mailfert, 2006; Daghir, 2008; Mailfert and Driver, 2008), which could lead to the death of the birds. Plate 14.1 shows birds panting, clearly indicating the effects of heat stress on the birds and the physiological response to alleviate heat load. The picture was taken at 09.00 hours on a smallholder farm in the Republic of Mauritius.

Plate 14.1: Smallholder broiler production systems showing birds panting with opened beaks (Source: Mailfert, 2006)

In addition, alkalosis will interfere with blood bicarbonate availability for egg shell mineralisation. This induces increased organic acid availability and decreases free calcium levels in the blood, thus affecting egg shell quality. In females, heat stress can disrupt the normal status of reproductive hormones at the hypothalamus, and at the ovary. Furthermore, the volume of semen, sperm concentration, number of live sperm cells and motility has been shown to decrease when male were subjected to heat stress. Climate change and heat stress would have an impact on the reproductive performance of poultry.

Effects of Heat Stress on the Immune Response of Poultry

Many studies have been conducted to assess the effects of chronic heat stress on the immune response of poultry. In general, all studies have indicated an immunosuppressing effect of heat stress both on broilers and laying hens (Daghir, 2008). The findings of the studies tend to indicate the risks represented by climate change on the potential outbreaks of diseases and emergence of new diseases, with major impact on food security. The risks will be greater on smallholder production systems, where the level of bio-security is low (FAO, 2006).

Heat Stress on Efficiency of Poultry Production

Many studies have reported (Bayraktar *et al.,* 2011; Ayo *et al.,* 2014) the detrimental effects of heat stress on the efficiency of broiler production for poultry meat production. Mailfert (2006) showed that broilers subjected to long periods of heat stress during most of their production cycle (minimum-maximum ambient air temperature and RH of 18.9 - 30.0 °C and 64 - 100 % respectively) had significantly reduced feed intake (- 16 %), lower body live weight (- 34 %), and higher feed conversion ratio (+ 26 %) at 42 days of age). According to Smith (1990), feed efficiency is maximised within the temperature range 21 - 26 °C, and a decrease in feed consumption and growth occurs above 21 °C for broilers of 3 - 7 weeks of age, indicating the great pressure imposed on the bird's physiology exposed to prolonged heat stress.

Furthermore, it has been reported that chronic exposure to high environmental temperature and heat stress negatively affects carcass quality in broilers by increasing fat deposition (Lara and Rostagno, 2013).

Studies have also indicated that heat stress adversely affects the productivity of laying hens by decreasing feed intake and feed efficiency, thus having a direct impact on egg production and egg quality, by decreasing egg shell thickness and increased rate of egg breakages (Daghir, 2008; Lara and Rostagno, 2013).

Heat Stress and Water Balance of Poultry

Maintenance of a constant body temperature is easier when birds are in a positive water balance state (Wiernusz, 1998). Voluntary water consumption is distinctly increased under heat stress (Belay *et al.,* 1993; Mailfert, 2008; Adesiji *et al.,* 2013), which together with a decreased feed intake is illustrated by the work of Borges *et al.* (2004) who obtained 24.7 % greater water: feed ratio. Belay and Teeter (1993) found a higher evaporative cooling, increased apparent respiration efficiency (number of calories of heat dissipated / breath), and decreased respiration rate in association with increased water consumption in a heat stress environment, showing thus its real importance. Belay and Teeter (1993) showed that water excretion of male broilers rose by as much as 64 % when environmental temperature increased from thermoneutral (24 °C) to 32 °C. However, since the water content of faeces was unaffected, it has supposedly been caused by a higher urine production (Belay and Teeter, 1993). Moreover, urine production was higher than in a thermoneutral environment for the same water consumption, outlining its independence to the latter (Belay and Teeter, 1993). Belay *et al.* (1993) showed as well an increased urine production per mL of water consumed during heat stress. This point is particularly relevant as birds consume higher quantities of water than needed for the simple replacement of that lost in evaporative cooling (Wiernusz, 1998).

In contrast, wild birds are capable of reducing their urine production while increasing their evaporative cooling efficiency and extent (Wiernusz, 1998). It can be speculated that owing to genetic selection taking place mostly under continuous availability of water and feed, modern strains are no longer capable of conserving fluids when exposed to heat stress. In the same line, the genetic potential of indigenous breeds of poultry in selection programmes for heat- resistant birds needs further exploration.

Impact of Heat Stress on Food Safety

Food safety has become a major issue to the production of poultry meat and hen eggs. Heat stress has been associated with undesirable meat characteristics and quality loss in broilers (Lara and Rostagno, 2013). In laying hens, it has been reported that heat stress has a negative impact on the quality and safety of eggs produced.

Foodborne pathogens of concern in poultry products are: *Salmonella* and *Campylobacter.* Both pathogens constitute major public health and economic concern in poultry and egg production, given their transmission from infected birds along the human food chain. There is increasing evidence to demonstrate that environmental stress is a factor leading to the colonisation of the intestinal tract of poultry by pathogens, namely *Salmonella* and *Campylobacter,* thus increasing the contamination of poultry meat and hen eggs and risks of transmission to humans during slaughtering/processing (Lara and Rostagno, 2013).

Recent epidemiological studies have demonstrated that both *Salmonella* and *Campylobacter* are capable of exploiting the neuroendocrine alterations due to the heat stress response in the host to promote growth and pathogenicity (Freestone *et al.,* 2008; Verbrugghe *et al.,* 2012). Therefore, heat stress can potentially (i) alter the host-pathogen interaction, (ii) the duration and (iii) level of contamination of faeces voided in the environment. All three factors combined will lead to an increased dissemination of food-borne pathogens. The risks of climate change on the safety of poultry products constitute a very important food-security issue and cannot be overemphasized, given that public health is at risk.

Consequently, the ecology and epidemiology of pathogens, in particular food- borne pathogens, in poultry flocks under high temperature or heat stress conditions, need to be further explored for the implementation of mitigation strategies to reduce the risks of food contamination.

Climate Change and Impact on Feed Supply for Poultry

Crop production is negatively affected by climate change (Wheeler and Reynolds, 2013) with prospects of lower feed supply, in particular cereal crops, for poultry. Projected reductions in cereal crops will impact on the costs of poultry meat and hen eggs (Adesiji *et al.*, 2013). Adaptive strategies to maintain sufficient feed supplies, in particular cereal crop yields, for smallholder poultry production in Africa, are key challenges to be addressed. Feed costs account for approximately 70 % of the variable costs associated with the production of poultry. The implementation of mitigation mechanisms to ensure the medium to long-term supply is critical for Africa, given the expected increase in population over the next decades and the resulting increase in demand for poultry products.

Climate Change Risks and impact on the Vulnerabilities of the Smallholder Poultry Production Systems in Africa

The following definition of vulnerability of livelihoods, formulated at the World Food Summit in 1996 (FAO, 1996), is used in the context of this chapter:

"Vulnerability is key to food insecurity, as it relates to people's lack of ability to cope with risks (e.g. drought, flooding, climate change, heat stress etc.). Food insecurity, the opposite of food security, can therefore be described as a condition in which people lack the basic food intake necessary to provide them with the energy and nutrients required for fully productive lives" (FAO, 1996).

Case Studies carried out in regions of Africa have indicated the vulnerabilities of the smallholder poultry production to the impact of climate change (Ojwang' *et al.* 2010; Adesiji *et al.*, 2013). Poultry production will continue to support the livelihoods of rural households (Mc Leod *et al.*, 2009), by providing an important source of home consumption of poultry meat and hen eggs, a source of family income and a source of livelihood for women. It will therefore be imperative to promote climate-change risk management that mainstreams climate effects into the improvements of smallholder poultry livelihoods.

At the same time, there may be potential for a sustained growth of the smallholder poultry sector in Africa, given the projected increases in demand for livestock products. The driving factors for an increased demand are,

- Projected increases in income;
- Increases in population;
- and Increased urbanisation that will take place in Africa (Table 14.7).

Interactions between Food Supply, Nutrition, Climate Change and Resilience of the Smallholder Poultry Production Systems in Africa

Climate change will decrease physical and economical accessibility to food, due to increased commodity prices. The net effects will likely be translated in increases in malnutrition, especially of young children (Herrero *et al.*, 2010). Climate change is likely to increase the number of malnourished children in both 2025 and 2050. These effects will probably be exacerbated in areas of high vulnerability. Without climate change, child malnutrition levels are projected to decline from 19 % in 2000 to 15 % by 2025 and 11 % by 2050 (Herrero *et al.*, 2010).

Africa remains the region with the highest prevalence of undernourishment, with 25 % of the people estimated to be undernourished (FAO, IFAD and WFP, 2013). However, there are regional differences. Sub-Saharan Africa remains the region with the highest prevalence of undernourishment (26.4 % of total share of undernourished globally), with very slow progress in recent years. Over the last two decades, the prevalence of undernourishment declined from 32.7 % to 24.8 % (FAO, IFAD and WFP, 2013). By contrast, Northern Africa is characterised by a much lower prevalence of undernourishment. Undernourishment trends are illustrated in Figure 14.2. Data shown in Figure 14.2 indicate that the region is not on track to achieve the Millennium Development Goals (MDGs) and the current status can be further exacerbated by the challenges of climate change facing smallholder producers.

The trends indicate that mitigating and adaptive strategies will have to be implemented in the most vulnerable regions to decrease the impact of climate change on vulnerable smallholder livelihoods. Structural changes in agriculture are needed to create resilience against climate change and programmes are needed to ensure adequate diets for the vulnerable livelihoods. A commitment to mainstreaming food security, climate change mitigation and adaptive strategies and nutrition in public policies and programmes for smallholder poultry producers in Africa are needed, particularly in sub-saharan Africa.

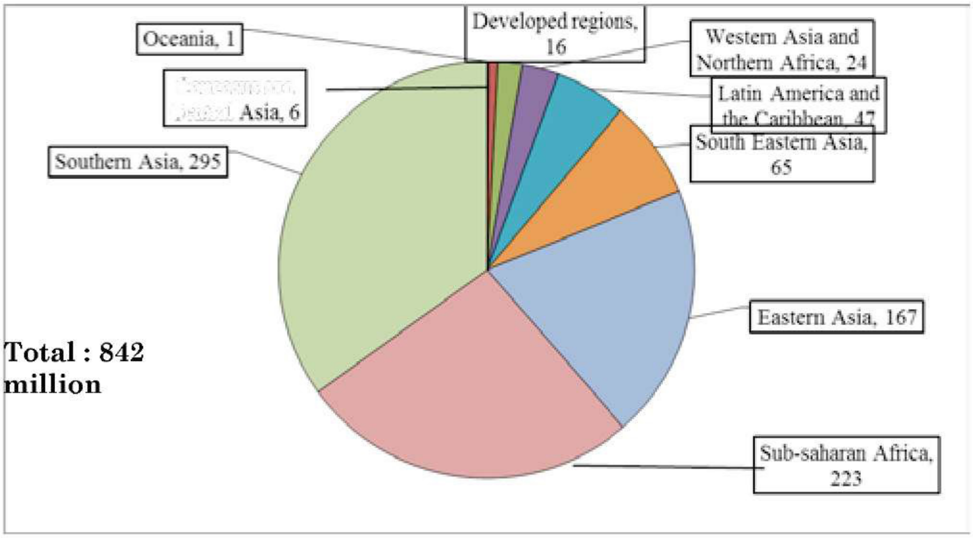

Figure 14.2: Undernourishment in 2011-2013, by region (millions) Source: FAO, IFAD and WFP, 2013

Increasing the Resilience of Smallholder Poultry Production Systems in Africa

Strategies aimed at strengthening the resilience of smallholder poultry production in Africa will have a direct impact on the food security of the smallholder livelihoods, by reducing the vulnerabilities of the systems of production. Both mitigation and adaptation strategies have been implemented to reduce the impact of climate change on the smallholder poultry production systems in Africa (Ojwang' *et al.,* 2010; Adesiji *et al.,* 2013). As indicated in the section under concerns, challenges and opportunities facing the smallholder poultry sector in Africa:

- Mitigation strategies aim at reducing the *magnitude* of the impact of climate change on production systems in the medium and long-term by forecasting and taking *ex-ante* actions;
- Enabling adaptation mechanisms aim at reducing the sensitivity of smallholder livelihoods to adverse impacts of climate change.

There are no unique solutions for either mitigation or adaptation. The measures need to be tailored to specific contexts, as illustrated in the situations and challenges proposed in the Case Studies (Boxes 14.1-14.4). Published studies clearly indicate that the Risk Management will work best when tailored to local circumstances (Ojwang' et al., 2010; Adesiji et al., 2013; FAO, IFAD and WFP, 2013). Furthermore, the published studies indicate the potential opportunities for further research and development (R&D) to reduce the sensitivity of smallholder production systems to climate change risks (FAO, 2009; FAO, IFAD and WFP, 2013).

The sections which follow review and assess the potential mitigation mechanisms and enabling adaptation strategies to alleviate climate change risks faced by smallholder poultry production in Africa.

Mitigation Strategies: Developing Ex-ante Climate Change Risk-responsive Technology Strategies and Policies for the smallholder poultry sector in Africa

Mitigation aims at promoting ex-ante climate change risk-responsive Technology Strategies and Policies to prevent the magnitude of impacts of climate-related hazards and to promote effective responses to the impacts (FAO, IFAD and WFP, 2013). The benefits of the strategies will be the creation of opportunities for increased sustainability and resilience of smallholder livelihoods.

The strategies are captured in Table 14.8 and are briefly discussed in the sections which follow.

Table 14.8: Developing ex-ante Climate Change risk-responsive mitigation strategies for smallholder poultry sector in Africa

Technology Strategies	Policies
1. Genetic selection of breeds showing increased heat tolerance	1. “Safety Nets”
	2. Insurance
2. Development of heat-stable live vaccines	3. Early Warning Systems (EWS)
3. Alternatives to feed supply of cereals	4. Comprehensive Risk Management (CRM) strategy

Climate Change Risk-Responsive Mitigation Technology Strategies for Africa

Genetic Selection of Breeds Showing Increased Heat Tolerance

Genetic selection of breeds is an important breeding tool that can be used for improving the capacity of poultry to coping with heat stress conditions (i.e. increased heat tolerance). The parameters used in the selection of breeds should explore the possibilities of associating high growth rate with better heat tolerance by focusing on the use of major genes, namely the naked neck (Na) gene, the frizzle (F) gene and the dwarf (dw) gene (Lin et al., 2006).

There is evidence that the Na gene reduces feather mass (relative to body weight) by 20 % and 40 % respectively, in the heterozygous (Na/na) and homozygous (Na/Na) birds, respectively (Lin et al., 2006). In broiler chickens, the use of Na gene (for example the Sasso breed), resulted in a higher growth rate and meat yield, compared to fully-feathered breeds kept under heat stress conditions. The F gene may increase the heat tolerance of the birds by reducing the heat insulation of the feathers by reducing their size and by curling. Research work on the use of the dw gene should continue to assess their contribution to heat tolerance in poultry (Lin et al., 2006).

The utilisation of native, indigenous breeds of poultry offer opportunities for the development of breeding programmes for smallholder poultry production in Africa, as indicated in the challenge proposed in case studies reported in Boxes 14.1 and 14.2.

Development of Heat-Stable Live Vaccines

The adoption of thermostable live vaccines has enormous potential in the development of smallholder production. For example, the use of I2 thermostable vaccine against Newcastle disease, has contributed to a significant reduction in mortality of village chicken in selected districts of Ethiopia (Nega et al., 2012), reducing mortality from 44.6 % to 8.2 %.

Case Study documented in Box 14.3 poses the students with the challenge of assessing the use of I2 thermostable vaccine against Newcastle. The students are expected to focus on the challenges faced in the field by smallholder poultry producers and the urgent need for the development of thermostable efficient live vaccines. Students are expected to reflect on the research priorities as part of the challenge to increase the resilience of smallholder poultry production systems in Africa, thus strengthening food security.

Alternatives to Feed Supply of Cereals

Market access and price volatility of cereals (mostly maize and soyabean) constitute major risks for the smallholder poultry producers in Africa. Furthermore, pests and disease outbreaks can be substantial, increasing the vulnerability of smallholder livelihoods (Wheeler and Reynolds, 2013; Harvey et al., 2014). Alternatives to feed supply of cereals should be developed. The focus should be on the development of locally available, drought-resistant varieties of cereal crops and alternative feed ingredients. Some examples of alternative feed ingredients that can be explored include the use of cassava roots, cassava by¬products, sorghum, triticale and aquafeed ingredients.

Climate Change Risk-Responsive Policies for Africa

'Safety Net' Poultry Flocks

Mc Leod et al. (2009) predict that 'safety net' flocks will continue to exist in 2030, particularly in regions of Africa, given the reliance on low market inputs and minimum competition on the supply markets. However, a comprehensive risk assessment of the effects of climate change on the 'Safety Net' poultry flocks has not been carried out. This is important given the expected increases in African population by the year 2050 and the increased urbanisation of the population.

Insurance

To increase the resilience of smallholder poultry production systems, the creation of an institutional capacity to implement climate change risk insurance programmes could be considered. The programmes can be designed in a multi- stakeholder partnership, involving government, farmers and insurance firms.

Early Warning Systems (EWS)

The development of Early Warning Systems (EWS) is conducive to the implementation of effective climate change adaptation measures. EWS involves the identification, assessment, monitoring and warning on climate change, and its effects on the environment and smallholder livelihoods. Adequate and reliable information on climate patterns and hazard, and vulnerability assessment is needed in vulnerable regions of Africa for modelling of climate risk management. Furthermore, the short duration of available records in some regions makes the modelling work and the development of scenarios more difficult.

A multi-stakeholder approach is required and involves the government, scientific community, smallholder producer groups, NGOs, International Organisations etc for concerted efforts, to increase the availability of adequate records on climate change processes for the successful implementation of EWS.

Implementation of a Comprehensive Risk Management (CRM) Strategy

The risks facing smallholder production systems are so complex that there is an urgent need for developing policies that mainstream climate change adaptation and mitigation through a Comprehensive Risk Management (CRM) strategy for African countries. The CRM will constitute a framework that will support the development of strategies and policies to reduce the impact of climate change risks on smallholder poultry production systems. A CRM strategy for smallholder poultry production systems needs implementation. The proposed CRM may include coping mechanisms, mitigation and adaptation tools.

Adaptation Mechanisms for the Smallholder Poultry Sector in Africa to Cope with Climate Change

The adaptation mechanisms have been the focus of major research work. Table 14.9 captures the array of different approaches used and has focused essentially on measures to alleviate heat stress. The effectiveness of the interventions is discussed in the sections which follow.

Table 14.9: Adaptation mechanisms for the smallholder poultry sector in Africa

1. Environmental management	- Shading - Ventilation - Open-sided housing
2. Nutritional interventions	- Diet formulation
3. Use of feed additives	- Vitamins - Antioxidants - Electrolytes - Coccidiostats
4. Access to water	- Design of drinkers

Environmental Management

Environmental management involves a number of management practices, including the provision of shade for the poultry, the use of open-sided housing systems that promote natural ventilation (Plate 14.2), the use of sprinklers for cooling the environment and the use of an intermittent light regime (Daghir, 2008) for reducing heat load of the birds.

Nutritional Interventions

Feed intake by poultry is reduced at high temperature, and is severely affected by concurrent high relative humidity (Daghir, 2008). Heat stress causes broilers to decrease feed intake and consequently nutrient intake (North and Bell, 1990; Daghir, 2008). Therefore, the dietary nutrient concentrations should be increased. The energy content of the diet, along with other nutrients, should be increased. As protein contributes more to metabolic heat production than carbohydrates and fat, the formulation of diets with slightly lower protein levels, but inclusion of higher methionine and lysine contents, should be considered (North and Bell, 1990; Daghir, 2008).

Case study reported in Box 14.4 aims at highlighting the extreme environmental conditions that can affect the efficiency of smallholder poultry broilers. The students will be expected to assess the impact of the environmental conditions on the productivity of the birds. On the basis of the analysis made, coping mechanisms through nutritional interventions can be proposed, to alleviate the effects of heat stress.

Use of Feed Additives

The use of vitamin C, as an anti-stress agent, is often considered during periods of heat stress. The use of proper coccidiostats and of appropriate anti-oxidising agents should be envisaged (North and Bell, 1990; Daghir, 2008). Supplemental salts (electrolytes) such as protassium bicarbonate, potassium chloride, sodium chloride and ammonium chloride have also been used. The function of the salts promotes water consumption in the birds.

Access to Water

Water consumption is essential to alleviate heat stress in poultry. Panting is accompanied by an increase in water loss by the lungs. Therefore, more water has to be consumed by the birds during hot weather in order to prevent dehydration. Cool drinking water stimulates both feed and water intake (North and

Bell, 1990; Daghir, 2008). When the temperature of drinking water is lower than body temperature it will absorb body heat. Therefore, access to adequate and cool drinking water is extremely important to heat stressed broilers. All management practices that result in increased water consumption during heat stress will benefit the survival rate of the birds. The proper design and number of drinkers available for the birds is therefore critical. The use of plasson drinkers (Plate 14.3) is recommended, compared to the use of fountain drinkers (Plate 14.4) that require regular filling during the day. The plasson drinker is automatically filled from a main reservoir and ensures a constant supply of water to the birds.

Case Studies: Climate Change-risk Responsive Strategies and Mechanisms for Smallholder Poultry Production in Africa - "Extending Theory to Practice"

The Case Studies contained in Boxes 14.1 — 14.4 aim at preparing the students in developing local climate change mitigation and adaptation strategies, which focus on concrete local actions in their home country, whilst addressing the global challenges. The Case Studies offer specific practices to enable the students acquire the competences. The experience of this indigenous knowledge practices in climate mitigation strategies and adaptation mechanisms is important because climate change adaptation policies should be considered part of the development process and be implemented at the local level. It is believed that when such holistic interventions are up scaled the problems associated with food security might be resolved sustainably.

The Case Studies aim at raising awareness among learners that a combination of local knowledge with additional scientific and technical expertise will help smallholder poultry communities reduce their risks and adapt to climate change. The gaps in knowledge will also be identified. A mapping of research priorities for the African region will be highlighted.

Plate 14.2: Open-sided housing system

Plate 14.3: Plasson drinker

Plate 14.4: Fountain drinker

Box 14.1: Better Breeds - "Breeding Strategy for Increased Resilience"

In Cameroon, village chickens represent over 60% of total national poultry population, however its contribution to poultry meat and egg supply is estimated to be below 35%, suggesting that better management could increase the output of the indigenous poultry sector. Village chickens are known to be more adapted to local hard climatic conditions as compared to commercial birds. The highly diversified local genetic material must be better known if any scientific exploitation is envisaged.

A total of 419 local chicken birds from Cameroon Western Highlands including 190 roosters and 229 hens were described according to FAO (1981) and results are summarised in Table 14.10. Average live body weight was 1676±319 g for males and 1278±242g for females. The effect of season on genetic type was subsequently assessed using 478 birds (Table 14.11).

Table 14.10: Type and feather distribution of local chicken hen of the Western Highlands of Cameroon)

Trait	s		9		S + 9	
	n	%	n	%	n	%
Type of feathering						
Soft	71	37.4	222	96.9	293	69.9
Silky	119	62.6	7	3.06	126	30.1
Total	190		229		419	
Feather distribution						
Normal	129	67.9	140	61.1	269	64.2
Naked neck	7	3.68	1	0.44	8	1.9
Feathered shank	48	25.3	46	20.1	94	22.4
Crested head	5	2.63	40	17.5	45	10.7
Naked neck + feathered shank	1	0.53	0	0	1	0.24
Crested + feathered shank	0	0	1	0.44	1	0.24
Naked neck + crested	0	0	1	0.44	1	0.24
Feathered wattle	0	0	6	2.62	6	1.43

Average live weight (kg): Normal (1.45±0.35); Feathered shank (1.55±0.33); Crested head (1.28±0.25); Naked neck (1.47±0.21); n = number of birds

Questions:

Using data in Tables 14.10 and 14.11, you are expected to:

- Propose selection strategies to help small scale farmers keeping village chickens to improve their productivity. Justify your choices.
- Propose a scheme for using local genetic material to eventually upgrade commercial broiler lines for a higher resilience of smallholder producers to climatic change.
- Discuss the scientific rationale of your proposal with precision on the multidisci- plinary scientific team to be involved in such work.

Table 14.11: Genetic type of Cameroon Western Highlands local chicken hens (g body live weight) as affected by sex and season

Genotype	Age (weeks)	Rainy	season	Dry season	
		s	?	s	?
	Day-old	0.15	1.45	-1.44	0.08
	4	-3.99	31.8	-31.6	-3.99
Naked neck	8	-16.8	54.1	0.57	-16.8
	12	39.9	161	36.8	39.9
	16	7.24	76.0	-10.9	7.26
	Day-old	1.38	3.34	0.27	1.15
Feathered	4	1.18	30.0	-33.4	1.17
shank	8	-10.2	71.6	18.0	-10.3
	12	-76.4	37.2	-24.7	-76.3
	16	12.9	144	-5.07	12.9
	Day-old	-1.81	-0.17	-2.42	-1.25
	4	-10.8	17.4	-45.9	-10.7

Crested head	8	-21.8	26.9	-26.6	-21.8
	12	-21.9	117	-7.25	-21.8
	16	-16.9	2.22	-84.6	-16.9
	Day-old	0.41	1.50	-1.59	0.16
	4	-7.64	43.3	-20.2	-7.73
Normal	8	-23.0	52.2	-1.28	-23.0
	12	6.53	183	58.5	6.56
	16	-18.7	72.8	-14.2	-18.6

Source: Hako Touko *et al.*, 2009

Box 14.2: Better Breeds - "Breeding Strategy for Increased Resilience"

Table 14.12 shows the performance of local hens kept under village conditions in Ethiopia (Demeke, 2004). The performance of the local breeds of hens is compared to the commercial laying hens namely White Leghorn.

Table 14.12. Performance of local laying hens and White Leghorn kept under village conditions in Ethiopia

Trait	Local laying hens	White Leghorn
Sexual maturity (days)	169	165
Production (eggs / hen)	39	56
Egg weight (g)	38	52

Source: Demeke, 2004

Questions

Given the low production capacity of local hens, why should we not promote the use of high-yielding hybrids and thereby obtain much more eggs? How can we upgrade indigenous stocks of laying hens through cross-breeding? What will be the benefits to the smallholder poultry sector and the resulting impact on food security.

- Propose breeding approaches that will promote the use of local stock in selective breeding to provide birds that are tolerant to local conditions while also capable of reasonable performance.
- You have been consulted to coordinate a regional programme in Africa to study the "Genetic Diversity and Conservation of Genetic Resources of indigenous laying hens in your country".
- Which types of data will you collect?
- Discuss the need for the use of molecular markers.
- Focus on the importance of closely monitoring the characteristics of the production environment, given the threats imposed by climate change.

Assess the potential of modern genetics and genomics to give a better understanding of gene function, to achieve a specific targeting of genetic improvement of the indigenous laying hens in Africa for greater resilience of the smallholder poultry sector.

Box 14.3: Better Health — "Health Strategy for Increased Resilience"

Evaluation of 12 thermostable *Newcastle* disease vaccine on local chickens in Amhara Regional State, Ethiopia

Newcastle disease (NCD) is mentioned as one of the disease problems in backyard chickens in most parts of Ethiopia. It has many different local names in different areas and the most common one is *"Fengil"*. The disease has already become endemic in village poultry population and thus it recurs every year inflicting heavy losses. Vaccination is the most important method of disease control particularly to decrease mortality from NCD. More recently, there are research outputs to evaluate the effectiveness of I2 thermostable *Newcastle* disease vaccine and to reduce the mortality of village chickens using Hemagglutination Inhibition Test.

Questions

- You are contracted to develop and implement a project on prevention of *Newcastle* disease for the backyard /small-scale poultry producers. Use data given in Table 14.13 to assist in your Consultancy Report. Show all your calculations and assumptions used.
- Discuss the scientific rationale that supports your recommendation(s) and demonstrate how a thermostable I2 Newcastle diseases vaccine can improve production of smallholder poultry production.
- What are the key recommendations and strategies that you would include in your Consultancy Report for consideration by relevant stakeholders: government; producer cooperatives; NGOs *etc.*

Table 14.13: Antibody titer of Newcastle disease antibody before and after vaccination using I2 thermo-stable vaccine in four local chicken ecotypes in Northwest Ethiopia

Local chicken ecotypes	Seroprevalence of Newcastle disease before vaccination		Antibody titer after first vaccination	
	Positive (> 1:16) n (%)	Negative (< 1:16) n (%)	Positive (> 1:16) n (%)	Negative (< 1:16) n (%)
Tillili	20 (50%)	20 (50%)	50 (90.9%)	5 (9.1%)
Mecha	34 (53.1%)	30 (46.9%)	62 (83.8%)	12 (16.2%)
Farta	33 (60.0%)	22 (40%)	66 (91.7%)	6 (8.3%)
Melohamusit	34 (58.6%)	24 (41.4%)	77 (95.1%)	4 (4.9%)
Total	121 (55.8%)	96 (44.2%)	255 (90.4%)	27 (9.6%)

Source: Nega et al. (2012)

Box 14.4: Better Feeds — "Feeding Strategy for Increased Resilience"

Implementing an effective feeding intervention

A trial was performed on a smallholder chicken meat producer in the Republic of Mauritius, during the hot summer period (January — February 2013), on one 42 days broiler cycle. The open-type poultry house used was made of concrete with a natural ventilation static system. The combined data of ambient temperature and relative humidity (RH) indicated that the birds were kept under conditions of heat stress during the rearing period (Figure 14.3). Productivity of the birds was jeopardized during this period, which conversely corresponded to the time when the demand for poultry meat for end of year festivities is highest, resulting in a serious financial loss for smallholder producers.

Figure 14.3. Minimal and maximal environmental temperature and relative humidity inside the poultry house of a smallholder chicken producer (Source: Mailfert, 2006)

Questions

- Use the data of ambient temperature and relative humidity depicted in Figure 14.3 to assess the challenges and risks to smallholder chicken producers' birds during the 42 days broiler cycle and the negative impact on the productivity of chicken meat production.
- Propose one effective feeding intervention that could be adopted to mitigate the detrimental effects of climate change and the risks of increasing environmental temperature and RH, on smallholder chicken meat production for improved productivity of the producers.
- Provide justification in support of your proposal.
- Focus on the importance of interdisciplinary research and its role in contributing to the resilience of smallholder chicken meat producers facing the challenges of climate change.

Sustaining Smallholder Poultry Production in Africa: Pathways to Resilience

Gaps in Knowledge: Capacity Building, Knowledge Improvement and Dissemination

This chapter has highlighted the importance of creating, and disseminating knowledge of the nature of the risks and their impact on smallholder poultry production systems in Africa. The challenges that they face and the existing

coping strategies that farmers use need further documentation. The chapter has also shown that the development of mitigation strategies and enabling adaptation mechanisms that build on the smallholder's knowledge and locally feasible solutions, constitute the support for the development of resilient smallholder production systems in Africa.

The Case Studies 14.1—14.4 have provided examples of on-the ground information, of relevance for development organisations, policy-makers and donors focused on food security for greater resilience of smallholder livelihoods in Africa. Collection of hard data is important as further work is required on the development of climate change scenarios and models for regions of Africa which are more at risk. Evidence-based knowledge and research are critical for the advancement of smallholder livelihoods facing climate change risks. As illustrated in the Case Studies, the challenges are multiple and include the,

- Identification of information needed;
- Assessment of sources of knowledge;

- Identification of research and information needed;
- and Interpretation of the validity, quality and relevance of the knowledge obtained.

Knowledge Informing Relevant Policy Development

Climate Change has been described as a "public good" (Ojwang *et al.*, 2010). Climate change, a domain of public endeavour, can only be advanced by policy formulation. To have an impact at ground-root levels, the policy must be knowledge-informed, implemented, monitored and evaluated. The challenge that faces Climate Change as a "public good" is the generation and application of knowledge to inform relevant policy making and the development of tools to monitor and establish an on-going evaluation of the policy initiatives. Accordingly, an evidence-based approach, will lead to a greater efficiency in the provision of effective policy development for the smallholder systems of production. The Case Studies 14.1-14.4 have shown that the application of scientific knowledge and evidence can help resolve problems and assist in defining a range of relevant and feasible options for policy-makers.

Conclusions: Balancing Opportunities Against Risks

Demand drivers, namely growing incomes and urbanisation (Table 14.7) will continue to fuel the production and consumption of poultry products in Africa.

We can anticipate that the demand in food and poultry products will increase in Africa, and this will represent a major opportunity for smallholder production systems. The challenges faced by Climate Change risks provide an opportunity for developing strategies and policies focused on supporting resilient, sustainable smallholder poultry production systems in Africa. Smallholder livelihoods, faced with climate change risks, can be transformed into vibrant communities by the implementation of sound mitigation and adaptive strategies.

Questions for Discussion

1. Analyse the trends in the production and consumption of poultry meat and hen eggs in your country. State the sources of data used to inform your analysis.
2. Evaluate the contribution of smallholder poultry production to the supply of poultry products in your country.
3. Use the data available in FAOSTAT database to assess the differences in the security of supply of poultry meat and hen eggs in different regions of Africa. What is the contribution of smallholder poultry production systems to the security of supply of animal-based protein in your country? What are the key challenges facing the sector?
4. Assess the risks of climate change on the productivity of smallholder poultry production systems in Africa.
5. Propose key adaptive strategies that could be implemented in your country to cope with the risks of climate change facing the smallholder poultry production in Africa.
6. In your opinion, what are the gaps in knowledge that need to be addressed to inform the development of key policies for the mitigation of climate change risks in the smallholder poultry sector in Africa.
7. Propose feasible mitigation strategies to reduce the magnitude of the impact of climate change in the medium and long-term.

Suggested Readings

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15

ENVIRONMENTAL SERVICES IN AGROFORESTRY SYSTEMS UNDER CHANGING CLIMATIC CONDITIONS

J.A.F. Obiri and D. Nyamai

Summary

Climate change is and continues to be a challenge to African farmers mainly because of the role it plays in enhancing agricultural risks. Varying rainfall and temperatures in terms of quantity and timing has greatly affected crop and livestock farming. One intervention that has proven to mitigate the climate effects to agriculture and thus lowered agricultural risks is agroforestry systems. The later has been largely heralded through tree components that possess many desirable traits such as nitrogen fixation, carbon sequestration, unlocking soil nutrients and root systems that reach and extract water from low water tables. In essence, agroforestry trees both provide and regulate various essential services that ameliorate agricultural risks from climate change vagaries. By limiting the effects of climate change, agroforestry systems provide substantial gains and profits to agricultural practitioners because it reduces agricultural risks. In order to enhance the approval of the agricultural systems, new policies that promote the advancement of agroforestry practices have to be established and adopted.

Resume

Services environmentaux dans les systemes agroforestiers dans un contexe de changement climatique

Le changement climatique est et continue d'etre un defi pour les agriculteurs africainsprincipalement en raison de son role dans l'accroissement des risques en agriculture. Les modifications au niveau des precipitations et des temperatures, en quantite et de calendrier a considerablement affecte l'agriculture et l'elevage d'animaux. Une intervention s'est averee capable d'attenuer les effets climatiques de l'agriculture et donc reduire les risques agricoles dans les systemes agroforestiers.

Ce dernier a ete largement salue a travers les composantes de l'arbre quipossedent de nombreux caracteres utiles tels que la fixation de I'azote, la sequestration du carbone, la liberation des elements nutritifs du sol et un systeme racinaires quipeut atteindre et extraire l'eau nappespeuprofondes. En realite, les arbres agroforestiers, fournissent et regulent divers services essentiels qui attenuent les risques agricoles dus aux caprices de changement climatique. En limitant les effets des changements climatiques, les systemes d'agroforesterie fournissent des gains substantiels et des benefices pour les praticiens de l'agriculture, car elle reduit les risques agricoles. Afin d'ameliorer l'adoption des systemes agricoles, de nouvelles politiques qui promeuvent les pratiques agroforestieres doivent etre etablies et adoptees.

Introduction

African Agriculture and vulnerability to Climate Change

Climate change and climate variability have significant socio-economic and environmental impacts in Africa (Obasi, 2005). They pose serious threats to ecosystems and social livelihoods in the continent, both in the medium- and long-term periods (Gonzalez, 2001; Van Shayk *et al.,* 2005). Among these threats is reduced agricultural production largely through altered cropping seasons, increased incidences of pests and diseases, drought and floods. Agriculture has been affected by climate change throughout the continent in terms of the shifting amounts and patterns of rainfall and temperatures (Challinor *et al.,* 2007). Events like intense droughts and floods that have negatively impinged on agriculture have been recorded in many regions of Africa (Brooks, 2004). It is not only the magnitude of these events that constitute agricultural risk but also their timing. For example early and delayed rains have been reported to adversely affect the seasons for planting, the varieties of crops to plant and even their modes of harvesting. Food security is subsequently affected, as it is largely influenced by climate both in terms of production and storage (Lobell *et al.,* 2008), and aggravated by climate variability (King'uyu *et al.,* 2000).

On a global scale, developing countries have been most affected largely because they are the least equipped to adapt to the effects of climate change though they are the least contributors to the causes of climate change (Pak, 2005). Given this scenario, concerted efforts that can be easily implemented and adopted by African farmers, have to be made to increase climate change adaptation (Fraser *et al.,* 2013). These efforts are discussed in the next section and further expounded throughout this chapter.

Environmental Services, Agroforestry and Climate change

Environmental services arising from agroforestry system can be used to curb the agricultural risks caused by climate change. Ecosystem services are benefits that mankind derive from ecosystems. This can be classified into three categories, which are: provisioning services, cultural services and regulatory services (Jose 2009; Barrios 2012). Provisioning services are mainly goods and products such as food, fresh water, herbal medicines, timber etc. Cultural services are non- material services that include factors like spiritual and recreation values while regulating services comprise of benefits from natural processes such as carbon cycle and climate regulation, pollination, photosynthesis, hydrological cycles and water catchment regulation, etc. The regulating services are intimately connected to climate change. For instance the carbon cycle determines the amount of carbon dioxide (a key greenhouse gas) that is released or sequestered from the atmosphere. Carbon sequestration in the environment can be enhanced through various techniques, which include the use of agroforestry systems. This chapter largely dwells on the provisional and regulating services, as these are closely linked to agricultural services, and less on the cultural services.

Does agroforestry hold any promise to risks associated with climate change?

Verchot *et al.* (2007) have argued that agroforestry is a key driver that can help smallholder farmers adapt to climate change. They argued that an agroforestry system with its tree component cushions farmers against both agricultural production risk and income risk. Agroforestry has both a practical and intellectual appeal to agriculture. Practically it is appealing as it draws the benefit of different species whose combinations have high yield with limited farmer inputs. Intellectually, it employs ecological and economic concepts that involve complex (multi-species) agricultural systems that are efficient in resource use, yield profits and are reliable to farmers.

Despite this, agroforestry has some challenges that include; time taken to established, slower investment returns, requires extensive knowledge and is labour-intensive. These notwithstanding, the potential of agroforestry in agricultural risk management are still high as highlighted in section 3.

Learning objectives

The objectives of this chapter are to:

1. Introduce the reader to the importance and relationships between ecosystem services, climate change, agroforestry and agricultural risks;
2. Serves as a resource for trainers preparing and conducting training in agriculture industry to identify and implement measures that enhance benefits of agroforestry services and minimize agricultural risks.

Learning Outcomes

At the end of this chapter, it is expected that the reader shall be able to:

1. Understand the concepts and theoretical groundings of ecosystem services, climate change and agroforestry systems;
2. Identify the fundamental factors linking climate change, agroforestry and agricultural risks management in Africa;
3. Comprehend agroforestry systems and practices relevant to Africa's ecosystems under changing climatic conditions;
4. Analyze in detail, case studies on agroforestry systems and climate change aspects in Africa; and their role in enhancing resilience to climate change.

The Role of Agroforestry in the Climate Change Theme

Agroforestry plays vital functions in climate change and agricultural risk management. These functions are largely anchored on the provision and regulation of vital services.

Provisioning services, such as the supply of biomass energy like charcoal, is generally well recognized and appreciated because they provide direct benefits to people. Regulating services provide indirect benefits, which in spite of their critical significance to mankind tend to be ignored and not considered in decision- making (Tomich, et al., 2004). The regulating services described here include the regulation of (1) micro-and macro-climate of habitats, (2) water and soil catchments (3) air quality and (4) soil fertility. The supporting services include nutrients cycling and soil moisture. The existence of biodiversity supports the primary production of trees that underpins the delivery of provisioning and regulating services.

Regulating services

Trees in agroforestry systems play major roles in regulating ecosystem processes by providing shade, reducing wind and raindrops velocity, reducing runoff and controlling floods (see Table 15.1). Furthermore, they improve soil temperatures, soil moisture and ground water recharge. In drylands, trees reduce the movement of dust thus reducing health risks to people and livestock from illnesses such as those of respiratory system. Trees sequester carbon and influence humidity regimes of the atmosphere. Through these processes the micro and macro-climate of the ecosystem are regulated. Trees also protect land from erosion hence making it available for other uses such as settlement and agriculture. Nitrogen (N) fixing trees convert atmospheric N into organic form in plant tissues through symbiotic association of roots and special types of bacteria hence improving soil N. In turn, trees by modifying the micro- and macro-climate of agroforestry ecosystems build the natural capital thus positively influencing overall productivity of ecosystems.

Table 15.1: Summary of Agroforestry regulating services

Regulated ecosystem services	Livelihood assets		
	Human	Natural	Financial
Micro-climate	Improve productivity of drylands hence implication on H&N	Provide shade, reduce wind and raindrops velocity reduce body energy loss from livestock	Indirect impact on income from other services
Air quality	Health by reducing Dust	Reduce dust movement, more soil cover	Same as above
Macro-climate	Improve productivity of drylands hence implication on H&N	Carbon sequestration	Same as above related value chains
Flood + groundwater control	Improve productivity of drylands hence implication on H&N	Reduce runoff amount and speed thus improved soil moisture and ground-water recharge	Same as above
Erosion control	Improve productivity of drylands hence implication on H&N	Reduce runoff amount and speed thus improved soil moisture, water quality.	Same as above
Pest and Disease control	Health of human and livestock		Same as above

As outlined in Table 15.1 among the key roles of agroforestry trees in regulation of climate in microhabitats are: water and soil catchments, air quality and soil fertility. These are discussed in the following sub-sections.

Improving microclimate of habitats and microhabitats

Microhabitats are important spaces that plants colonize and eventually occupy. These spaces are made ideal for colonizing plants (particularly by seedlings and saplings) by agroforestry trees that provide shade which reduces the temperature within the microhabitat. In essence, agroforestry tree species can act as nurse trees and facilitate better regeneration of seedlings.

Agroforestry systems and practices in African are characterized by trees/ shrubs often mixed with annual crops in the rangelands and the farmed fields. Combining woody and non-woody plants in mixtures modifies microclimatic factors such as wind speed, air and tissue temperatures, relative humidity and radiation, saturation deficit of understorey crops and consequently affecting evaporation (Monteith, *et al.,* 1991; Brenner, 1996). Therefore, compared to an open environment, the modified micro-climate under trees has reduced solar radiation and moderate temperature, higher humidity, lower rates of evapo- transpiration and higher soil moisture levels. This affects both crop growth and livestock performance.

Micro-climate modification by trees affects crop growth in various ways. In agricultural systems of the African dryland conditions, crops often use a small fraction of the rainfall input due to unproductive loss of water principally via soil evaporation, runoff and drainage (Lott *et al.,* 2009). Tree shade can significantly reduce supra-optimal temperature, radiation, soil evaporation of the near surface atmosphere leading to higher soil moisture (HR) with a major impact on crop performance (Lott *et al.,* 2009; Ludwig, 2003; Wallace *et at.,* 1999). In general, shade will create micro-climates with lower seasonal mean ambient temperatures and solar radiation as well as smaller fluctuations (Rao *et al.,* 2007). For example in Niger Republic, *F. albida* shade induced reduction of soil temperatures by 5°C to 10°C depending on the movement of shade particularly at the time of crop establishment, which contributed to better growth of the crops under these trees (Vandenbeldt and Williams, 1992). Trees can also lower mechanical impact of wind/rain speeds to minimize damage on newly established crops (Lott *et al.,* 2009; Tamang *et al.,* 2010). In coffee and cacao plantations, shade trees have been observed to buffer high and low temperature extremes by as much as 5°C (Beer *et al.,* 1998). Figure 15.1 compares weekly mean soil temperature at 5 cm soil depth, measured at Sapone, Burkina Faso, under large and small trees of nere *(Parkia biglobosa)* and small trees of karite *(Vitellaria paradoxa)* as well as in open field. It was clear that temperatures in the open field are generally higher than under the canopy with the lowest temperatures being under the large nere canopy (Jonsson et al., 1999). The results showed that the combined beneficial effects of temperature modifications and soil fertility could exceed the negative effect of tree shade (Jonsson et al., 1999). In contrast, in Mali (Kater *et al.,* 1992) concluded that lower sorghum yield under two tree species were due to changes in micro-climate, which increased the incidence of fungal diseases of crop seedlings. Thus, micro-climate changes can be beneficial or harmful depending on the season.

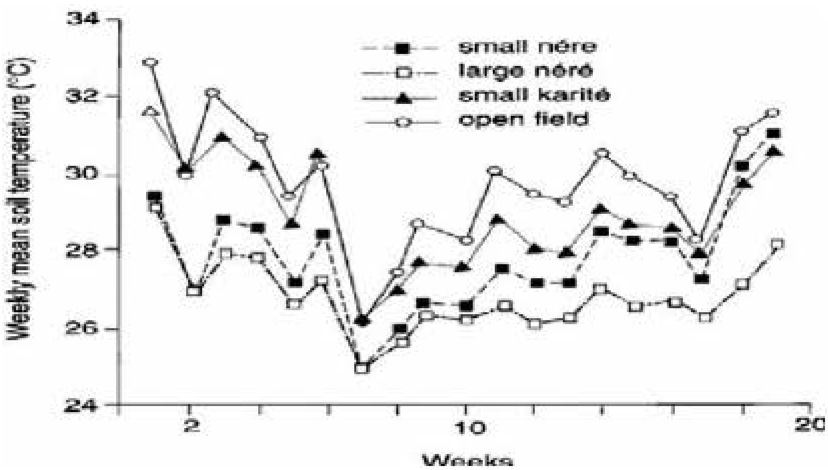

Figure 15.1: Weekly mean soil temperature at 5 cm depth, measured at Sapone, Burkina Faso under large and small nere (Parkia biglobosa) trees and small karite (Vitellaria paradoxa) trees in the open field. Tree crown diameters ranged from an average of 8.6m to 13.1m. (Source: Jonsson et al., 1999).

Micro-climate modification by trees also provides ecosystem services that are beneficial to livestock. In the rangelands of Eastern Africa, grass productivity was reported to be higher under trees due to the lengthening of the phenology of the grasses as a result of the combined effects of shade and water availability (Brenner 1996). Moderation of pasture micro-climate provided by trees further protect livestock from heat stress, wind, chills and severe weather events (Stigter *et al.,* 2011). Consequently, the use of agroforestry systems such as evergreen agriculture is an economically feasible way to protect crop plants from extremes in micro-climate and soil moisture and is a climate-smart adaptive strategy for farmers (Lin, 2007).

Regulation of water cycle

Trees play an important role in managing water cycle compared with other plant forms. They extract and transpire water from the soil into the atmosphere, and at the same time reduce surface runoff thus increasing infiltration. As a result, trees contribute to increasing the below-ground water storage fraction. However, the water use efficiency of a tree is dependent on specific attributes of a particular tree species as well as other factors such as, tree site-related ecological attributes (Beer *et. al* 1998). Trees may further increase transpiration losses depending on the climatic conditions of the growing site, reduce evapotranspiration losses by shading, reduce storage by roots' hydraulic redistribution, increase surface runoff by dripping following canopy interception, or increase overall water use efficiency of the agroforestry system by reducing root competition with crops Kimaru *et. al* 2009).

To a large extent, it is the attributes of the tree life form that make an individual tree instrumental in the water use efficiency thus influencing provision of water regulation services which is critical in maintaining the global water cycle. However, the overall contribution to surface runoff regulation and hence to flood and soil erosion control within an agroforestry ecosystem depends on the spatial extent of the tree cover relative to that of the crops. With respect to forests, for example, it has been suggested that in semi-arid and arid areas a cover of 3.5% to 6% would suffice for conferring the surface runoff regulation benefits to the rest of the land (Shvidenko *et al.,* 2005). Water regulation that increases infiltration and storage by reducing surface runoff is usually beneficial for agroforestry systems, which is one of the most important soil and water conservation role that trees and forests provide to the environment. To this end, it is imperative that, a careful, science and experience-based design and management of tree species selection is done to balance the mutual trade-offs between the soil-water management and land use specific objectives.

Air quality and human health

People living in dryland areas, particularly in the drylands ecosystem of Africa are constantly exposed to dust storms but rarely consider dust as a threat to their health. Researchers and development programmes advocate trees planting in the landscape and around human settlements to act as shelterbelt in reducing exposure to dust, and therefore provide health protection. Also, dust stresses livestock, upon which the nutrition and livelihoods of the populations in Africa's drylands largely depend hence affecting their health (see Plate 15.1). Exposure to dust is a threat to human health because, when dust is inhaled, it causes a range of respiratory diseases, including asthma, chronic obstructive pulmonary disease and pneumonia (Sandstrom and Forsberg, 2008). In addition, dust impairs visibility for both humans and livestock and is a transportation safety concern. Surprisingly, little attention has been paid to the health effects of dust exposure in Africa.

Plate 15.1: Dust caused by swirling winds - a common sight in African drylands. Courtesy of E.O. Wanjira (2013)

De Longueville (2010) identified this remarkable lack of interest in the health impacts of dust exposure in West Africa. Studies indicate that African drylands contribute over 50% of total global atmospheric dust circulation. This dust concentration is systematically higher than any other region of the world. The high child mortality associated with respiratory illnesses in developing countries, especially in Africa, has been partly attributed to exposure to dust (Smith et al., 1999). Regional variations show high wind speeds prevail in the coastal parts of Somalia and Djibouti as well as the Lake Turkana area of Kenya. These are dryland areas with significant areas of bare soil and thus are likely to have high dust loads.

Lack of vegetation cover is a major factor that increases the atmospheric dust loads. This partly explains why barren lands in desert areas are a major source of dust. Dust is also generated in moister drylands when overgrazing and land degradation expose soils which otherwise would have been protected by vegetation. Both grasses and trees reduce wind erosion and help prevent the loading of dust into the atmosphere. In addition, trees have the potential to reduce the load of an already dust-laden airstream by lowering wind velocity to below the threshold at which particles remain airborne (Smith et al., 1999).

Thus, having trees around human settlements reduces dust exposure, which could have a positive impact on human health. To date, these potentially positive effects of trees on the health of African dryland residents have received limited attention. Compelling arguments would be required to convince decision-makers that there is a need to develop policies to foster the planting and regeneration of trees in drylands to improve human and livestock health. Currently, it would be difficult to develop such convincing arguments because the underlying information and evidence base is limited. We need insights into and data regarding the negative impacts of dust exposure on human health in the drylands of eastern Africa.

Soil fertility regulation and enhanced provision of lock-up nutrients

Roots of agroforestry trees act as hydraulic lifts that bring water to surface from lower depths. The same roots also act as nutrient pumps and access nutrients at low soil depths, bringing them to upper surface (Ludwig 2003). Thus, trees improve soil fertility through recycling of nutrients from the deep soil horizons to the topsoil layers and by fixating atmospheric nitrogen (N). The recycling of nutrients by trees takes place either through capture of nutrients from deeper soil horizons or interception of nutrient leaching beyond the crop rooting zone by tree roots (Ludwig 2003). These nutrients are then released to topsoil horizons through litter and root turnover.

These processes play important roles in the recycling of nutrients in agroforestry systems (Smithson and Giller, 2002; Mafongoya et al., 2006) and are critical for the ecological sustainability of improved fallow, woodlot and other agroforestry practices common in dryland areas. The recycling of phosphorus (P) by trees is usually limited by high P-fixation in acid soil, low mobility in the soil, and low foliar P concentration (Young, 1997). Consequently, external P input is necessary to sustain crop yield on P-deficient soils because the amount recycled by short-rotation fallows of 1-3 years is often lower than amounts extracted via crop harvest (Smithson and Giller, 2002). However, in areas with sub-soil P reserves, trees raise topsoil N and P to levels sufficient for maize production (Mafongoya et al., 2006). Trees also accumulate other nutrients from the soil and may alleviate nutrient deficiencies, especially potassium (K) that can arise when sufficient levels of N and P are supplied (Sanchez and Jama 2002).

Agroforestry trees transfer atmospheric nitrogen through N-fixation trees to nearby crops. The transfer takes place on the surface and below-ground through decomposition of pruning or litter, root and nodule turnover, roots exudates via mycorrhizal connections and via the build-up of soil organic matter (Young 1997; Smithsonand Giller, 2002). The amount of N fixed varies widely among species but for fast growing tree species like Sesbania sesban (L.) Merrill., Cajanus cajan L. Mill sp., Gliricidia sepium (Jaqua) and Tephrosia vogelii Hook. f., fixation can accumulate about 100-200 kg of N per hectare per year (Sanchez and Jama, 2002). These amounts are substantial and can replenish soil N to levels sufficient to grow up to three subsequent maize crops on N deficient sites (Mafongoya et al., 2006).

Trees also improve soil structure and fertility through the build-up of soil organic matter (SOM). Trees add SOM by fixing carbon during photosynthesis and subsequent transfer to the soil through litter fall and root turnover. These plant materials are then converted to SOM by soil microbes through decomposition and humification processes. Besides, nutrient supply, the decomposition of SOM may increase plant-available nutrients in the soil through the reduction of P-sorption capacity of soil and supplying energy sources to soil micro-organisms responsible for nutrient cycling (Barrios et al., 2012). It is natural to find higher populations of micro-organisms in soils under agroforestry compared to treeless land-use (Barrios et al., 2012). Besides improving soil quality, micro-organisms, such as mycorrhizal fungi, enable terrestrial plants to effectively access nutrients and water under stress conditions by forming association with plants that can alleviate the stress symptoms (Marulanda et al., 2003). Thus, trees drive nutrient cycling and transformation in an ecosystem through their influence on SOM, soil micro-organisms and chemical processes in the soil.

Provisioning services

Trees in agroforestry systems are the natural capital underpinning the provision of tree-related foods, fodder, medicine, oils, construction materials, wood fuels, gums and resins and other products not discussed in this chapter. The provision of these goods would not be there without trees and just like other capital, it requires investment and careful management. Table 15.2 shows seven categories of goods that trees provide to enhance human capital through improved health and nutrition. The collection, processing and marketing of tree-related products also strengthens social assets (Jose 2009). Construction wood is an important ecosystem service underpinning the physical assets of people's livelihoods. All seven provisioning ecosystem goods also support financial capital dimension of people's livelihoods through product sales. People with secure livelihoods (e.g. high incomes and living standards) and are agricultural practitioners are less likely to suffer from the vagaries of agricultural risks. These include risks associated with farmers practicing poor farming methods (e.g. poor tilling, non utilization of agricultural inputs like fertilizers etc.), lack of awareness or non value-chain addition to agricultural products including poor storage and marketing of their agricultural produce. Where people have secure land tenure and have access to the benefits (e.g. wood and fruit products). They manage trees better with a hope to continue reaping the benefits for themselves. The more communities are socially organized and connected to different institutions such as government, private sector research and development organizations with respect to harvesting, processing and marketing the more benefits they derive from agroforestry systems (See Case study on climate smart agroforestry (Box 15.1)). Enabling policies and regulations, especially those that have been internalized by local communities, promote harmonious relationships among them (Pak 2005). Peaceful relationships are also experienced between the local people and other individuals and institutions, thus creating conducive environment for sustainable natural resources management (NRM).

Table 15.2: Livelihood resilience provided by trees in agroforestry systems through provisioning of ecosystem goods supporting five livelihoods assets

Provisioning services	Livelihood assets				
	Human	Social	Natural	Physical	Financial
Food and nutrition	H&N through fruits, leaves and staples consumed	Product Sharing, SN while collecting	NC provisioning Food		Income from Sale
Fodder for livestock	H&N through consumption of animal products	Status from livestock & Ceremonial use	NC provisioning fodder and forage		Income through sale of animals & animal products
Medicine	Health	Associations among herbalists	NC provisioning medicine		Income from Sale
Oil	H&N from cooking and cosmetics	SN in processing, Harvest and marketing	NC provisioning oils		Income from sale of raw material and oil products

Construction materials	Health protecting from weather and greater security		NC provisioning Construction materials	Fences, houses, furniture	Income from sale of wood and timber
Wood fuel	H&N from cooked food	SN during fetching, production and Marketing	NC provisioning wood fuels		Income from sale of firewood and charcoal
Gums, Resins	Health from sanitation detergents	SN from harvest, processing and marketing and Ceremonial use	NC provisioning Gums and resins		Income from sale and payment for collection

Source: Leeuw et al. (2013); H&N = Health and Nutrition; SN = social networks; NC = natural capital.

Case Studies on climate smart Agroforestry Systems in Africa

Box 15.1: Making the most of carbon trade from agroforestry systems and practices REDD+ project brings climate change resilience to Kenyan communities

Introduction: Tropical forests lock-up about 300 tonnes of carbon per hectare in above- ground biomass. However, if the same forests are converted to grasslands or crop fields such as paddy rice, this figure drops to 5 tonnes per hectare or less (ICRAF, 2008). Many scientists and consortia are convinced that a carbon trade designed to address global warming can dramatically reduce deforestation if farmers are adequately rewarded for the carbon stored in trees and forest. A perfect case study in this respect is the Kasigau Corridor REDD+ (Reducing Deforestation and Forest Degradation) project.

Situational analysis: The Kasigau project is the first carbon offset project in Eastern Africa under the voluntary carbon market. The project is managed by a private company, Wildlife Works Ltd since 1998 and carbon credits started being sold from 2009. The project covers 500,000 hectares of land, which include both private and community land tenure located in Taita-Taveta Counties in Kenya. The Kasigau corridor is a vital wildlife hotspot since it links the Tsavo East and West national parks, which are Kenya's largest wildlife refuges. The Kasigau Corridor REDD+ project is unique and regarded as an island of success having created an economic incentive for land owners and communities within the corridor to protect their forest. It enables Wildlife Works Ltd to supports landowners and local communities to implement forest management plans such as agroforestry systems and reforestation. After a successful pilot Phase I (2008-2011), the project expanded from 30,000 hectares in the Rukinga forest in 2010, to 170,000 hectares of similar dryland forest, mainly owned by community groups, or 'group ranches'.

Wildlife Works negotiated Carbon Rights Agreements/Easements with the neighbouring community landowners to execute the sale of carbon credits (at approx. US$9 per ton) under the voluntary carbon market. The carbon right belongs to the landowner but Wildlife Works Ltd manages them and sells carbon credits on behalf of the group ranches. The revenues are shared equally between 3 groups: Wildlife Works to cover administrative costs, the shareholders of the land and the communities through budget allocation to community groups. The project has several impacts such as supporting education and health sectors, making eco-friendly products, protecting wildlife, job creation, environmental restoration, etc.

Biodiversity conservation and ecosystem services provision

Agroforestry systems and practices play a key role in biodiversity conservation. Biodiversity is the degree of variation of life forms within a given species, an ecosystem, a biome or the planet. Human societies depend on the supporting services offered by biodiversity because they underpin the capacity of the world's ecosystem in providing most of its goods and services e.g. drylands are endowed with a rich biodiversity including agroforestry plants.

Drylands host a vast number of trees and shrub species such as acacia and baobab and many of the world's grasses however, this potential is often overlooked. In agroforestry systems, people manage this diversity in intensively managed landscapes, where They may selectively promote native species. This enriches the diversity of ecosystem services. Besides species diversity, other factors like the spatial arrangement and size of trees has significant effect on regulating and supporting services (Nyadzi *et. al.,* 2003). For example, size and spatial arrangement of trees in farms and landscape units over large areas influence the micro-climate, particularly temperature and soil moisture.

Provision of soil fertility and fodder from agroforestry trees

The Faidherbia-maize system in Tanzania and the Faidherbia-teff system in Ethiopia are traditional agroforestry practices in which *Faidherbia albida* is retained and managed by farmers for soil fertility improvement and provision of other ecosystem services such as dry-season fodder for livestock (see Plate 15.2). Other dryland agroforestry practices in Eastern Africa for soil fertility management include improved fallow and rotational woodlots in Tanzania (Nyadzi *et al.*, 2003) and in Kenya (Jama *et al.*, 2008). Fallows of fertilizer trees can improve soil fertility at levels sufficient to reduce inputs of N and P fertilizers by 50% (Kimaro *et al.,* 2009). In semi-arid zones, crops yield improvements by tree/ shrubs fallows can partly be associated with alleviated soil moisture competition due to sequential cropping (Kimaro *et al.,* 2009). Moreover, deeper rooting and slower initial growth of perennials relative to most cereal crops (Mafongoya *et al.,* 2006) may reduce competition through differentiation of root niche and peak resource demand; hence facilitating coexistence of perennials and annuals in mixture even in the drier areas in Eastern and Southern Africa (Kimaro *et al.,* 2009).


Plate 15.2: *Left: Faidherbia albida* retained on-farm and maintained by farmers to enhance fertility in maize-based systems in Tanzania. *Right*: Teff-based systems in Ethiopia Photos courtesy of: M. Mpanda (*left*) and E. Birhane (*right*)

Agroforestry Systems and Practices for Enhanced Resilience to Climate Change

Resilience, ecosystem services and livelihood benefits provided by agroforestry

Agroforestry systems and practices provide many benefits through a variety of ecosystem goods and services. Most trees in agroforestry systems are hardy because of their deep rooting system which allows access to water resources that not available to other life-forms (Ludwig 2003). These trees enhance resilience by providing goods and services during the "hungry season", i.e. the period at the end of the dry season and the start of the rainy season, when foods from crops and livestock are inadequate to satisfy demand.

This type of resilience is indirect and arises when trees strengthen livelihoods' buffering capacity in normal years, a buffering capacity that can be drawn upon when hazards caused by climate change arise. Trees offer resilience largely from accumulated wood and other tree products that offer people with resources to use and a continued source of benefits and income during the height of drought when they are vulnerable (Jama *et. al* 2008). Resilience arises when trees increase the primary production of agroforestry landscapes, thus increasing the benefits from crops, trees, livestock and other organisms.

Agroforestry contributions to agro ecosystem resilience

Dryland agricultural practices in semi-arid and arid zones in Sub-Saharan Africa are characterized by extensive rather than intensive farming practices as a strategy to increase crop production (Kimaro *et al.,* 2013). In Eastern Africa, this approach gives low maize yields of 1-1.2 tons per hectare despite increasing the area under cultivation by about 8 million ha since the late 1960s (Sanou *et al.,* 2012). This trend of agricultural expansion (without adapting the methods to combat low-rainfall/higher temperature conditions) in Eastern Africa is unsustainable and is often associated with deforestation and land degradation. However, fertilizer trees can rehabilitate degraded farmlands, and increase the resilience of dryland farming systems (Sileshi *et al.* 2011; Sanou *et al.*, 2012).

Increased resilience of dryland farming systems with trees is attributed to a number of factors. These include moderating micro-climatic effects of trees on crops (Sanou *et al.,* 2012; Nyamadzawo *et al.,* 2012) and higher structural and functional diversity relative to monoculture systems (Isaac and Kimaro, 2011). These factors help to sustain and diversify production cycles in agroforestry systems and hence, minimize risk due to climate variability in the semi-arid and arid zones. Good examples are the improved moisture retention in soils under *Sesbania sesban* fallows in Malawi and *Acacia* spp. in woodlots in Tanzania compared to maize fields and *F. albida* canopy in the Ethiopian parklands relative to the open area (Nyadzi *et al.,* 2003) (See Figure 15.2). The shading effects by trees on-farm increase millet production in dryland agro-ecosystems in the Sahel (Sanou *et al.,* 2012). Research also indicates that maize yield fluctuations resulting from climate rainfall and temperature variability can be mitigated by strategically combining legume trees and supplemental fertilization to increase rainwater use efficiency (Sileshi *et al.,* 2011).

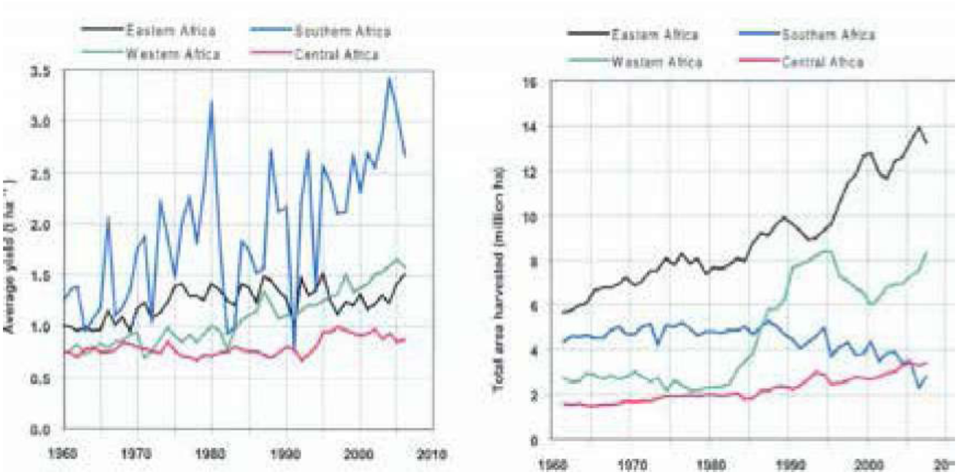

Figure 15.2: Trends in average grain yield and area of maize harvested in different regions of Africa, with average annual yields for 1961-2007 in each region obtained from FAO (2008). Source: ICRAF Policy Brief No. 02 2009).

Conclusion

Current socio-economic and environmental impacts in Africa are largely driven by climate change. These have serious risks to livelihoods and ecosystem management in Africa in both short and long-term periods. The risks include increased incidences of pests and diseases, drought and floods that reduce agricultural productivity. The agroforestry-based efforts that can be adopted by African farmers to institute increased climate change adaptation include provision of regular livelihood services, cultural services and regulatory services. Provision of regular services are mainly goods and products (e.g. food, fresh water, herbal medicines, timber etc), cultural services are non-material services (e.g. spiritual and recreation values) while regulating services are natural process benefits (e.g. those from carbon cycle and climate regulation, pollination, photosynthesis, hydrological cycles and water catchment regulation).

The provision and regulating services are more connected to agroforestry systems. Indeed, agroforestry plays vital functions in climate change and agricultural risk management such as regulation of micro- and macro-climate of habitats, water and soil catchments, air quality and soil fertility. Provisions of livelihood services include tree-related foods, fodder, medicine, oils, construction materials, wood fuels, gums and resins among others. Furthermore, ecosystems services of agroforestry systems ameliorate the harsh conditions of arid and semi-arid land thus increasing resilience in dryland farming.

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16

Vulnerability of Fresh-Cut Vegetables and Ornamental Plants to Climate Change

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Summary

Global human population increase of the last decades has been accompanied by a rapid rise in horticultural crop production in many developing countries (vegetables, fruits, wine, etc.), including the production of ornamental plants and flowers although many challenges still persist such as the risk of emerging plant diseases and most importantly climate change. In order to overcome these challenges, the present status and sustainability of the horticultural industries needs to be known in order to identify the areas of concern so as to proffer the necessary solutions to manage these challenges. This chapter was developed solely to provide adaptable information on the safe production, handling, storage and transport of fresh cut vegetables and ornamental plants in order to minimize hazards and impact of climate change throughout their lifecycle.

Resume

Vulnerability des legumes frais recoltes et des plantes ornementales au changement climatiques

La croissance globale de la population, cette derniere decennie, a ete suivie par un ac- croissement rapide de la production de plantes horticoles (legumes, fruits, vin, etc.) dans la plupart des pays en developpement, y compris la production de plantes ornementales et de fleurs, bien que de nombreux defispersistent, tels que les risques d'apparition de maladies et surtout le changement climatique. Pour faire face a ces defis, le statut et la durabilite des industries horticoles doivent etre connus en vue d'identifier les zones d'om- bres, afin de proposer les solutions idoines pour la gestion de ces defis. Ce chapitre a ete congu en vue de fournir des informations adequates sur la saine production, manuten- tion, stockage et le transport des legumes frais et de plantes ornementales recoltees, en vue de minimiser les risques et l'impact du changement climatique tout au long du cycle de vie de ces plantes.

Introduction

Horticultural Practices and Climate Change

To cope with the changing agricultural production trends compounded by climate change, Good Agricultural Practices (GAP) are required to address environmental, economic and social sustainability for on-farm processes. The concept of GAP has evolved to address the concerns of different stakeholders about food production and security, food safety and quality, and the environmental sustainability of agriculture. The stakeholders include: governments, food retailing industries farmers and consumers who seek to meet specific objectives of food safety, food production, production efficiency, livelihood and environmental benefits. GAP offers the means to help reach those objectives. Good quality exists when the product complies with the requirements specified by the client (vanReeuwijk,1998).To be able to counter these challenges, there is need to ensure participation of small-scale producers, processors, extension staff and retailers who are in the horticultural supply chain. Empowering all those involved in the production process can enhance basic food quality standards that foster their health and that of the consumers.

The Challenges of Developing Countries in Horticulture Production

Many challenges exist in the production of horticultural products worldwide. These challenges include: increased «protectionism» where consumers in many developed countries have become more interested in understanding the sources of the foods that they eat; the growth in supermarkets and corporate farming., urbanization on the global scale, has led to an increasing proportion of the world's population living in urban environments where their interest in food production is becoming increasingly deficient. The growth in the scale of new producers has shifted horticulture in countries where land and labour allow cost-competitiveness; and the issue of genetically modified crops (GMOs), which is now widely used in a number of countries for production of large scale agronomic crops such as maize, soybean and canola (oil seed rape) (EPZA,2005).

Impact of Climate Change on the Growth and Marketing of Horticultural Products

Increasing Temperatures

Horticultural crops are sensitive to temperature, and most of them have specific temperature requirements for high yield sand quality. Decisions on the location of production as well as crop and cultivar selection, are influenced by temperature, access to and timing of markets, suitable soils as well as availability and reliability of irrigation water

Changes in Rainfall Amounts, Distribution and Intensity

Horticultural industries have a dependence on irrigation, only very little rain- grown production occurs. Most of the production is done under controlled conditions in greenhouses. Rainfall has positive and negative effects on horticultural production. With normal occurrence of rainfall, irrigation storages (dams and aquifers) are replenished, and the amount of irrigation required to grow crops is reduced. High intensity of rainfall leads to devastating consequences for product quality and production (Deuter, 2008). All horticultural regions will continue normal production for extended periods of time as droughts develop. This situation has occurred in many horticultural regions for a number of years without significant rainfall. This is a direct contrast with much of the broad- acre and grazing industries which depend on pre-planting and in-crop rainfall to produce economic yields. Where future changing climates deliver less rainfall, and consequently less runoff, changes will need to be made to the capture and storage of irrigation water together with more water-use efficient irrigation systems, for growers to be able to continue production (Nzomoi et al., 2007).

Specific Impacts

Many horticultural regions have already experienced arise in both maximum and minimum temperatures as a result of climate change. Due to these changes, growers have already experienced up to 1°C rise in temperatures, and are trying to adapt to these changes. Climate indices and thresholds for the large range of horticultural crops are also not well known, especially for the vegetable sector. There is no clear and defined understanding of how climate change will impact cropping systems and businesses in specific regions. Arriving at an understanding is even more complex considering the large number of commodities classified as horticultural crops. Defining specific impacts on this large range of commodities across all production regions is currently not possible (Deuter, 2008). The following impacts, including some examples, have already occurred and are likely to continue to occur, with a further increase in temperature.

Is Horticulture Sustainable with the Changing Climate?

Due to the global climatic scenario, it is assumed that all genetic resources are potentially valuable and should be conserved for posterity. The present value of the existing resources cannot be assessed because of future developing technologies. To achieve sustainability, it will be important to develop suitable agronomic adaptation measures for reducing the adverse-climate related production losses. Simulation models for horticultural crops are required to enable regional impact, adaptation and vulnerability analysis. Researchers should be involved in identification and refinement of indigenous technological knowledge to meet the challenges of weather related aberrations. It will be important to carry out studies on managing plant architecture and quantification of carbon sequestration potential of perennial horticultural systems (Warner and van der Geest, 2013). Capacity building is crucial in order to train researchers, horticultural extension personnel and farmers on climate change issues. Infrastructural development also needs to be taken up to make horticulture resilient to climate change. There is also need for more storage structure and training on value added products, which can augment the farm income to make farmers more resilient to adverse situations.

Learning Objective

The objective of this chapter is to provide broad-based scientific and practical information on the safe production, handling, storage and transport of fresh cut vegetables and ornamental produce. This chapter will:

1. Provide a teaching tool to train students who will facilitate the safe production, handling, storage and transport of horticultural products in developing countries f o r export to markets in developed countries and elsewhere;
2. Serves as a source for trainers preparing and conducting training to assist those in the produce industry in identifying and implementing appropriate measures to minimize the risk of microbial contamination while reducing other hazards (chemical and physical) and maintaining market quality.

Learning outcomes

a. The students will know the differences between food safety and quality.
b. The students will be aware of food safety management systems and quality assurance and know the scope of use and limitations for such programmes.
c. Trainers are expected to understand risk reduction principles of microbial hazards on fresh-cut vegetables and ornamental produce farms because current technologies cannot eliminate all potential food safety hazards associated with these produce that are eaten raw.

Developments in Horticulture (Vegetables and Ornamental Plants)

Developments in horticulture have been reviewed in the context of the risk of emerging plant diseases including the movement towards a global horticultural market, the growth of the horticultural industry in many developing countries, and the economic integration of the European Union (Dehnen-Schmutz *et al.,* 2009). Based on the review, North America is well ahead of other regions in economic developments, and in horticulture, which is evidenced by the growing importance of Mexican growers. Asia is rapidly catching up in horticulture, with China and India becoming key producers. Australia and New Zealand show the impact of change in horticulture extension services. The Eastern enlargement of the EU is having profound influences on fruit and vegetable growers both in the new and old member countries. Similar developments are taking place in South America and Africa. In all continents, there is a general trend towards fewer and larger horticultural growers, an increasing role of supermarkets and a concentration of their tail pathways. These developments have consequences for the control of plant pathogens and invasive species.

Global human population increase of the last decades has been accompanied by a rapid rise in horticultural crop production (vegetables, fruits, wine, etc.), including the production of ornamental plants and flowers (Menini, 1987; Lawson, 1996; Harrison, 2003; Janick, 2007; Hoffmann, 2009). Currently there is increased adoption off ree market policies and trade agreements, which have reduced trade barriers to plant shipments among different countries of the world, although hurdles in the horticultural trade are, in many cases, still substantial (Rae,2004). At the same time, the global horticultural expansion has been enabled by continuous product improvement. The global horticultural expansion has thus been beneficial to many emerging economies, although many challenges still persist (Groot,1999). Developing countries are trying to develop horticulture industries to increase export revenues and to benefit rural communities (Warrington, 2005; Lumpkin, 2007). Greenhouse agriculture, through technical innovations, are likely to be essential to maintain sustainability of food production (JiangandYu, 2007). Attempts to improve plant inspection policies at countries' borders using probabilistic models have been done to reduce the risk of spreading invasive plants, diseases and pests (Surkovet al.,2007; Mwebazeet *al.,* 2010).

Emerging Market Opportunities for Environmentally Sound Horticulture Practices

Emerging methods of production of horticultural plants include phyto- technologies such as green roofs, green walls, green corridors, greening of riparian strips, urban heat is land reduction, and water management applications such as rain gardens. Other techniques include phyto remediation applications in which plants are used for depolluting air, soil and water and expanded use of ornamental plants for greening purposes in cities, semi-urban and rural areas.

Ornamental horticulture plant scan provides solutions to climate change by mitigating its impact. Municipalities are devoting more of their budgets for building green infrastructure (versus grey infrastructure). This opportunity cannot be taken for granted as consumers have many choices on where to spend their discretionary income. Younger generations are conditioned to seek solutions that are convenient and easy and therefore require ornamental products that deliver instant satisfaction with minimal care.

To seize the opportunities for growth in the domestic market, China is undergoing rapid urbanization where plant solutions can make congested cities more livable and raise the quality of life. To compete globally in these markets, the sector needs market research, new product introductions, and new technologies to enable production, post-harvest and shipping over long distances in compliance with importing countries' phytosanitary regulations. The development of green infrastructure solutions is an emerging market with global potential.

International trade in ornamental products, as well as climatic changes, has increased the range of diseases and pests experienced by producers in many regions (Harris, 2003). The need for effective control strategies to manage these pressures-ideally using biocontrol technologies for minimal environmental impact-is an urgent priority so that growers are equipped with the advanced tools they need to maintain high yields and outstanding quality. In the current intensely competitive merchandising environment, it is difficult to raise prices and therefore managing costs of production of traditional products is vital to remaining competitive. Research that enables growers to adopt innovative practices as well as technologies that will lower their costs of production are high priorities.

Cost reduction can be achieved through methods that allow more efficient use of inputs, including water, nutrients, energy and labour. The sector needs to improve its environmental image and reduce its carbon footprint. The mass merchandisers and big box stores are more and more demanding products labeled with environmental indicators in their drive to expand adoption of sustainable practices (Satin,2000).

On account of the diversity of production types, systems and crops in ornamental horticulture, the development of best environmental practices that lower the carbon footprint requires research and then knowledge transfer to all the parts of the value chain where the research results can be adopted. The sector's priorities reflect strategies for both seizing opportunities and mitigating competitive threats. Research and innovation across the nine priority areas identified in this strategy are the solution to enabling the sector to reach its potential and contribute to future prosperity and quality of life.

Innovations in vegetables and ornamental Plants:

Innovation in ornamental horticulture sector could be achieved through:

1. Increase profitability throughout the value chain by:
   - Increasing profitability throughout the value chain which could be attained through:
     - increasing the value proposition, i.e. that amount that the consumer is willing to pay;
     - increasing yield (productivity) without increasing input costs and;
     - reducing costs throughout the value chain including shrinkage and loss.
   - Profitability is also correlated with stability and predictability-to provide greater assurance of appropriate returns, it is important to mitigate risks that can be disruptive to markets and cost structures;
   - Achieve a higher level of integration along the value chain as measured by less reliance on foreign technologies and imported products as well as greater domestic market share.
2. Grow the market across the value chain:
   - Increase the value perceived by consumers for the sector' products and services by understanding consumer needs and effectively communicating with consumers;
   - Position the sector as a solution-provider tour ban needs for plants;
   - Think globally to determine how to increase the overall market share of the ornamental sector, utilizing the resources and the sector's technology to penetrate other markets.
3. Increase the favourable image and positive perception of the sector across society by being leaders in the adoption of best practices.
4. Enable the sector to adapt to and comply with regulations in line with society's expectations and contribute information that allows regulations to be science-based.

Food Standards

Standards provide common frames of reference for defining products. Food standards specify precise criteria to ensure that products fit their stated purposes and meet the legitimate expectations of consumers. This makes standards useful to consumers, the food industry and regulatory bodies. Food standards may include specifications for product appearance, quality, nutritional value, product safety, labelling, packaging, methods of analysis and sampling.

Food standards are used to maintain uniformity of product's quality and safety, to gain market access and establish market presence, to provide different consumers with equal information about the product and to prevent economic fraud or market exclusion. Standardization allows for correct food labeling the basis for consumer confidence (FAO,2006, CAC, 2005).

All fruits, vegetables and ornamentals are living parts of plants containing 65 to 95 percent water. They continue their life metabolisms after harvest and thus change their characteristics depending on product handling, storage and treatment, all of which have a decisive impact on the life of the product. The nature of the produce strongly influences its vulnerability to different types of deterioration. Deterioration spoilage and contamination of fresh produce may be the result of biological, microbiological, physiological/ biochemical or physical factors acting on the products (Table 16.1). These factors are usually the result of lack of proper training for product handlers, inadequate storage structures, unsuitable handling technologies, ineffective quality control and adverse environmental conditions (Satin,2000).

Table 16.1. Causes of post-harvest losses in fruit and vegetables

Deterioration factor	Deterioration causes
Biological and physiological Pests (e.g. .insects, rodents, birds)	Inadequate good agricultural/manufacturing practices
Spoilage and contaminating microorganisms (e.g. bacteria and fungi)	Inadequate hygiene and sanitation practices
Respiration rate	Excessive heat and high temperatures
Ethylene production	Environment (temperature, atmospheric pressure)
Growth and development	Time and environment
Maturation, ripening, senescence	Time and environment
Transpiration and water loss	Time, environment and improper packaging
Chemical and biochemical	
Enzymic	Environment, handling and bruising
Oxidation	High oxygen concentration and availability
Non-enzymic changes	Improper packaging, composition, heat
Light oxidation Physical	Improper packaging
Bruising and crushing	Improper handling and packaging
Wilting	High relative humidity and improper packaging
Texture changes	Environment and improper packaging
Moisture changes	High relative humidity and improper packaging

Source: (UN, 2007)

Safety Hazards

Microbial pathogens pose the greatest threat to the safety of fresh produce. The following principles should be borne in mind in any horticultural operation:

1. Once a product is contaminated, removing or killing the pathogens on the produce is very difficult;
2. Accordingly, prevention of microbial contamination a tall steps of operation is strongly favoured over treatment to eliminate any contamination that may have occurred.

Bacteria pose a common food safety risk due to their ubiquity in our environment, pathogenic bacteria potentially contaminate fruit and vegetables in all stages of the production chain. The number of individual bacteria that must be present to cause actual human disease varies with the type of organism as well as the age and condition of the host. Irrigation water is another potential vector through which contaminants maybe brought in contact with fruits and vegetables. Irrigation water if contaminated with human pathogens may contaminate soils, and splashing of soils by irrigation or heavy rain may facilitate produce contamination (Wachtel *et al.,* 2002). A number of recent studies have also indicated that fresh produce maybe contaminated through root uptake of human pathogens during irrigation with contaminated water (Solomon, etal.,2003; Wachtel *et al.,* 2002). It is currently unclear if root uptake of human pathogens is a significant source of contamination of fresh produce. However, direct contact of contaminated water with edible potions of crops is an obvious means of produce contamination by human pathogens.

Biological hazards in fresh produce come from micro-organisms such as bacteria, fungi (yeasts and moulds), protozoans, viruses and helminthes (worms), which can also be termed microbes. In some cases, microbial contamination is in directly introduced by pests. The term pest generally refers to any animals of public health importance, such as rodents, birds, insects (e.g. cockroaches, flies and their larvae), that may carry pathogens that can contaminate food. Microorganisms capable of causing human disease may be found in raw produce. Sometimes they are part of the fruit or vegetable microflora as incidental contaminants from the soil and surroundings. In other instances, they are introduced into or on food by poor handling practices in agricultural production or post-harvest processes.

Micro-organisms of Concern

Harris *et al.*, (2003) extensively reviewed outbreaks associated with fresh produce and reported that most common human pathogens associated with produce food borne illness outbreaks are: *E. coli* (O157:H7), *Salmonella spp., Shigella spp., Listeria monocytogenes, Crytosporidium spp., Cyclospora spp., Clostridium botulinum,* hepatitis A virus, Norwalk virus, and Norwalk- like viruses. These micro-organisms can be categorized as follows:

a. Soil-associated pathogenic bacteria (e.g. *Clostridium botulinum, Listeria monocytogenes);*
b. Feces-associated pathogenic bacteria (e.g. *Salmonella spp., Shigella spp., E.coli* (O157:H7), etc);
c. Pathogenic parasites (e.g. *Cryptosporidium spp, Cyclospora spp);*
d. Pathogenic viruses (hepatitis A, enterovirus, Norwalk-like viruses).

Viruses can pose serious health hazards, even in very low concentrations. Consequently, prevention of product contamination is essential during the production process:

1. proper sanitation and hygiene measures during food handling in agricultural and post-harvest operations; packing.

Management of growing conditions is of paramount importance in preventing the contamination of fresh produce by human pathogens. There are risk factors to consider, such as: growing conditions, agricultural practices used by specific growers, the time of year, growing region/environment, and management practices that may change over the course of a season. Climate, weather, water quality, soil fertility, pest control, as well as irrigation, and other management practices are difficult to integrate towards the development and implementation of microbial risk prevention and reduction programs on the farm.

Because some bacteria have very low infective doses, prevention of bacterial contamination is the most important control factor to enhance product safety. Also, it is essential to take action to ensure that pathogens already present cannot reproduce and grow to hazardous levels. If conditions are favourable, the generation time of bacteria can be as short as 15-30minutes, allowing the population of bacteria to reproduce very rapidly. Under optimum conditions, a single cell could thus produce a population of over one million cells within 10 hours.

The two main strategies to prevent hazardous levels of bacterial contamination in fresh produce are:

1. Preventing bacteria from reaching the product surface and/or keeping their initial number slow (prevention of contamination);
2. Ensuring that bacteria that have reached the product cannot grow (prevention of further growth).

Hazards

Chemical Hazards and Fresh Produce

Chemicals, either naturally occurring or artificially added synthetic substances, can pose serious health hazards for consumers. In order to minimize risks of chemical contamination of fresh produce, it is important to:

1. Make minimal and correct use of chemical additives (e.g. agrochemicals, processing and treatment agents, packing additives, pest control agents, antibiotics);

2. Prevent contamination during product handling and processing by identifying potential risks and implementing adequate proper practices and counter measures.

Physical Hazards and Fresh Produce

Foreign material in fresh produce can result in serious injury and illness for the consumer. Most of these physical hazards are related to poor handling practices during harvesting, washing, sorting and packing of products. To ensure the food safety of fresh produce, the following principles should be borne in mind:

1. Identify possible physical hazards along the production chain (agriculture and post-harvest processes);
2. Implement proper practices and counter measures and create awareness and responsibility among workers.

Good Agricultural Practices

Good agricultural Practice (GAP)have different meanings and implications. For this discuss, the term is used as a formally recognized terminology in international regulatory frameworks in association with codes of practice to minimize and prevent the contamination of food and thus to enhance the safety of food in agricultural production.

The use of good agricultural practices in the production of fresh fruit and vegetables is essential to prevent pathogen contamination. When implementing GAPs in field operations, key areas of concern are: the use of land, soil and water in an integrated and risk sensitive approach as well as control of wildlife and pests, proper worker hygiene, sanitation, harvesting and cooling practices, among others.

Current use of Adjacent Land and Area

The risk of produce contamination at the production site can be influenced by activities in the neighboring area:

- Check current use of land and activities in the neighboring area and assess risk of cross-contamination;
- Contamination can reach produce through multiple means, including water drainage and run-offs, subterranean water flow (water wells), wind erosion and transport by workers, animals, vehicles and equipment;
- It may be necessary to create physical barriers to prevent cross contamination (e.g. water diversion channels, wind erosion protection).

Prior use of Cultivated Land

Identify possible sources of microbial and chemical contamination associated with prior use of land such as:

- For animal feeding or domestic animal production;
- As a waste disposal site (garbage or toxic industrial waste);
- As a sanitary waste management site;
- For mining activities, oil or gas extraction;
- For former agricultural activities;
- Prior use of adjacent land and neighboring areas (risk of cross contamination);
- History of flooding in area of concern.

Importance of Quality of crop Production Water

Wherever water comes into contact with fresh produce, its quality may directly determine the potential for persistent pathogen contamination (Box16.1). Consequently, ensuring proper quality of crop production water on site is the key to safe production of fresh fruits and vegetables.

Box 16.1. Case Study on the use of polluted irrigated water for production of fresh cut vegetable in some West African countries

Water is important in crop production because it is used in many activities such as irrigation, washing and cooling. Irrigation water can spread pathogens, microorganisms (E.g.*Salmonella spp., E. coli* (O157:H7) and *Cryptosporidium parvum*) that cause disease in humans, Every time contaminated water comes in direct contact with fruit or vegetables, there is a risk that these pathogens maybe transferred to the produce.

A study conducted on improving food hygiene in Africa where vegetables are irrigated with polluted water was funded by European Union in 2005. The purpose of the study was to determine the current level of exposure of the Ghanaian local population to faecal coliform (FC) through the consumption of wastewater irrigated vegetables and to analyse and improve the effectiveness of common washing methods on the reduction of faecal micro-organism populations on the surface of wastewater-irrigated vegetables. The levels of pathogen on market vegetables produced with wastewater were determined.

Questionnaire s were also used together information on common methods used in washing vegetables in 11 cities in West Africa. The efficacy of the common decontamination methods was measured in terms of log reductions in FC populations on homogenized contaminated vegetable samples. High FC and helminth eggs contamination levels exceeding common guidelines for food quality were recorded on the market vegetables.

Methods used to wash vegetables vary widely within Ghana and in neighboring francophone West African (WA) countries. However, several of the most common methods do not reduce the contamination to any desirable level. Significantly, different log reductions are achieved depending on the washing method and contact time.

Manure Treatment

Composting is a natural fermentation process by which organic material is decomposed and broken down into stable humus by micro-organisms such as bacteria and fungi. This heat-generating process eliminates much of the microbial pathogenic load within a few days and significantly reduces contamination risks by organic fertilizers.

If animal manure and human biological waste intended for use as fertilizers are not treated appropriately, the risk of serious microbial produce contamination can be extremely high. Potential risks can be significantly reduced by following good agricultural practices in mainly two areas of focus (Box 16.2);

Focus 1: Treatment procedures to reduce the potential pathogenic microbial load in manure or bio solid waste;

Focus 2: Prevention of direct or indirect contact between organic fertilizers and produce.

Box 16.2. Study on Prevalence of *Salmonella* Species and *Escherichia coli* in fresh Cabbage and Lettuce sold in Abeokuta metropolis, Nigeria.

Food borne illness outbreaks associated with fresh fruits and vegetables continue to be a significant concern for the produce industry. Most of these outbreaks have been traced to contamination of fresh produce with microbial pathogens arising from either animal or human faeces. In some cases, this fecal contamination occurs via poor practices, such as fertilizing produce fields with untreated manure or inappropriately treated compost.

A study was conducted on cabbage and lettuce in Abeokuta, Nigeria with the aim of finding the effect of manure application to the microbial safety of vegetables. Samples were collected from farmers using manure from different sources in cultivating vegetables. The samples were analysed microbiologically using standard laboratory procedures. Coliforms, *E. coli, Salmonella* spp., which are fecal contaminants and could be from the manure in the soil on the farm, were found to be present. The results identified *Salmonella* spp. from contaminated manure as a source of contamination for vegetables.

Animal Exclusion

All animals are potential sources of produce contamination or spoilage. They should therefore be prevented access to crop fields and kept away from post- harvest processing and packing areas. Domestic and farm animals pose as great a threat as wild animals and thus need to be dealt with similarly. The main sources of contamination by animals are faecal matter containing pathogenic microbes as well as pathogenic micro-organisms that are harboured by animal skin, fur and feathers. Pesticides can be extremely harmful to both humans and the natural environment. They may represent chemical hazard for consumers when fresh produce are accidentally contaminated by pesticides. Consequently, pesticides have to be applied, produce handled and stored carefully by well- trained personnel. Integrated pest management can be used to control pest in agricultural operations by; Setting action thresholds; Monitor and Identify pests; Prevention and control.

Good sanitation is the key to animal and pest control in produce production and handling areas. All areas where produce is grown and handled should be kept clean and free of garbage or other waste.

Workers' Hygiene

Good workers' health facilitates better productivity and greater food safety within the operation system. Efforts should be focused on

1. Providing workers with sound and safe working environment and health programme in order to prevent diseases;
2. Dealing adequately with sick or injured workers in order to prevent pathogen contamination of produce or disease transmission to other persons.

Workers in the field should have access to proper sanitary facilities in order to prevent risks of serious microbial produce contamination. Any inadequate or improper accessible facility poses a threat to contamination of soil, water, crops and the workers themselves.

Research Priorities for Horticultural Production

Future research priorities in horticulture include:

1. Efficient Water use and Effective Nutrient Management

The sector takes a holistic view of water use, from the beginning of the growth cycle through to the use of ornamental products by the end user (consumer, municipality, green space operator,etc.), seeking to optimize the use of water at each point in the cycle. Optimal water use requires research into species/cultivar specific factors that require understanding how much water the plant requires as well as when and how it is best administered from production to consumer level; understanding what soil media best retain moisture and create optimal conditions for root development. It also calls for

Understanding the minimum quantity of nutrients, including micronutrients, required by the plant at each stage of growth and how they are most effectively administered to minimize leaching. Optimal water use also requires an understanding of technologies to optimize water usage and conservation, to collect and store water, to adjust water pH levels, and to treat water for recirculation to remove pathogens while allowing residual nutrients to be used by the plant. The proposed research initiatives are expected to significantly reduce the amount of water used per unit and this could also reduce the amount of nutrients applied per unit without compromising yield and plant health.

2. *Market and Consumer Research*

Understanding unique consumer needs is crucial for ornamental horticulture. For The sector competes for consumers' money in the impulse category for spending on discretionary items like cut flowers; it must be current and responsive to trends. Many trees and shrubs have long rotation periods (over ten years) before their products are ready for sale. This extended lead-time for introducing new products requires an excellent understanding of consumer trends, including what factors motivate consumers to buy (or not to buy), in order to be able to predict what product offerings might be in demand ten years ahead. Market research requires asking the right questions and obtaining the best answers to predict future purchase habits and consumer preferences to be able to position the value chain to have the right ornamental products and services to offer. The outcomes include gaining a clear understanding of the different segments of the market including what drivers motivate consumers to purchase ornamental products in order to better respond to consumer needs and expectations, contribute to perception of value and the commitment to pay for it. This response involves not only offering the right products at the right price points but understanding how to communicate information to consumers to enable them enjoy their ornamental products to the fullest extent.

3. *Environmental Best Practices*

Like climate change, environmental best practices concern a number of factors which are dynamic. They include steps: to reduce the carbon footprint of the production cycle (in sod, woody plants, perennials and greenhouse crops (bedding plants, potted flowering crops, cut flowers, etc.); to reduce the use of plastic materials in production equipment and product containers by identifying better alternatives; to recover value from co-products to optimally utilize soil as a valuable resource and renew soil health in crop production cycles; and to use ornamentals to reduce nutrient run off. Best practices are intended to provide a benchmark for measuring environmental impact and reduce packaging materials and carbon consumption while increasing carbon sequestration.

4. *Development of Green Infrastructure*

Green infrastructure refers to green roofs, green walls and green spaces developed in intensive urban areas. As more building codes mandate green infrastructure in new building design, the sector needs to understand what ornamental plant products offer the best configuration for each application across different cities and hardiness zones. In addition to questions of optimal design, there is a need to understand how to best grow, implement and maintain green infrastructure to ensure longevity and effectiveness. Useful outcomes from research on green infrastructure will nurture leaders in the design and supply of green infrastructure and drive double digit growth in this market and provide lower cost, as well as more environmentally friendly alternatives to grey infrastructure for municipalities and commercial institutions. This could also lead to increased ornamental horticultural applications to mainstreams of needs that have traditionally used other solutions.

5. *New Product Introductions in Horticulture*

The ultimate goal is to have new product introductions for which the plant breeder's rights are held so that royalties from licensing accrue back to researchers. The need for a steady stream of introductions across different product segments has been identified and requires understanding the genetic components and how they can be modified to achieve specific trait expression. Traits of interest include drought resistance, heat tolerance and winter hardiness. The Product is defined broadly to include not only the plant itself but the container and presentation as well as new supporting products that could benefit the industry, such as new substrates, new fertilizers, etc. Participants expressed the view that there is a trend towards edible ornamentals and see demand potential for new products that answer this need. The benefits in this area will include expanding the use of integrated pest management practices throughout the value chain; developing the use of biological controls in application to nursery crops and sod, and strengthening leadership in application of biological controls in greenhouse production.

6. *Human Resource Best Practices/Workers' Productivity*

There is need to ensure the development of technologies that maximize workers' productivity and reduce the risk of repetitive strain injury. The ability of robotic and other automation tools to be adapted in horticultural applications from one crop to another will increase their utilization and return on investment. Focus on best practices will increase workers' productivity each year and reduce the cost of workers' compensation premiums.

7. *Post-Harvest Technologies and Handling*

To service export markets, it is necessary to further develop soil free technologies for long distance shipping and plant viability. In the domestic market, this will improve the shelf life of products at consumers' level including cut flowers and potted flowering crops. Post-harvest technologies should be directed towards strengthening the sector's capacity to improve products' shelf life (cut flowers, potted crops) and ship product over long distances while maintaining high plant quality.

8. *Integrated Pest Management Practices*

The goal is to achieve integrated pest management strategies in production and across the entire value chain. Where feasible, the goal is to optimize the use of biological controls to maximum yield and plant quality while minimizing cost and environmental impact. Achieving this goal will require: effective chemical and biological control tools (including biopesticides and bioherbicides), working on an integrated pest management strategy for every crop and type of production up to municipalities' and consumers' level, and expanding the use of biological controls which will reduce environmental impact and increase the effectiveness of control measures against common pests like aphids and whitefly. There is need for rapid research during time of crises in order to identify pest or disease issues and determine how it can most effectively be addressed. Biocontrol production systems are sensitive and integrated and when chemical crop protection agents are introduced, it can severely impact the balance. Much research is needed in determining the compatibility of mutual interactions among agents to have a responsive biocontrol management system for diseases and pests. Bio- surveillance is needed to document and record disease and pest pressures and track how they are changing. The impact of such research includes expanding the use of integrated pest management practices throughout the value chain; developing the use of biological controls in application and strengthening leadership in the application of biological controls in greenhouse production.

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Section 5

Gestion des risques lies a l'utilisation des intrants agricoles

Section 5: Introduction

Plusieurs parties du monde sont touchees par l'insuffisance alimentaire et la pauvrete (FAO, 2012). En Afrique, la production agricole constitue l'activite economique principale qui peut assurer la securite alimentaire et la reduction de la pauvrete surtout pour les menages ruraux (PAM/FAO, 2009). Dans toute l'Afrique et particulierement, dans les zones sahelo-saheliennes, les agriculteurs sont confrontes a d'enormes difficultes lies a differents facteurs que sont les conditions climatiques difficiles (secheresse, inondations...), nature des sols, invasions de ravageurs, guerres ... (Hountondji, 2008). Tous ces parametres rendent impossibles ou tres difficiles les activites agro-pastorales dans certaines regions d'Afrique. Les consequences sont une faible productivite associee a des pertes de recolte et de post-recoltes pouvant aller jusqu'a 100% (Launois, 1996 , Singh et Singh, 1992). Face a ce constat, l'utilisation des intrants agricoles est devenue incontournable. L'agriculture moderne est donc devenue dependante des intrants. Certains produits chimiques bien que contribuant a assurer de meilleurs rendements agricoles, cause des risques graves sur l'environnement, la biodiversite et sur la sante humaine et animale. Le developpement d'une agriculture durable impose donc la recherche d'autres alternatives de lutte mais aussi et surtout une gestion raisonnee de l'utilisation des intrants agricoles.

Generalement, on definit le risque comme la possibilite de survenance dun dommage resultant dune exposition a un danger ou a un phenomene dangereux. Le risque est la combinaison de la probabilite d'occurrence dun evenement redoute (incident ou accident) et la gravite de ses consequences sur une cible donnee. Dans le cadre de l'agriculture, il existe un certain nombre de risques intervenant au niveau de l'utilisation d'intrants (engrais, produits phytosanitaires) dans le systeme de production agricole, de la dissemination des genes du fait de l'utilisation d'organismes genetiquement modifies par exemple, de la biodiversite, de l'erosion des sols, de la securite alimentaire, de la sante publique.

On entend par intrant, l'ensemble des elements entrant dans les productions agricole et pastorale. On distingue deux types d'intrants :

- Intrants agricoles

  Il s'agit des semences, des engrais mineraux et organiques, des pesticides chimiques et biologiques et le materiel et outillage agricole.

- Intrants zootechnique et veterinaire

  Il s'agit de : vaccins, aliments betails, medicaments veterinaires.

Cette section de cet ouvrage a pour objectif de relever les risques lies a l'utilisation des intrants agricoles en agriculture et d'en proposer des solutions. Pour atteindre ses objectifs, la section a ete subdivisee en trois chapitres qui sont :

1- Gestion des risques lies a l'utilisation des fertilisants ;

2- Gestion des risques lies a l'utilisation des semences ;

Lutte biologique et gestion des risques.

17

GESTION DES RISQUES LIES A L'UTILISATION DES FERTILISANTS

K.I. Kouassi, B. Camara, J. Ipou Ipou et J.K. Yatty

Resume

Le present chapitre propose une gestion efficace des risques en agriculture lies a l'utilisation des elements fertilisants en Afrique. Elle concretise les notions de strategies de gestion des risques en relation avec les elements fertilisants dans l'agriculture comme la connaissance des fertilisants, leur mode d'emploi, les mecanismes de transfert des fertilisants dans le paysage agricole, l'identification des risques associes a l'utilisation des fertilisants et le processus de gestion de ces risques. A la fin de la lecture de ce chapitre, l'utilisateur doit etre capable de faire la difference entre les fertilisants, d'identifier non seulement les voies de transfert de ces fertilisants dans le paysage agricole mais aussi les risques qui leur sont associes et d'elaborer des strategies pour la gestion durable de ces risques en fonction de la localisation de l'exploitation agricole. Ce chapitre est destine avant tout aux enseignants chercheurs, aux autorites d'execution, conseillers agricoles, agro-entrepreneurs, ainsi qu'aux agriculteurs interesses.

Summary

Risk Management Related to Fertilizer Use

This chapter provides an effective risk management in agriculture related to the use of fertilizers in Africa. It embodies the concepts of risk management strategies in relation to the nutrients in agriculture such as the knowledge of fertilizers, their usage, the fertilizer transfer mechanisms in the agricultural landscape, the identification of risks in fertilizer use and these risks management process. After reading this chapter, the user should be able to tell the difference between fertilizers, to identify not only the pathways of these fertilizers in the agricultural landscape but also the risks associated with them and develop strategies for the sustainable management of these risks based on the location of the farm. This chapter is intended primarily for teachers and researchers, the implementing authorities, agricultural advisors, agro-entrepreneurs, and interested farmers.

Introduction

En Afrique de façon generale et particulierement dans les zones a forte activite agricole, les producteurs sont beaucoup preoccupes par le rendement de leurs exploitations agricoles. Pour cette raison, ils utilisent de nombreuses techniques d'amelioration de la fertilite des sols, encourages en cela par la politique des Etats a assurer une autosuffisance alimentaire. Parmi les techniques d'amelioration de la fertilite des sols, figure en premiere position l'utilisation des fertilisants par les agriculteurs. Dans certains pays d'Afrique de l'Ouest par exemple, des programmes regionaux (Projet de Commercialisation des Intrants au Niveau Regional Plus : MIR Plus) sont mis en place afin de rendre accessibles les engrais aux producteurs. La consommation mondiale d'elements fertilisants s'est elevee a 179,4 milliards de kilos en 2007 : 61,6% d'azote, 23,1% de phosphates, et 15,3% de potasses (Banque mondiale, 2013). Selon la FAO, depuis 1999 jusqu'a aujourd'hui, la consommation d'engrais a diminue dans les pays developpes (environ moins

12 %) et a augmente dans les pays en developpement de 7,8%. Il apparait clairement que cette forte consommation des fertilisants bien que resolvant une preoccupation majeure des agriculteurs pose en amont un veritable probleme de menace societale : risques sanitaires, risques environnementaux, risques financiers etc. Ces risques sont exacerbes par leur mauvaise perception par les producteurs agricoles. Le risque est la combinaison de la probabilite d'occurrence dun evenement redoute (incident ou accident) et la gravite de ses consequences sur une cible donnee. Cet aspect generalement non integre dans les activites humaines genere des consequences qui s'etalent sur des annees. Actuellement, le nouveau defi des Etats africains est d'assurer la conservation de l'environnement afin de rendre disponibles des ressources naturelles pour les generations presentes et futures (Badiane and Delgado, 1995). Pour ce faire, il faut limiter le risque et non agir sur le danger car le danger est inherent a l'activite. La gestion des risques consistera des lors a prendre des mesures appropriees et proportionnelles en fonction du niveau du risque tel qu'il a ete evalue par les moyens que nous definirons. Dans l'interet dune agriculture qui s'integre dans un developpement durable, les utilisateurs des fertilisants doivent se former a la gestion des risques qui leur sont associes (Fernandez et *al.,* 1995 ; Brouwer et Powell, 1995). L'objectif general de ce chapitre est de presenter un certain nombre de concepts et d'exemples pour donner du contenu a la notion de gestion des risques lies a l'utilisation des fertilisants. Ce chapitre voudrait juste « donner a penser » a des lecteurs en leur fournissant un cadre d'analyse et d'investigations pour ensuite approfondir, agir et innover dans le domaine de l'utilisation des fertilisants en Agriculture.

Objectifs d'Apprentissage

Ce present chapitre se propose de fournir quelques reponses aux questions que se posent souvent certains professionnels du secteur agricole telles que :

- Quels sont les compartiments (eau, sol, air et etres vivants) sur lesquels orienter le diagnostic afferent a l'utilisation des fertilisants?
- Quelles sont les methodes pertinentes et disponibles, notamment les indicateurs, permettant de diagnostiquer les contaminations et les impacts associes a l'utilisation des fertilisants ?
- Comment planifier l'application des fertilisants pour limiter leur diffusion dans l'environnement ?
- Quelles methodes de suivi des impacts environnementaux peuvent etre mises en reuvre pour une agriculture durable ?

Resultats d'Apprentissage

A la fin de ce chapitre, le lecteur doit retenir les modeles d'utilisation des fertilisants pour un developpement durable en Afrique. Ainsi, les utilisateurs doivent etre capables,

- d'etablir une distinction entre les fertilisants agricoles et de decrire leur mode d'action ;
- d'identifier les voies de transfert des fertilisants dans le paysage agricole ;
- D'identifier les risques associes a l'utilisation des fertilisants par des outils d'evaluation et de diagnostic ;
- de definir des modeles de gestion durable des risques lies a l'utilisation des fertilisants.

Types de Fertilisants et Modes d'Action

Fertiliser le sol, c'est le rendre le plus apte possible a la culture de vegetaux. Les fertilisants sont apportes aux sols fertiles et infertiles dans le souci d'augmenter leur rendement. Pour ce faire deux categories de fertilisants sont utilisees en agriculture (Berger, 1996 ; Duval et Weill, 2007):

-**Amendements :** Les amendements sont des substances qu'on incorpore au sol pour ameliorer les proprietes du sol. Ils consistent en un apport d'humus ou de calcaire en fonction de la nature du sol.

- **Engrais :** Les engrais sont des substances renfermant des elements chimiques indispensables a la croissance des plantes. On distingue principalement les engrais chimiques et les engrais organiques (fumier, compost, corne broyee, sang seche, guano, poudre d'os, aretes de poissons, engrais verts). Les engrais verts sont des cultures de vegetation qui enrichissent le sol en azote par l'activite symbiotique des bacteries situees au niveau de leurs nodosites. Ils sont mis au sol a la fin de chaque culture. Les engrais chimiques sont des engrais dont des elements mineraux inertes sont issus de l'industrie chimique qui sont directement assimilables par les vegetaux (Noura, 2007). A la difference des engrais organiques, les engrais chimiques agissent de maniere beaucoup plus rapide. Les engrais chimiques sont constitues en priorite des elements suivants l'azote (N), le phosphore (P) et le potassium (K). Actuellement, ce sont les engrais les plus couramment utilises en agriculture et sous diverses formes (liquides, granules et batonnets). Sur une etiquette d'emballage d'engrais, l'indication engrais NPK 15-5-10 signifie que cet engrais contient 15 % d'azote, 5 % de phosphore et 10 % de potassium (Dugue, 1995 ; Ganry et *al.*, 1998 et Lompo, 2008)

Risques Lies a l'Utilisation des Fertilisants Risques Financiers

Il se definit comme l'evenement aleatoire pouvant avoir un impact sur le resultat de l'exploitation agricole et pouvant affecter ses benefices tels que la presence de substances toxiques provenant des fertilisants dans la production vegetale. Le risque financier est un risque initial pouvant entrainer a son tour l'occurrence d'autres risques. L'utilisation des fertilisants augmente les couts de production ce qui fait chuter les revenus agricoles. L'emploi excessif d'engrais n'est qu'une face de la medaille, l'autre face, ce sont les pertes de substances nutritives. Les resultats de recherches de l'universite de Wageningen montrent que, dans 37 pays africains, pendant les 30 dernieres annees, des quantites importantes de substances nutritives ont ete perdues dont la valeur actuelle s'eleve a 11 milliards de dollars US (Amhad, 2008).

Risques Environnementaux

Les fertilisants non absorbes par les vegetaux, lessives par les pluies se retrouvent dans les sols, les fragilisant et diminuant d'autant leur capacite depuration. Les engrais phosphates deposent du cadmium, les engrais azotes favorisent la formation de nitrates. La fertilite des sols peut etre considerablement reduite par l'emploi excessif d'engrais.

Au niveau de l'eau, les fertilisants gagnent les eaux superficielles ou souterraines par ruissellement ou infiltration. L'azote sous forme de nitrate, transporte par les eaux de surface, peut entrainer des concentrations accrues de nitrate dans l'eau potable et l'eutrophisation des eaux de surface (moindre oxygenation et enrichissement en nutriments) avec pour corollaire le developpement des marees vertes. Les symptomes d'eutrophisation comprennent une biomasse de phytoplancton, d'algues fixees et de macrophytes, et s'accompagnent d'une modification des caracteristiques de l'habitat due a un changement de la composition des plantes aquatiques et au remplacement des poissons existants par des especes moins desirables.

Dans lair, les activites agricoles contribuent a la dispersion de nombreux polluants tels le methane, ammoniac, le protoxyde d'Azote, le dioxyde d'Azote et le dioxyde de carbone. Ces elements sont en grande partie responsables des bouleversements climatiques tels que des canicules, de plus importantes moussons, entres autres (Banque Mondiale, 2013).

Risques Sanitaires

Les principaux risques sanitaires resultent du transfert d'elements nocifs vers les plantes cultivees (residus dans l'alimentation), vers les eaux souterraines (par lessivage et infiltration des couches superieures du sol). C'est donc a travers l'alimentation essentiellement, et de fa^on minoritaire a travers les eaux de boisson, que la population generale est susceptible d'etre exposee. Elle est exposee de fa^on chronique a de faibles ou a de fortes doses. Les odeurs degagees par les eaux, certains fertilisants (dechets menagers, feces, engrais, etc.) sont aussi les causes des maladies respiratoires, du fendillement des pieds, de la toux et autres maladies constatees chez les producteurs. Les dangers lies a ces engrais: ils peuvent etre respiratoires (bronchites), cutanes (brulures, lesions, irritation); oculaires (conjonctivite), ou digestifs (desordres gastriques) et meme cardiaques (arythmie cardiaque) (Dejoux, 1988; Banque Mondiale, 2013).

Gestion des Risques Lies a l'Utilisation des Fertilisants

La gestion des risques doit repondre avant tout a des exigences de securite, celle-ci est relative a la securite des biens et des personnes, a la protection de l'environnement et a l'amelioration des conditions de travail (hygiene et sante). Pour une gestion durable des risques lies a l'utilisation des fertilisants, l'agriculteur doit connaitre les indicateurs suivants (Brossier, 1989; Jean et *al.*, 2008),

- La quantite et les caracteristiques des intrants organiques et les engrais chimiques ;
- Les pratiques limitant l'erosion et la degradation des sols ;
- La rotation des cultures sur un cycle plus ou moins long ;
- Les actions qui reduisent l'usage d'intrants et protegent les ressources en eau (bandes enherbees autour des ruisseaux et riviere).
- Le recours a des processus naturels et regenerateurs, comme les cycles nutritifs, la fixation biologique de l'azote et la reconstitution des sols ;
- Et les actions visant a reduire la production de dechets non reutilises en creant des interdependances avec d'autres activites economiques, dans un objectif de plus grande efficacite globale.

Le processus de gestion des risques est structure en 5 phases: la definition de la strategie (type de risque, outils d'evaluation et de traitement), l'analyse (causes et consequences), le traitement des risques (Reponse ou strategie), le suivi (veille) et la capitalisation (bases de donnees).

Gestion des risques financiers lies a l'utilisation des fertilisants

L'usage de dechets bio solides sur les terres agricoles s'avere une alternative interessante pour de nombreux agriculteurs. Ces dechets fournissent des elements nutritifs pour la croissance des vegetaux et constituent une source de matiere organique pour les sols. Ils peuvent contribuer a reduire les couts en engrais et a ameliorer l'etat des sols. En outre, de nombreux essais et resultats de recherches ont montre que les petits paysans en Afrique peuvent mettre a disposition des substances nutritives a moindres frais, par exemple par des techniques agroforestieres. Tout contribuerait a reduire l'utilisation des engrais chimiques et augmenter les gains financiers des producteurs (Bekunda et *al.,* 1999).

Gestion des risques environnementaux lies a l'utilisation des fertilisants

Toute personne qui epand de l'engrais doit prendre en consideration : le site (vegetation, topographie et conditions pedologiques) ; les conditions meteorologiques et la legislation afferente a la protection de l'environnement. La gestion des risques environnementaux passe egalement par le developpement d'autres formes d'agricultures telles que l'agriculture raisonnee, biologique ou de terroir (Anne et *al.*, 2011 ; Devez, 2004) .

En Afrique, de fa^on generale ces exemples de mesures peuvent etre adoptes pour gerer les risques environnementaux :

- En zone sahelienne de pluviometrie (500 mm a 700 mm), realiser des cultures par rotation. Apporter de la fumure minerale a dominance phosphatee ;
- Realiser une culture par rotation avec des legumineuses ;
- Assurer une bonne formation des producteurs combinee a une meilleure strategie d'approvisionnement des producteurs en fertilisants ;

- Developper des systemes de culture associes en tenant compte des zones agro climatiques et des habitudes alimentaires des populations ;
- Introduire dans les zones de productions agricoles a fertilite faible des varietes ameliorees adaptees a ces zones et garanties de toute securite environnementale et sanitaire ;
- Adapter les cultures aux rythmes saisonniers ;
- Et favoriser la fertilisation organique parce qu'elle est a l'origine dune intensification du cycle de carbone (Jurgen, 1976 ; Bationo et *al.,* 1997).

Gestion des risques sanitaires

Cette gestion exige des mesures de protection individuelle et meme collective telles que :

- Former les agriculteurs a la bonne utilisation des fertilisants ;
- Remplacer tout engrais dangereux par ce qui n'est pas dangereux ou moins dangereux ;
- Utiliser des equipements de protection adaptes aux fertilisants tels que le port de gants en nitrile ou neoprene, de masque avec cartouche filtrante de type A2B2P2, de caches nez, de combines et de bottes surtout lors de la manipulation des fertilisants concentres ;
- Apres utilisation, les equipements d'epandage doivent etre laves a l'eau savonneuse puis ranges dans un endroit propre autre que le local de stockage des fertilisants et a l'abri de la poussiere ;
- Apres une premiere utilisation la cartouche filtrante doit etre changee au bout de six mois au maximum (ou avant des que l'on sent des odeurs de fertilisants a travers la cartouche) ;
- Il est imperatif de conserver les fertilisants dans leur emballage initial afin de reperer les informations sur l'etiquette en cas d'intoxication aigue ;
- Amenager dans l'exploitation agricole un lieu specifique pour la preparation du fertilisant ;
- Utiliser un pulverisateur dote dune cuve d'incorporation et de rin^age des mains ;
- Et faire controler periodiquement l'appareil (Robert et *al.,* 2005).

Etudes de cas

Box 17.1 : Etude de cas 1 : Gestion de la fertilite des sols dans la culture du mil en regions saheliennes de l'Afrique de l'ouest (Samba et al., 2010)

Le mil {Pennisetum glaucum (L.) R. Br.} est la sixieme cereale la plus importante du monde (National Academy of Sciences, 1996). Le mil est la cereale la plus importante dans cette partie de l'Afrique tant par la superficie emblavee que par la production totale. Il serait cultive sur environ 38 millions d'hectares (FAO, 2000). La production globale depasserait les 31 millions de tonnes par an. Approximativement 40% de la production

mondiale de mil provient de l'Afrique et l'Afrique de l'Ouest fournit environ 80% de cette production. Les principaux pays producteurs sont : le Nigeria, le Niger, le Burkina Faso, le Mali, la Mauritanie et le Senegal. Au moins 500 millions de personnes dependent du mil pour leur survie (World Bank, 1995). C'est une culture essentielle dans une zone reputee pour une pluviometrie inadequate et incertaine, des surfaces importantes de sols infertiles et fragiles. Les contraintes relatives a la production du mil dans cette zone sont multiples et variees. Elles concernent a la fois les contraintes biotiques, abiotiques et socio-economiques. Parmi les contraintes abiotiques, figure en bonne position la qualite des sols caracterisee par son appauvrissement en elements mineraux suite a la pratique d'une agriculture miniere. Dans la zone sahelienne, les pertes en elements nutritifs ont ete chiffrees en moyenne a 660 kg N ha-1, 75 kg P ha-1, et 450 kg K ha" 1durant les 30 dernieres annees sur la base de 200 millions d'hectares cultivables dans 37 pays africains (Sanchez *et al.* 1997). Pour faire face a ces contraintes, de nouvelles technologies relatives a l'amelioration de la gestion de la fertilite des sols et celle des cultures sont proposees aux producteurs. Elles concernent la fertilisation des cultures par l'utilisation de la fumure organique ou organo-minerale combinee a l'utilisation de bonnes techniques culturales comme les associations et rotations culturales. En outre, les producteurs devraient etre bien formes a l'utilisation des intrants agricoles et a la notion de preservation du capital sol puis la strategie d'approvisionnement en fertilisants devrait etre amelioree. Cette etude de cas donne des strategies d'une gestion durable de la fertilite des sols dans la culture du mil dans les zones saheliennes. Cette gestion durable passe par une amelioration de la fertilite des terres agricoles, une intensification et une diversification de l'utilisation des terres par des produits a haute valeur commerciale (Sanchez *et al.,* 1997).

Question :

Apres avoir releve les differentes contraintes relatives a la fertilite des sols dans la culture du mil en region sahelienne en Afrique de l'ouest, proposez un schema organisationnel de la gestion de la fertilite des sols dans ces zones qui permettrait d'integrer la production du mil dans un developpement durable.

Box 17.2 : Etude de cas : Risques lies a la fertilisation de l'ananas

Cette etude de cas vise a faire face au probleme de la culture de l'ananas qui est une culture pas comme les autres car necessitant une programmation de toutes les operations par le producteur. Les etudiants a travers les questions seront amenes a comprendre les differents types de choix des operations a realiser en fonction des objectifs de productions pour les petits producteurs. Ils seront egalement amenes a identifier la meilleure approche de fertilisation qui tient compte de de la rentabilite pour le petit producteur en fonction du marche.

L'ananas a connu un essor important lorsque la firme americaine Del monte a lance dans les annees 90 une nouvelle variete cree a Hawaii en 1970, le MD2, appele aussi

sweet, Extra sweet ou Golden Sweet, cultive dans d'immenses plantations au Costa Rica. Le Sweet au Bresil, de l'Equateur, du Honduras et de Panama a surclasse le Cayenne lisse qui dominait depuis longtemps deja, les exportations africaines vers l'Europe. La deferlante de ces ananas produits par les firmes industrielles a pratiquement reduit a neant l'activite de nombreux petits et moyens planteurs africains. Une des causes de cette baisse des exportations est la presence de residus de pesticides constatee dans les fruits sur les marches europeens. Lorsque la presence des residus dans les fruits etait decelee, cela entrainait un rejet systematique des productions entrainant de grosses pertes de devises pour les producteurs qui revenaient au pays avec d'enormes dettes. Une non maitrise des fertilisants en culture d'ananas entraine des risques de perte de production car l'ananas est comme un « ordinateur » qui necessite une programmation des differentes operations relatives a sa culture.

A l'instar de la plupart des plantes, la nutrition minerale represente une des operations culturales les plus importantes. Les besoins de l'ananas sont relativement eleves et la pauvrete des sols cultives rend imperatif l'apport a la plante de la quasi-totalite des elements dont elle a besoin. Les etudes entreprises ont permis de definir les besoins moyens d'un plant d'ananas pour la production d'un fruit frais dans les conditions locales : il s'agit de 4g d'azote ; 10g de Potasse ; 2 a 3g de Magnesium. Les besoins en calcium sont bien moins precises, cet element accompagne souvent les engrais phosphores ou magnesiens et les besoins sont donc couverts lors de ces apports. Pour realiser une bonne Fumure il ne suffit pas d'apporter de l'engrais aux plants, il faut que ceux-ci puissent en absorber les elements actifs avec le meilleur rendement possible : l'efficacite des engrais doit etre la plus grande possible. Pour cela il faut connaitre les modalites de l'absorption de l'engrais et l'incidence de differents facteurs sur celle-ci.

L'objectif est d'elaborer dans les conditions d'un pays des techniques de production de la variete d'ananas MD2 par la mise en place d'un itineraire technique pour les petits producteurs en vue de promouvoir un accroissement durable de la production nationale de l'ananas.

Question :

En tant que petit producteur, vous voulez realiser une plantation d'ananas de la variete MD2 dans votre pays ou l'itineraire technique n'est pas maitrise.

Elaborez l'itineraire technique de l'ananas MD2 ou toute autre nouvelle variete d'ananas en tenant compte des zones agro-climatiques de votre pays pour les petits producteurs.

Conclusion

La gestion des risques liee a l'utilisation des fertilisants dans les exploitations agricoles est une nouvelle donne que les producteurs africains doivent integrer dans la programmation de leurs activites agricoles. Cette gestion des risques

passe imperativement par l'identification des risques qui peuvent etre d'ordre financier, sanitaire et environnemental. La connaissance de ces risques permet d'elaborer un plan strategique integrant la topographie du site de production afin de reduire au mieux l'incidence negative de l'utilisation des fertilisants sur les consommateurs, les producteurs eux-memes, l'environnement et les couts de production. Cette nouvelle forme d'agriculture dite « agriculture durable » rendrait d'avantage plus competitif les produits agricoles provenant des pays africains sur le marche international.

Questions de Discussion

Les risques agricoles peuvent etre egalement classes en risques unitaires et risques composes. Les risques unitaires concernent le prix de marche, le rendement, la qualite et le cout de production (ce dernier etant lie au prix des intrants). Les risques composes combinent plusieurs risques unitaires ; ils touchent le chiffre d'affaires et la marge par production et par exploitation. Chacun de ces risques peut etre traite par des instruments particuliers. Le traitement du risque choisi par les exploitants a des repercussions sur l'ensemble des filieres agroalimentaires. L'evolution de l'environnement economique et politique de l'agriculture, favorisant a la fois une plus grande volatilite des cours et une fragilite croissante des entreprises aux aleas, conduit a s'interesser aux questions suivantes :

- Comment l'agriculteur per^oit-il les risques traditionnels (prix, rendement, qualite, cout de production) et nouveaux (responsabilite en matiere de securite sanitaire et environnementale des productions) auxquels il doit faire face ?
- Comment reagit-il face a la volatilite des cours et a la probabilite de pertes « catastrophiques » ?
- Quels sont les risques qui influencent le plus ses decisions de production et de commercialisation ?
- Quel est son consentement a payer pour les differents instruments de gestion des risques ?

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18

GESTION DES RISQUES LIES A L'UTILISATION DES SEMENCES

M S.W Ouali-N'Goran , J. Ipou Ipou , I. Bagre et A.M. D'Almeida

Resume

La semence represente l'intrant indispensable a toute production agricole. La disponibilite de semences de qualite est donc un prealable a l'atteinte d'un bon niveau de productivite. Ce chapitre a pour objectif de presenter les risques lies a l'utilisation des semences d'origine vegetale et de proposer des elements de gestion de ces risques. La nature des semences varie selon l'espece vegetale et le mode de reproduction. Au plan international, le premier marqueur de qualite et de securite est la semence certifiee. Dans la plupart des pays africains, la production de semences reste encore traditionnelle ou informelle. Les equipements speciaux pour le controle de la qualite des semences restent indisponibles. Une meilleure formation des producteurs de semences peut etre une alternative au respect des procedures de production. Les risques lies aux semences sont dus aux conditions de conservation, aux aleas climatiques, aux pesticides, aux varietes genetiques, a l'utilisation des OGM et a la resistance des insectes ou des plantes nuisibles. Le brevetage des varietes creees risque de faire augmenter le prix des semences. La fragilite de la future agriculture peut etre due a la perte de la diversite biologique. La gestion des risques doit etre perdue de façon objective et integree par tous les acteurs. Elle doit prendre en compte, la technologie liee a la selection des varietes; l'aspect economique s'appliquant a la production et a la commercialisation et la composante juridique. Les semences constituent un materiel vegetal vivant et donc en constante evolution.

Summary

Riks Management Related to Seed Use

Seed is the indispensable input for all agricultural production. Therefore the availability of quality seed is a prerequisite for achieving a good level of productivity. This chapter aims to present risks related to the use of vegetable seeds and propose to manage these risks. The nature of the seed varies on the plant species and the reproduction mode. Internationally, the first marker of quality and safety is certified seed. In most African countries, seed production is still traditional or informal. Special equipment for quality control of seeds remain unavailable. Better Seed Growers training can be an alternative to compliance with production procedures. Risks related to seed due to storage conditions, the weather, pesticides, genetic varieties, the use of GMOs and the resistance of insects or weeds. The patenting of varieties developed could increase the price of seeds. The fragility of the future agriculture may be due to loss of biodiversity. Risk management must be viewed objectively and integrated by all stakeholders. It must take into account the technology related to the selection of varieties; the economics applicable to the production and marketing and the legal component. The seeds are a living plant material and therefore constantly changing.

Introduction

L'agriculture moderne repose sur l'exploitation de la richesse naturelle contenue dans la biodiversite. L'ensemble du potentiel exploitable par l'humanite pour subvenir a ses besoins est designe sous le vocable de Ressources Genetiques qui comprennent entre autre les elements qui peuvent lui permettre d'assurer sa survie et son developpement actuels et futurs tels que les productions agricoles, les semences, etc (FAO, 2010). Selon la FAO, l'IBPGR, l'IPGRI et la Bioversity International, le nombre total d'accessions conservees *ex situ* de par le monde a atteint 7,4 millions reparties dans 1750 banques de genes (FAO, 2011). Qu'en est-il de la reserve semenciere dont dispose l'Afrique en generale et l'Afrique subsaharienne en particulier ?

En Cote d'Ivoire, le nombre total d'accessions et de genotypes conserves *ex situ* dans les centres de recherche et les Universites est estime a 49323 parmi lesquelles on denombre 367 especes, dont l'utilite est averee. Cent trente- neuf (139) de ces especes peuvent etre considerees comme des semences qui interviennent dans l'alimentation humaine et animale (KOFFI, 2013).

Selon la FAO (2009), les objectifs fondamentaux du Millenaire pour le developpement sont d'accroitre la productivite agricole de maniere durable en vue de la reduction de la faim et la preservation de l'environnement. Comment les gouvernements africains releveront-ils ces defis? Un investissement important dans l'agriculture sera necessaire. En agriculture la semence constitue le premier intrant de la culture. La semence peut etre de nature animale (ex. sperme) ou vegetale. Le present chapitre sera axe sur les semences vegetales. Les semences sont des graines, des fragments de plantes ou des organes de reproduction, selectionnes pour etre semees.

Comme toute entreprise, la production agricole est exposee a des aleas climatiques, de mauvais rendements, aux mauvaises qualites des productions, aux meventes etc.). Les agriculteurs sont confrontes a des risques specifiques lies a la nature de leur activite et a son impact sur la sante des populations et sur l'environnement. L'un de ces risques est lie aux semences. Le risque peut etre defini comme etant une exposition a un danger potentiel, inherent a une situation ou a une activite. Pour les agriculteurs, reduire le danger c'est reduire la vulnerabilite de leur exploitation. Selon la FAO (2009), des mesures gouvernementales et le renforcement de l'investissement public et prive a long terme dans le secteur semencier sont urgents pour que l'agriculture puisse relever le defi de la securite alimentaire dans un contexte de croissance demographique et de changement climatique en particulier en Afrique. Quels sont les risques lies a l'utilisation des semences ? Comment peuvent-ils etre controles ? La gestion de ces risques s'avere capitale ou indispensable pour la prosperite des activites agricoles.

Objectifs d'apprentissage

Il s'agit dans ce chapitre de presenter les risques lies a l'utilisation des semences et de proposer des elements de gestion de ces risques.

Resultats d'apprentissage

A l'issue de ce cours, les apprenants seront a mesure de :

- definir de façon precise et coherente les notions de semence ;
- determiner la nature des semences et les repertorier de fa^on exhaustive ;
- recenser ou identifier les risques lies aux semences ;
- et proposer des solutions a la gestion des risques lies a l'utilisation des semences.

Generalites sur les semences

Les semences constituent l'intrant indispensable a toute production agricole. Depuis des milliers d'annees, les semences ont ete selectionnees et conservees de fa^on empirique, mais c'est a partir de la fin du 18^{toe} siecle que de grands progres ont ete accomplis, grace a l'amelioration systematique des plantes.

L'amelioration des semences a ete particulierement favorisee par la comprehension des mecanismes de l'heritage genetique. Ces mecanismes permettent de transferer des caracteristiques selectionnes d'une plante a ses rejetons. Ainsi, des varietes ont ete obtenues grace a une meilleure connaissance de leur developpement et des progres significatifs ont ete enregistres dans la production agricole au niveau mondial. L'Afrique reste toutefois en retard dans ce domaine et son agriculture repose encore sur des varietes traditionnelles. La productivite de l'agriculture africaine est faible, en raison notamment du fait que les semences utilisees ne sont pas souvent renouvelees et perdent donc de leurs qualites. Plus de 80% des producteurs sont tributaires encore de systemes traditionnels ou informels de production de semences, basees sur la pratique familiale d'utilisation d'une partie de la recolte precedente comme semence (MA/DNA, 2012).

La disponibilite, en temps utile, de semences de qualite ou ameliorees, est donc devenue une condition prealable a l'atteinte d'un bon niveau de productivite agricole.

Qu'est-ce qu'une semence?

La semence est une matiere premiere biologique dont la qualite influe directe- ment la production finale. Pour mieux comprendre la notion de semence, il faut apprehender et analyser ses trois composantes : technologique, economique et juridique. La composante technologique porte sur la selection des varietes ; la composante economique s'applique a la production et a la commercialisation ; la composante juridique concerne les regles et reglementations qui regissent les deux aspects precedents.

La production de semences necessite un grand soin, de la precision dans les procedures et donc des competences techniques. Pour avoir acces a des semences en quantite et de qualite, il faut un grand nombre de producteurs, il faut respecter les regles de reproduction des plantes, et introduire des procedures de controle de qualite pour garantir une bonne qualite genetique et physiologique des semences pendant le processus de multiplication, les phases de post-recolte et de conservation, jusqu'aux semailles suivantes. Grace aux progres de la technologie, les systemes semenciers ont evolue. Dans les pays en developpement, et notamment en Afrique, deux types de systemes semenciers se cotoient : le systeme formel, oriente vers le marche et developpe par le secteur public et/ou prive et les systemes de production familiaux ou communautaires, principalement bases sur une auto approvisionnement en semences par le biais d'echanges entre voisins et le marche informel. Le systeme informel s'appuie sur des pratiques ancestrales et sur l'experience des producteurs en matiere de selection. Quant au systeme formel, il est base sur la recherche scientifique, notamment la selection varietale par un systeme de controle en laboratoire et d'experimentation (Plate 18.1). Le systeme formel rend egalement possible l'introduction de nouvelles varietes, qui offrent une meilleure performance et une meilleure resistance aux maladies, a la secheresse et d'autres facteurs de limitation de rendement biotiques ou abiotiques (MA/DNA, 2012).

Nature des semences

Selon l'espece vegetale et son mode de reproduction, la semence peut etre :

- une plante : le cas du bananier qui se multiplie a partir d'un plant (Plate 18.2) ou d'un rejet ;
- un fragment de la plante : cas des plantes qui se multiplient par marcottage (en horticulture) ou par vitro plant ;
- un fruit : aubergine etc. (Plate 18.3) ;
- un fragment dun fruit : cas de l'igname qui se multiplie par bouturage de fragments ;
- une graine : cas du riz, du mil, du ma'is etc. (Plate 18.4) ;
- le noyau, la feve ou le pepin dun fruit : la mangue, le cacao, les agrumes.

Plate 18.1: Evaluation de la qualite des semences (GEVES : Groupe d'Etude et de controle des Varietes Et des Semences, 2014)

Plate 18.2: Semences plants (FAO, 2009)

Plate 18.3: : Semences fruits : aubergine africaine (FAO, 2009)

Plate 18.4: : Semences graines (FAO, 2009)

Importance de la semence

Les semences ou les plants sont utilises par les agriculteurs pour etre ensemence et produire :

- du grain qui sera ensuite transforme en farine, en huile, en tourteau ;
- du fourrage pour l'alimentation du betail ;
- des legumes pour la consommation humaine ;
- des fruits ;
- des fleurs ;
- des fibres pour l'industrie textile.

La semence sert a :

- assurer la perennite des varietes ;
- accroitre quantitativement et qualitativement la production ;
- assurer l'alimentation de l'homme et des animaux ;
- assurer le bien-etre par l'amelioration des revenus ;
- creer un capital semencier de qualite des varietes ;
- contribuer a la securisation de l'agriculture nationale (MA/DNA, 2012).

Qu'est-ce qu'une semence de bonne qualite

La qualite de la semence est essentielle.

Selon Sidibe *et al.* (2008) ainsi que GNIS (2014), une semence de bonne qualite (Plate 18.5) doit presenter les caracteristiques suivantes (Figure 18.1) :

- avoir une bonne faculte germinative et un taux de germination eleve ;
- etre bien mure et bien seche, avec un taux d'humidite optimal de 8-9% et au maximum 12% et bien conservee ;

- etre genetiquement pure c'est-a-dire toutes les graines appartiennent a la meme variete ;
- etre homogene c'est-a-dire avoir la meme forme, taille, couleur, presence ou absence de poils - etre propre et exempte de matieres inertes : elle ne doit pas etre melangee a des matieres inertes, comme les glumes, des debris vegetaux, des cailloux ou de la terre (Plate 18.6) ;
- etre saine et exempte de graines d'autres especes etrangeres, en particulier de semences d'especes adventices ;
- repondre aux besoins du producteur.

Au plan international, le premier marqueur de qualite est la semence certifiee ; c'est une garantie de qualite et de securite.

Pour les industriels, les caracteristiques genetiques des differentes cereales sont primordiales, notamment les criteres technologiques (valeur boulangere, teneur en proteines, etc). Or, ces caracteristiques sont liees a la variete. En l'absence de garantie de purete varietale, les industriels perdraient leur capacite de maitrise technologique et de recherche et developpement de nouveaux produits. L'obliga- tion d'utiliser des semences certifiees (Figure 18.1) est donc logiquement de plus en plus frequente dans les cahiers de charges entre agriculteurs et collecteurs.

Quelques definitions techniques pour une meilleure comprehension des systemes semenciers.

Le developpement des systemes semenciers met en jeu une serie de facteurs biologiques et technologiques. Il est donc important de connaitre quelques definitions techniques. On distingue deux types de plantes : les plantes autogames et les plantes allogames.

Les plantes autogames sont auto fertilisantes et s'autofecondent, il n'y a donc pas besoin dune intervention exterieure. La pratique traditionnelle de conserver les semences est parfaitement adaptee a ce type de plante.

Qu'en est-il de la reserve semenciere dont dispose l'Afrique en generale et l'Afrique subsaharienne en particulier ?

C'est en ce sens que l'intervention de la technologie des semences et des selecteurs permet d'introduire des genes qui peuvent renforcer les caracteristiques intrinseques dune plante.

Avec ces plantes allogames a pollinisation ouverte, les producteurs ont recours au marche pour s'approvisionner en semences car celles qui proviennent de leurs champs perdent leur purete genetique et donc leur vigueur tres rapidement notamment dans le cas des varietes hybrides. A l'inverse, les plantes autogames demeurent fortes plus longtemps et les producteurs choisissent plutot leurs semences (Koffi, 2013).

En consequence, les plantes autogames sont mieux adaptees aux systemes semenciers traditionnels ou informels. Tandis que les plantes allogames s'adaptent mieux au secteur formel et a l'investissement prive qui peuvent ainsi developper des varietes ameliorees beaucoup plus performantes que les varietes traditionnelles. Cependant, les couts de production sont plus eleves que ceux des semences traditionnelles.

Dans la plupart des pays africains, les systemes semenciers formels sont encore aux stades preliminaries de developpement. Les semences sont essentiellement produites par les systemes traditionnels ou informels. Un des principaux problemes rencontres par les systemes semenciers est le controle de la qualite des semences.

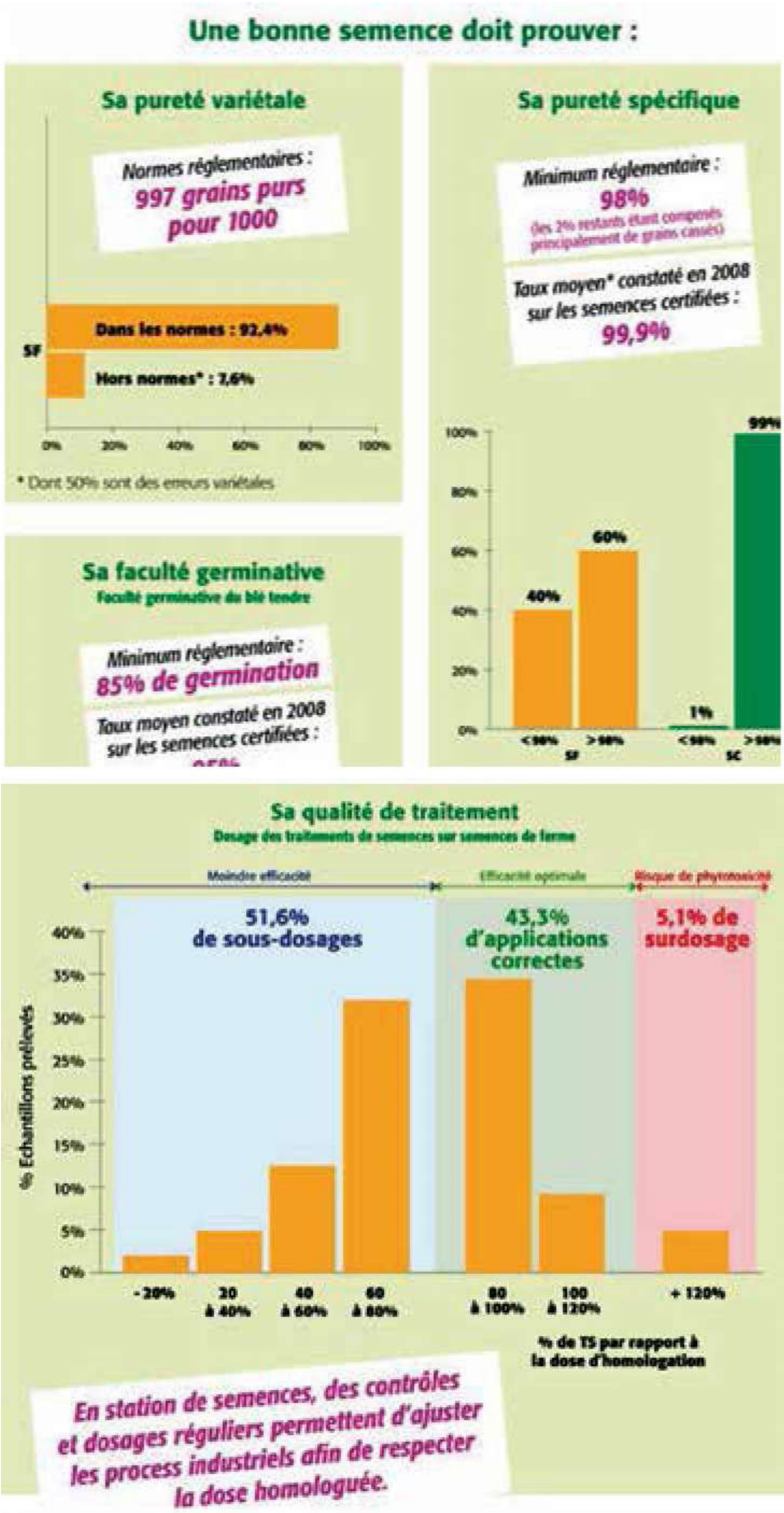

Figure 18.1 : Caracteristiques d'une semence de qualite (GNIS, 2014)

Plate 18.5 : bonne semence (MA/DNA, 2012).

Plate 18.6 : semences malades ou endommagees (MA/ DNA, 2012).

Comment obtenir des semences de qualite ?

La production des semences doit etre rigoureuse et faire l'objet dun suivi plus attentif. L'inspection des cultures et les essais des semences doivent etre realises a divers niveaux pour preserver leur purete genetique et leur capacite de germination. La qualite des semences fait l'objet de procedures de controle qui commence dans les champs : avant les semis, pendant les phases de developpement de la plante, de maturation et de recolte. Le controle se poursuit ensuite en laboratoire, sur les semences recoltees et conditionnees (MA/DNA, 2012). Elles doivent etre testees en termes d'humidite, de purete physique et varietale, de viabilite, de contenu en mauvaises herbes et de presence de maladies.

Des equipements speciaux sont necessaires pour realiser ces tests de qualite et tous les pays n'en disposent pas. Toutefois, une meilleure formation des producteurs de semences peut etre un premier pas vers la garantie du respect des diverses procedures de production de semences de bonne qualite.

Le systeme de production de semences oriente vers le marche passe par divers stades de production, comme la selection des varietes, la production des semences elle-meme, le conditionnement, la conservation, le controle de qualite, la certification et enfin la distribution et la commercialisation (Figure 6). Le secteur prive comme le secteur public qui participe a cette chaine ainsi que le systeme semencier sont regis par une reglementation specifique.

Dans tous les cas, une variete traditionnelle de bonne qualite est meilleure qu'une variete amelioree de qualite mediocre.

S'ils observent les precautions d'usage, les agriculteurs peuvent, a travers le systeme traditionnel de production de semences, obtenir des varietes traditionnelles de bonne qualite, en conformite avec les exigences indiquees ci- dessus. Un des avantages des systemes traditionnels et communautaires est qu'ils offrent davantage de diversite en termes de ressources genetiques (base genetique large) que les systemes orientes vers les marches, ou il existe une exigence d'uniformite et de purete varietale, qui conduit a un retrecissement de la base genetique. Les systemes traditionnels restent la principale source de semences dans les pays en developpement ; toutefois, ils sont soumis a diverses contraintes provenant:

- de la difficulte a acceder a des varietes ameliorees adaptees aux conditions locales ;
- de l'absence d'infrastructures susceptibles de multiplier les semences de qualite ;
- d'un manque de controle de qualite et de structures de gestion post recolte et de stockage ;
- du manque de reconnaissance officielle qui en fait, dans certains cas, une cible de lois prohibitives.

En Afrique, les systemes formels de production de semences ont des difficultes a se conformer aux exigences de production qui permettraient d'obtenir des semences de qualite. Il est donc necessaire d'assurer la formation des producteurs de semences et de leur fournir les equipements adequats.

Les strategies destinees a rapprocher les deux systemes semenciers pourraient aider a compenser les imperfections du systeme traditionnel et faciliter les transferts de technologie. Elles pourraient contribuer a ameliorer les competences des producteurs de semences, a promouvoir une meilleure cooperation entre les secteurs public et prive, qui sont tous deux utiles et surtout complementaires pour rendre le systeme semencier plus efficace.

La FAO a publie une directive specifiant les normes de qualite des semences (Anonyme, 2012). Dans chaque pays il devrait etre possible d'etablir une liste de varietes labellisees : «Semences de qualite declaree». L'enregistrement des producteurs de semences par les autorites competentes chargees de tester un echantillon des semences destinees a etre vendues comme «Semences de qualite declaree» est recommande. Les agriculteurs pourraient ainsi s'approvisionner exclusivement aupres de ces vendeurs et ne dependraient plus de vendeurs qui proposent des semences de qualite ou d'origine douteuse.

Risques lies aux semences

La semence certifiee est l'etape incontournable pour limiter les risques sanitaires de la filiere. La qualite est une preoccupation constante de toute la chaine de production. Afin d'assurer des semences saines, 3 axes principaux font l'objet de precautions particulieres et d'efforts de recherche constants : les traitements de semences, le travail de la station de semences et les varietes ainsi que les espoirs de la genetique (GNIS, 2014).

Risques menagant les stocks

Toutes les semences stockables pour leur conservation sont exposees :

- Aux attaques des insectes et des rongeurs (Johnson *et al.*, 2012 ; 2014 ; Ouali-N'goran, 2014) ;
- Aux mauvaises conditions (defavorables) de stockage telle que l'humidite, l'invasion par des champignons et la moisissure ;
- aux incendies ou inondations ;
- Certaines semences sont initialement de mauvaises qualites : ce sont des semences d'exploitations locales, communautaires : mauvaises graines, graine de faibles rendement etc. ;
- Les semenciers peuvent s'approvisionnement en semences commerciali- sees de mauvaise qualite provenant de l'importation etc.

Risques menagant les semences constituees de plants

- Les semences sous forme de plants et conservees en champs ou en parcelles cultivables sont exposees aux aleas climatiques (rechauffement climatique, trop forte ou trop faibles pluviometrie, incendies, inondations, attaque d'insectes ou autres) pouvant entrainer la destruction des champs ou des parcelles ou provoquer la deterioration de la qualite des semences ;
- La selection de mauvaises plantes : des plantes malades, de faibles rendements etc....peuvent par inadvertance etre selectionnees par l'agriculteur. Ce qui aura un impact negatif sur la productivite.

A partir des donnees ci-dessus se degagent deux categories de risques. Les risques lies aux semences emmagasinees (semences *ex-situ)* et les risques lies aux semences en champs (semences *in situ)* (Beye *et al.*, 2005)

Risques lies a l'exposition des semences aux pesticides

Dans l'agriculture moderne, l'utilisation des pesticides est devenue incontournable, ainsi les facteurs cibles et non cibles peuvent etre touches a toutes les etapes (Labrie et Theriault, 2014) :

- Durant le stockage ;
- Durant les semis : derive de poussieres des traitements de semences ;
- A la floraison de la plante : ingestion de pollen contenant l'insecticide de traitement de semence ;
- Dans l'eau presente dans les champs.

Risques lies a l'utilisation des OGM

S'il existe des avantages indiscutables a produire des OGM, il n'en reste pas moins que tous les doutes sur de possibles consequences nefastes n'ont pas ete completement leves. Le premier de ces risques est la menace que font peser les OGM sur la sante humaine. De nombreux scandales sanitaires comme l'amiante, la vache folle ont affaibli la confiance des consommateurs. Mais d'autres risques sont pointes du doigt, notamment sur le modele ideologique et economique qu'imposent les OGM (Periault, 2010).

Risques pour la sante humaine

Les deux types de risques associes a la consommation d'OGM ou de produits issus d'OGM sont l'allergie et la toxicite. Des travaux scientifiques ont indique que la consommation du soja OGM ferait encourir les risques tels que le cancer du sein, les dommages au cerveau pour les hommes et le developpement anormal pour les enfants (Smee, 2012).

Risques pour l'environnement

Les principaux risques lies a l'environnement concernent la biodiversite. Des etudes ont montre que les toxines produites par des cultures OGM tuent indifferemment des insectes nuisibles ou inoffensifs pour la culture. Par exemple, une experience en laboratoire a montre que la toxine *Bt* tue un grand nombre de chenilles du Papillon Monarque qui n'est pas la cible initiale (1). Un autre probleme de la culture plein champ des OGM est lie au transfert de gene. Certains scientifiques craignent que le deplacement du pollen de la plante GM a une mauvaise herbe entraine un transfert de gene et donne a celle-ci des proprietes de resistance aux herbicides. Mais ce phenomene est aussi valable pour la contamination des cultures non GM par la proximite des cultures GM. Ce phenomene est la pollinisation croisee. Un groupe de scientifiques de Washington confirme que c'est la une des plus grandes craintes concernant l'effet des OGM. La dispersion des genes des especes OGM aux especes sauvages, peut changer la diversite et les processus genetiques des ecosystemes entiers.» (Smee, 2012).

Risques agronomiques

La resistance des insectes ou des plantes nuisibles aux cultures posait deja un probleme en agriculture avant l'apparition des OGM. En effet, il reste toujours, apres epandage d'un produit chimique, quelques insectes ou quelques plantes resistantes a ce produit. Ils se reproduisent et au bout de quelques annees, la population entiere d'insectes nuisibles devient resistante a l'herbicide ou a l'insecticide. Des solutions alternatives pour retarder ce phenomene de resistance, comme la rotation des cultures existent. Mais l'utilisation des OGM de fa^on massive risque d'induire une resistance de tous les insectes sensibles a la toxine *Bt* par exemple. Les pesticides deviennent moins efficaces et il faut alors en mettre plus ou en inventer d'autres... Ce phenomene peut s'etaler aussi bien dans le temps que dans l'espace.

Exemple : Resultats dune etude australienne sur la remanence des toxines Bt sur un champ de culture OGM-Bt : Toutes les varietes de coton OGM-Bt, etudiees, ont libere des toxines dans le sol, alors que les non-OGM n'en liberaient pas. Le biotope, les micro-organismes et la faune du sol autour des racines (rhizosphere) sont touches davantage et plus longtemps qu'on ne le pensait (Smee, 2014). La fragilite de la future agriculture peut etre due a la perte de la diversite biologique (Smee, 2012).

Preoccupations d'ordre economique

Le processus de recherche-creation-mise en marche d'un OGM agro-alimentaire coute evidemment tres cher et les compagnies souhaitent que la filiere soit rentable. Ainsi, le brevetage des varietes creees risque de faire augmenter le prix des semences et de leser les petits producteurs. Sauf si ceux-ci decident de ne pas en planter. Mais le risque vient dune contamination involontaire des champs, auquel cas, la culture sera classe comme OGM et les agriculteurs seront obliges de dedommager l'entreprise proprietaire de la variete OGM. C'est le cas d'agriculteurs americains accuses par la compagnie Monsanto de s'etre procure des semences OGM illegalement, sans avoir verse la redevance. Eux se defendent, mettant sur le compte de la pollinisation croisee la contamination de leurs cultures.

Gestion des risques lies aux semences

Objectifs de la gestion des differents risques

La gestion du risque vise a reduire les differentes formes ou sources des risques. Elle constitue un aspect indispensable des activites du secteur agricole et son amelioration constitue une preoccupation permanente des agriculteurs et des pouvoirs publics qui ont inscrit cette problematique du risque parmi les objectifs de leur politique agricole. L'etude de la gestion du risque permet d'elaborer un cadre permettant d'utiliser les resultats en agriculture pour analyser et concevoir efficacement des politiques dans ce domaine. Dans le cadre de la gestion des risques lies aux semences, une approche globale prenant en compte tous les aspects est indispensable. La gestion du risque doit etre analysee comme un systeme ou de nombreux elements interagissent (les acteurs, les infrastructures, les equipements, l'environnement, le climat etc.).

La precision de la gestion du risque est fondamentale, puisque c'est elle qui peut empecher les avaries.

Phases de la gestion des risques lies aux semences

a- Perception des risques lies aux semences en agriculture

La gestion des risques dans la maximisation de l'agriculture devra etre perdue de fa^on objective et integree par tous les acteurs aussi bien les agriculteurs, les pouvoirs publics que la societe civile. Tous devront etre unanimes pour la recherche de solutions idoines pour la resolution du probleme. Ainsi en Cote d'Ivoire et au plan mondial, face aux besoins de plus en plus croissants des producteurs a disposer de semences plus performantes pour accroitre la productivite agricole, d'une part, et les conditions de production fragilisees par le changement climatique, d'autre part, des efforts sont faits pour garantir la perennite de la production des semences. A cet effet des structures et des dispositifs sont mis en place pour une gestion efficiente. On peut citer : l'Office des Semences et Plants (OSP), charge de preparer et de mettre en reuvre une politique semenciere performante (en Cote d'lvoire), la FAO, l'IBPGR, l'IPGRI et la Biodiversity International interviennent au plan mondial. Ces structures aident les agriculteurs a detecter les symptomes et les signaux d'alertes en cas de risque. Ces signaux sensibles sont par la suite identifies.

Analyse des contraintes

Les contraintes sont liees a l'offre et a la demande.

> Au niveau de l'offre :

Les prix des intrants et des produits agricoles, ces risques sont principalement les risques climatiques influant sur la maitrise de l'eau et les risques economiques, lies au prix de vente des produits.

Les interventions de l'Etat portent sur la regulation du prix des produits a la consommation afin de preserver le pouvoir d'achat du consommateur urbain et des ruraux deficitaires. Les paysans ont beneficie de prix subventionnes. Ensuite, les prix des engrais etaient liberalises.

La politique interventionniste de l'Etat dans le secteur des engrais ne permet pas un developpement normal des activites des importateurs prives d'intrants agricoles. Les importateurs et distributeurs prives d'intrants, en particulier d'engrais, ont de tres grandes difficultes a batir des strategies commerciales, compte tenu des politiques fluctuantes de l'Etat dans le secteur des engrais et des perturbations induites par les frequentes ventes d'engrais subventionnes.

La reaction des importateurs professionnels afin de limiter les risques est de reduire les importations, d'ou la diminution de volume d'engrais distribue.

Contraintes liees a l'approvisionnement

La faiblesse du volume d'importation vient du fait de la faiblesse du reseau de revendeurs : les paysans sont limites dans leur pouvoir d'achat. En plus, leur formation technique concernant Taction et l'interet des produits, ainsi que leurs competences en gestion sont tres limitees

Le manque d'infrastructures telles que l'insuffisance et/ou la deterioration du systeme routier et des autres voies de communication ainsi que des infrastructures portuaires et de stockage constitue d'importants obstacles.

> **Au niveau de la demande :** une faiblesse de la demande paysanne est observee. Elle serait due a de nombreux aleas possibles (aleas climatiques et sanitaires, maitrise de l'eau tres souvent insuffisante, vols et autres facteurs d'insecurite, etc.), ce qui amene les paysans a privilegier des «strategies anti-risques».

Gestion du risque par les agriculteurs

La strategie majoritaire adoptee par certains exploitants est l'extensivite de la production et le sous - investissement. Ce que l'on considere comme des reticences aux innovations s'avere etre la plupart du temps une strategie de limitation du risque par le paysan.

Le risque agricole porte sur quatre points : les risques d'acces aux facteurs de production (l'eau, le foncier, les engrais), les risques de production (climatique, delictueux), les risques de consommation et les risques de commercialisation (problematique de fluctuation de prix, d'acces au marche : taxes, transports, proximite de marches, etc.).

Incidence des capacites de stockage

La duree de la periode de soudure est un facteur important de la strategie des agriculteurs, et notamment dans le cadre de leur besoin de credit. «La strategie des agriculteurs de vendre une partie de leur production des la recolte (cas du riz) pour faire face a des besoins d'argent urgents, diminue les stocks et allonge la duree de la soudure». La periode de soudure peut osciller entre 3 et 10 mois.

Conseil agricole

Un nombre tres reduit de paysans beneficie actuellement de conseils agricoles suite au desengagement de l'Etat et a la faiblesse des interventions des autres operateurs dans le domaine du conseil.

Systemes d'information sur le marche

Des systemes d'information sur les prix des produits agricoles existent (Observatoire du riz de la FAO, systeme d'information sur le prix des fruits et legumes du projet FERT/Fruits et legumes, statistiques sur les prix des produits locaux sur les marches urbains ou ruraux du MAEP), mais les donnees ne sont pas generalement accessibles aux producteurs.

Identification des differents types de gestion des risques lies aux semences en agriculture

Suite a la perception des risques leurs gestions doivent etre identifiees et priorisees en fonction de leur importance ou de l'importance des signaux d'alertes.

Gestion des risques menagant les stocks

Les risques sont multiples.

- Preservation des semences contre les attaques des insectes et des rongeurs ;

- Preservation des semences contre les mauvaises conditions de conservation : l'humidite, l'invasion par des champignons, les moisissures etc....
- Encadrement des agriculteurs au plan communautaire ou continental pour une meilleure selection de leurs semences. Les former a la reconnaissance de semences a fort rendement.
- Controles des semences aussi bien communautaires que commercialisees par des structures etatiques ou des organismes habilites.
- Controle ou repression de la fraude ou du trafic de semences par des semenciers ou des producteurs vereux.
- Preservation des semences contre les vols.
- Prevenir les sinistres tels que les incendies ou les inondations des lieux de conservation des stocks.
- Prevoir une structure de dedommagement des agriculteurs en cas de perte totale ou de vols de semences.
- Mettre en place differentes strategies pour le bon fonctionnement de circuits semencier :
- **Mesures preventives** : mettre en place toutes les dispositions pour la meilleure conservation des stocks.
- **Mesures correctives :** en cas de dommages trouver des parades pour limiter les degats.
- **Mesures palliatives** : Trouver un moyen de subvention ou d'indemnisation pour assister les agriculteurs sinistres.

Gestion des risques menagant les semences constituees de plantes

Gestion des champs et des parcelles pour la conservation des semences ou plants sains et a fort rendement.

- Preservation des semences contre les aleas climatiques (rechauffement climatique, trop forte ou trop faibles pluviometrie), envisager des solutions ;
- Preservation des semences contre les attaques d'insectes et/ou de rongeurs ;
- Selection des plants performants a tres fort rendement ayant un impact positif sur la productivite ;
- Preservation des champs contre les vols de semences sur pied ;
- Prevenir les sinistres tels que les incendies et les feux de brousses.

Egalement pour les champs et les parcelles cultivees mettre en place differentes strategies pour le bon fonctionnement du circuit semencier :

- **Mesures preventives :** trouver des parades contre le dessechement ou l'inondation des champs, contre les feux de brousse et les vols ;
- **Mesures correctives :** rehydrater les plants pendant la periode chaude ou desengorger rapidement les parcelles inondees suite a une forte pluviometrie. Trouver des parades pour les incendies et les vols ;
- **Mesures palliatives :** Assister les agriculteurs sinistres par un apport (soutien) financier pour leur subsistance dune part et pour la relance de leur activite d'autre part.

Gestion des risques lies a l'utilisation des pesticides : pour ce faire, il faut :

- utiliser des semences non traitees aux insecticides (neonicotino'ides) ;
- installer un deflecteur sur les semoirs a pression negative (vaccum) ;
- respecter les bonnes pratiques d'utilisation des semences traitees ;
- respecter les recommandations du fabricant du semoir sur les quantites de talc ou graphite a ajouter.

Gestion des risques lies a la qualite des semences

La selection vegetale a contribue et continue de contribuer de maniere significative a l'amelioration de la securite alimentaire tout en reduisant le cout des intrants, les emissions de gaz a effet de serre et la deforestation. Elle assure la securite des recoltes grace a l'introduction de resistances multiples.

Le role de la selection vegetale pour relever les defis multiples d'un monde en mutation rapide

- Des varietes ameliorees et des semences de qualite sont des conditions fondamentales d'une agriculture productive, qui est a la base du developpement economique durable dans les pays en developpement ;
- La selection vegetale a apporte une contribution enorme a l'agriculture mondiale (rendements, resistances aux stress biotiques, tolerances aux stress abiotiques, securite des recoltes, caracteres qualitatifs, y compris la valeur nutritionnelle, etc.) ;
- La selection vegetale peut apporter une contribution significative aux mesures prises pour relever differents defis a venir tels que la securite alimentaire, la reduction de la famine, l'accroissement des valeurs nutritives et le rencherissement des intrants ;
- La protection de la propriete intellectuelle est essentielle pour assurer une selection vegetale et un approvisionnement en semences durables ;
- La production de semences de qualite et le traitement des semences apportent une contribution significative a l'amelioration des semences et il est urgent de renforcer les capacites des pays en developpement dans tous ces domaines.

L'importance des ressources phytogenetiques pour la selection vegetale; acces et partage des avantages

- Le Traite international sur les ressources phytogenetiques pour l'alimentation et l'agriculture est un instrument juridiquement contraignant unique et novateur qui facilite l'acces au materiel genetique aux fins de selection vegetale au niveau international ;
- Le Systeme multilateral du Traite international prevoit une disposition relative a l'acces et au partage des avantages pour les activites de selection vegetale.

Protection des obtentions vegetales

- La mise en place de la protection des obtentions vegetales favorise la creation de nouvelles varietes ameliorees, et l'augmentation du nombre de nouvelles varietes. Cela constitue une source d'avantages pour les agriculteurs, les producteurs, l'industrie et les consommateurs, d'ou un interet pour l'economie dans son ensemble ;
- L'un des avantages de la protection des obtentions vegetales est d'encourager la creation de varietes ameliorees qui favorisent la competitivite sur les marches etrangers et le developpement de l'economie rurale.
- L'acces aux obtentions vegetales etrangeres est une forme importante de transfert de technologie, qui peut egalement contribuer a ameliorer les programmes de selection au niveau national.

Importance des semences de qualite pour l'agriculture

L'importance de la qualite des semences pour la productivite des cultures et la production agricole a ete mise en evidence par le fait que l'absence d'information sur la qualite des semences pouvait se traduire par de mauvaises recoltes et compromettre la securite alimentaire de pays entiers. A l'heure actuelle, l'infrastructure d'assurance qualite, en ce qui concerne l'essai des semences n'est pas suffisante dans les pays en developpement. L'evaluation de la qualite des semences n'a pas encore realise tout son potentiel et des innovations interessantes sont en cours de creation pour repondre a l'evolution des besoins du marche. Ces innovations rendront les essais et leurs applications plus pertinents, plus efficaces, plus fiables, plus rapides et meilleures marche. Des reductions importantes dans les budgets de la recherche et de l'enseignement scientifique ont restreint les possibilites offertes aux jeunes universitaires d'acquerir les competences techniques necessaries sur les semences. Les salaires non concurrentiels des analystes de semences dans les pays developpes rendent le secteur du controle qualite des semences peu attrayant pour les jeunes.

Facilitation du commerce et developpement des marches

Le marche mondial des semences a progresse rapidement ces dernieres annees pour atteindre quelque 37 milliards de dollars E.-U.

- L'utilisation de certificats internationaux pour la certification des varietes, les mesures phytosanitaires et les essais en laboratoire a considerablement facilite le developpement du commerce international de semences ;
- La production et la commercialisation de semences certifiees pour toutes les plantes agricoles sont fortement reglementees aux niveaux national et international. Un cadre reglementaire transparent et efficace est essentiel pour s'assurer que les agriculteurs ont acces a des semences de qualite a un prix raisonnable ;
- Le cadre reglementaire international est constitue par des mecanismes de certification fondes sur l'identite et la purete des varietes (OCDE, AOSCA), des mesures phytosanitaires (CIPV, SPS-OMC, ONPV), la protection des obtentions vegetales (UPOV) et l'essai des semences (ISTA, AOSA, etc.) ;
- Une bonne cooperation entre les parties publiques et privees dans l'elaboration et la definition de normes internationalement reconnues a facilite la delivrance de certificats qui, a leur tour, contribuent a la croissance du commerce ;
- La mise en reuvre de mesures visant a prevenir l'introduction et la diffusion de parasites est essentielle pour assurer le developpement dun marche mondial des semences viable et durable. Les Normes internationales pour les mesures phytosanitaires (NIMP) donnent des indications utiles sur l'application des mesures phytosanitaires pour le commerce international de semences.

b- Evaluation de l'aspect financier de la gestion des risques lies aux semences en agriculture

Suite a l'evaluation des risques et de ses consequences possibles, apres avoir defini l'ensemble des parametres : les causes, les objets de risque et prioriser les types de gestion, il faudrait faire une estimation du cout. Cette estimation doit etre confiee a des structures agreees si possible, ensuite faire une recherche de financement pour la resolution de la problematique.

• Cadre legistatif

Dans l'espace UEMOA, il existe des dispositions reglementaires en ce qui concerne les conditions de production, le controle de la production, le conditionnement, l'emballage, le stockage, la certification, la commercialisation, l'exportation-exportation...(UEMOA, 2009).

Sur le plan international, pourquoi existe-t-il une reglementation des semences et des plants ?

Les semences et plants constituent un materiel vegetal vivant et donc en constante evolution. De la qualite de ce materiel, c'est-a-dire notamment de sa purete et de sa germination, depend l'esperance de recolte des agriculteurs et des jardiniers. Il est donc necessaire que les professionnels specialises apportent le plus grand soin a la production, au conditionnement, au stockage, aux conditions de conservation, a la manipulation et a la vente de ce produit vegetal. Le probleme essentiel est que l'acheteur ne peut pas verifier instantanement et visuellement la bonne qualite du produit qu'il achete. C'est pourquoi, le commerce des semences et des plants, tout comme leur production, est reglemente. Cette reglementation a pour but de garantir a l'utilisateur la qualite des semences et d'eviter que la responsabilite des vendeurs soit engagee a leur insu. La reglementation est etablie dans l'interet de l'utilisateur ; elle protege egalement le commer^ant contre la concurrence deloyale (MINAGRI, 2014).

Les organismes intervenant dans la reglementation du commerce des semences et des plants sont :

- **le GNIS** (Groupement National Interprofessionnel des Semences et Plants) ;
- **la DGCCRF** (Direction Generale de la Concurrence, de la Consommation et de la Repression des Fraudes).

Ces organisations veillent aux interets des grosses entreprises du secteur, participe a l'elaboration des lois qui regissent le commerce des graines et surveille leur application. Un triple role propice aux conflits d'interets. Selon Agricorp (2011), il existe une indemnite liee au cout des semences qui peut etre une :

a) Indemnite de reensemencement ou de replantation ;

b) Indemnite de manque a produire ;

c) Indemnite de superficie omise.

L'indemnite liee au cout des semences indemnise les producteurs agricoles assures pour le cout reel des semences, tel qu'il est facture, jusqu'a un montant maximum, si, en raison d'un risque assure, une culture destinee a la transformation doit etre reensemencee ou n'est pas recoltee. L'indemnite liee au cout des semences est basee sur les couts factures pour les semences jusqu'au montant fixe dans l'accord de mise en marche de l'organisme appele Ontario Processing Vegetable Growers; ces couts sont inclus dans la fiche de renseignements relative aux regimes d'assurance pour les legumes de transformation.

Qu'en est-il de l'Option pour la construction des cadres reglementaires de controle des OGM et de protection des ressources genetiques (Kastler, 2005).

Reglementer les OGM, c'est accepter les OGM. Or les OGM sont refuses. Pour faire appliquer un moratoire, il suffit de se donner des moyens de controle et d'analyses. Mais nous vivons dans un monde ouvert ou les marchandises traversent les frontieres sous la pression de tous les accords et traites internationaux. Nous sommes donc obliges de nous interesser a la reglementation.

Toutes les reglementations internationales reposent sur la pensee scientifique occidentale pour qui le vivant, la biodiversite, se reduisent a une ressource lucrative. Or, pour la majorite des peuples de la planete, nous vivons tous en co-evolution avec l'ensemble des animaux, des plantes et des microorganismes, nous ne pouvons donc pas en disposer comme de n'importe quelle marchandise pour faire du business. Cette opposition traverse toutes les contestations les lois internationales.

Box 18.1 : Conditions de conservation des denrees stockees au marche

La production mondiale du niebe est estimee a 3,3 millions de tonnes de graines seches dont 64% sont realises en Afrique (FAO, 2011, 2012; INS, 2008). Cependant, sa consommation reste saisonniere car, sa culture et l'entreposage des denrees sont exposes a plusieurs dangers ou risques. Quels peuvent-etre ces dangers. Quels sont les facteurs de risques ? Comment peut-on gerer ces risques?

L'objectif general de cette etude est d'identifier le probleme specifique pose par la conservation des stocks de niebe. L'apprenant doit etre capable de :

1- decrire les differentes images presentees dans l'ordre ; (Plate 18.7, 18.8, et 18.9);

2- analyser les conditions de conservation des graines presentees ;

3- reveler les risques lies a l'utilisation des semences.

Les graines de Legumineuse dont celles du niebe *(Vigna unguiculata* Walp) sont largement consommees en Afrique. Elles apportent 20 a 25% de proteines et de mineraux peu chers. Elles constituent une source importante de revenus pour les petits exploitants, les commer^ants, les agroindustriels et les exportateurs (Nouhoheflin *et al.,* 2003; Dabire *et al.,* 2003). Malheureusement, ces denrees sont sujettes a des pertes enormes dues a differents facteurs.

Plate 18.8 : Graines de niébé à

Plate 18.8: Entreposage

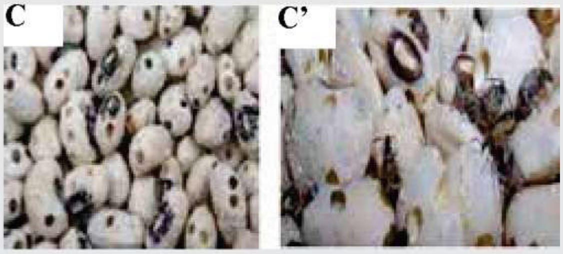

Plate 18.9 : Graines de niebe 3 a 6 mois apres entreposage, c : vue d'ensemble c' : vue detaillee

Question :

A partir de l'analyse de ces figures, identifier les risques lies a la conservation des produits de post-recoltes ? Quelles solutions pouvez-vous proposer?

Conclusion

L'utilisation de bonnes semences est entre autre un element determinant pour la reussite de sa campagne de production. La bonne semence est celle qui sera capable de gerer, de survivre apres germination et de developper les caracteristiques attendues de la variete semee par le producteur. La bonne semence aura un cout. Le choix des semences est fonction des objectifs de production et des contraintes rencontrees sur le terrain telles que l'inondation frequente, la toxicite ferreuse, les attaques des ravageurs, les maladies etc. Les pratiques de production et de conservation des semences determineront la purete et le taux de germination. Cela necessite donc des soins particuliers pour l'obtention dune production d'une purete satisfaisante sans corps etrangers et indemnes de maladies autrement on risque d'avoir une heterogeneite des plants, des mauvaises herbes et des maladies. La gestion du risque implique l'effort de toute la communaute agricole et leurs differents partenaires. Elle vise a reduire les differentes formes ou sources des risques. Mais elle a un cout qui necessite l'implication des etats et l'etablissement dune politique agricole locale, continentale ou mondiale. Ce sont des strategies qui visent a l'amelioration des conditions de vie ou contribuent au bien-etre des populations.

Questions

Rajouter ici quelques questions pour discussion pour les apprenants 1/ Comment definissez-vous une semence ? 2/ Quelles sont les caracteristiques dune semence de qualite ? 3/ Comment obtenir une semence de qualite ? 4/ Quel est l'interet d'utiliser une semence de qualite ? 5/ Que risque un producteur utilisant une semence tout venant ? 6/ Avez-vous deja observe des cas pratiques ?

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19

MANAGING RISKS LINKED TO USE OF BIOLOGICAL CONTROL AGENTS

A. Drame-Yaye and D.C. Munthali

Summary

Biological control is a very effective and environmental method of managing pests that affect crops worldwide. This chapter acknowledges that despite the fact that Africa has a rich biodiversity of indigenous natural enemies that can be exploited to manage many of the important pests of major crops grown on the continent, the use of biological control on the continent is still minimal compared to other continents. The potential use of: conservation biology; augmentation biological control and classical biological control are discussed as possible approaches. Examples of successful use of classical biological control in a few African countries are used to illustrate its potential for managing future threats from new exotic and invasive pests. Good practices regarding the pre- introduction; introduction and the post-introduction phases are outlined to provide practical approaches that can be used by those considering the use of exotic natural enemies. Like other pest control methods, there are potential risks to the use of biological control agents, especially when they are imported from other regions or continents to control exotic pests. Some of the potential risks posed by uncontrolled introductions of biological control agents are presented. We recognize that the agricultural research systems in most African countries are still very weak and ill equipped to conduct the necessary research and surveillance activities required for proper use of exotic as well as indigenous natural enemies. We therefore advocate for the strengthening of research capacities in the use of biological control in Africa.

Keywords: Biological control; Natural enemies; Conservation; Augmentation; Risks

Resume

Gestion des risques lies a I'utilisation des agents de lutte biologique

La lutte biologique est une methods environnementale et efficace pour la gestion des ravageurs des cultures qui sevissent a travers le monde. Ce chapitre reconnait que malgre le fait que l'Afrique ait une riche diversite biologique d'ennemis naturels indigenes qui peuvent etre exploites dans la gestion d'importants ravageurs des principales plantes cultivees sur le continent, l'utilisation de la lutte biologique est encore marginale sur le continent africain. L'utilisation de la conservation, l'augmentation et la lutte biologique classique est explique comme des approaches potentielles en matiere de lutte biologique.. Des examples de succes dans l'utilisation de la lutte biologique dans certains pays servent de cas pour illustrer le potential de gestion des menaces venant de nouvelles especes exotiques et invasives de ravageurs. Les bonnes pratiques devant regir la pre- introduction, l'introduction et l'apres-introduction sont developpees pour guider ceux qui envisagent l'utilisation des ennemis naturels exotiques comme moyens de lutte contre les ravageurs. Comme avec les autres methodes de lute, l'utilisation des agents biologiques peut poser des risques potentiels, surtout si ces agents sont importes d'autres pays ou continents. Certains des risques lies a l'introduction incontrolee des agents de lutte biologques sont presentes. Il faut reconnaitre que les systemes de recherche agricole de la plupart des pays africains sont encore faibles et mal equipes pour mener des activites de recherche et de *surveillance necessaires a l'utilisation des ennemis naturels aussi bien indigenes qu'exotiques. C'est pour cela que nous plaidons pour le renforcement des capacites dans l'utilisation efficace de la lutte biologique en Afrique.*

Mots cles: Lutte biologique; Ennemis naturels; Conservation; Augmentation; Risques

Introduction

Crops and forest pests have always represented and still represents a serious threat to food self-sufficiency and to the survival of human and animal populations in Africa. Pests can be plants (weeds), vertebrates (birds, rodents and other mammals), invertebrates (insects, mites, ticks or snails), nematodes and pathogens (bacteria, virus or fungus).

In Sub Saharan Africa, the most well-known pest control programmes were those against acridids and other species of grasshoppers, which were mainly based on large-scale use of pesticides. FAO (1990) assessed those programmes and showed that between 1986 and 1989, 26 million hectares of locust-infested areas were treated, and that 16 million liters of liquid and 14 million kilograms of dust pesticide formulations were used in the Desert Locust habitat. This raised serious concerns about the risks that chemical pesticides posed to human and environmental health (Krall et al., 1997).

Since 1950, the developed countries in America and Europe have promoted biological control as an alternative in reducing the massive use of the various kinds of pesticides that had flooded the markets (Agropolis International, 2007). Prior and Greathead (1989) considered the possibility of using biological control agents to replace chemical pesticides for the control of the acridids in Africa.

Biological control is the use of natural enemies—predators, parasitoids, pathogens and other competitors - to control pests and their damage. Most parasitoids and pathogens, and many predators, are highly specialized and attack only one or some closely related pest species (Flint et al., 1998, Hoffmann and Frodsham, 1993, Pedigo, 2000). The biological control option was considered to be ideal and judicious because the majority of pests, found in crops and forests, lived in their habitats with a multiplicity of natural enemies that successfully maintained the pest populations to acceptable levels and reduced crop and forest damage to below economic injury level.

Research conducted in developed countries such as America, Australia, France, the United Kingdom amongst others, has resulted in the identification and commercialization of biological control agents that are frequently used to control crops and forest pests (Agropolis International, 2007). In Africa, research on biological control is still at the experimental stage while many developed countries are importing and releasing commercial biological control agents to fight pests in commercial crops such as cotton, cocoa, coffee, tea; staple crops like maize and cassava and against invasive weed species.

Although many African countries have put in place binding laws to control the importation of biological control agents and rigorously monitor their use, the risks linked to the importation and use of biological control agents are not clearly understood. This is not a common discussion topic in many African countries at present; but this chapter intends to address it. The chapter will be based on literature review on the subject, and also on studies and/or results from African case studies.

Learning Objective

The main objective of the Chapter is to sensitize and develop knowledge on biological control, describe its advantages and the risks that it could expose the environment to.

Learning outcomes

At the end of this Chapter, learners will be able to:

- Define the various biological control agents;
- Describe the operational mode of biological control agents;

- Understand the risks associated with the use of biological control agents;
- Promote the use and adherence to phytosanitary laws and regulations that exist in African countries;
- Work with research, development and extension agencies to better protect populations, animals and the environment against accidental or voluntary introduction of exotic pests and natural enemies.

What is Biological Control?

Biological control is defined as the action of living organisms as pest control agents (Thomas and Willis, 1998). It is the beneficial action of predators, parasitoids, pathogens, in controlling pests and the damage they cause. These living organisms that provide biological control of insect pests, mites, plant pathogens, weeds, nematodes and harmful vertebrates are called natural enemies.

Biological control involves a purposeful manipulation of natural enemies to cause a reduction in the status of a pest species (Pedigo, 2000). The organisms used in biological control are diverse. They can be vertebrates, invertebrates or microorganisms that may act on the pests as predators, parasitoids or as pathogens.

Entomologists generally advance the view that biological control is the most desirable tactic in a pest management programme. There is no doubt that there are many benefits from the use of biological control for the management of serious pests (Drame Yaye et al., 2003). Strong advocates of the use of biological control methods argue that when successfully established, biological control is relatively less expensive compared to the use of pesticides; unlike pesticides, biological control does not contaminate the environment; once established, successful biological control agents will regulate the pest population at levels below the economic injury level; biological control is particularly effective in extensive perennial agro-ecosystems such as tree crops, orchards and vines; and biological control agents do not interfere with other pest control methods and are thought to be non-destructive to natural ecosystems (Thomas and Willis, 1998; Pedigo, 2000; Norris et al., 2003).

The biological control agents may be used in different ways:

Conservation biological control

Conservation biological control is mainly about protecting natural enemies through the habitat manipulation. Different types of naturally occurring, indigenous species of natural enemies attack various pests in the original habitat. Conserving those natural enemies can be done through agro-ecological practices that enhance the survival of the natural enemies. One such agro-ecological practice is the association of plant species and the avoidance of monoculture. Spatial and temporal association of plant species can restore biodiversity that contributes to ecological equilibrium and enhances the presence of locally existing natural enemies (Agropolis International, 2007). While it is recognized that indigenous natural enemies are playing an important role in regulating populations of many pest species in cropping systems in Africa, few agricultural research programmes on the continent are evaluating the potential role of indigenous natural enemies for use in conservation or augmentation biological control.

Augmentation biological control or classical biological control

The most successful biological control programmes in Africa have been those involving importation and release of exotic natural enemies in classical biological control. The use of classical biological control has offered a sustainable and effective alternative to the use of pesticides when exotic pests have been accidentally introduced. The successes achieved by classical biological control programmes have convincingly demonstrated the ability of introduced natural enemies to suppress and manage pest populations at levels below the economic injury levels (Thomas and Waage, 1996; Thomas and Willis, 1998). There are several strategies for augmentative release. An "inundative" release simply floods the target system with massive numbers of agents and is designed to give rather immediate pest suppression (Dent, 2000; Bailey et al., 2010). At the other end of the continuum is the "inoculative" release, in which a smaller number of agents (inoculum) are released at a critical time with the hope that their progeny will ultimately provide pest suppression. Cost will ordinarily play a decisive role in which approach is favoured. In some cases, it may be expedient to release not only the enemy, but the pest as well. For example, Encarsia formosa, an effective agent for control of greenhouse whitefly, Aleurodes vaporariorum, parasitizes the second instar larvae of its host; in greenhouses where whiteflies will surely colonize anyway, the crop can be artificially infested with whiteflies at strategic locations early in its development. These infestations can then be monitored to determine when the bulk of the pest population has reached the appropriate developmental stage for release of the parasite. Release when the pest is in the first instar results in few successes in oviposition of the parasite eggs inside the pest while those after the second instar do not allow the parasitoid to complete its life cycle before the pest emerges from the pupa. This results in failure of the parasitoid to control the pest. In Europe, this is often referred to as the "pest-in-first" technique. Release of both enemy and pest could of course be made simultaneously in those situations where the enemy's preferred host stage can also be released. Release methods are numerous and varied. At present, there is a critical need for innovative research, particularly with respect to application technology. Users of commercially available predators and parasitoids must either rely on information from the producer and (or) supplier, or devise their own application procedures.

Classical biological control has been used successfully to control several invasive plant species and exotic aquatic weeds in South Africa:

- The water fern (*Salvinia molesta, salvinia*) through release of the exotic curculionid weevil, Cyrtobagus salvinia (*Calder and Sands*) imported from Namibia;
- The water lettuce (*Pistia stratiotes*) through introduction of the weevil *Neohyalinomus affinis* (Hustache), imported from Australia;
- The red water lettuce (*Azolla filiculoides*) through the release of the curculionid weevil, S*tenopelmus rufinasus*, imported from Florida (USA);
- The parrot feather (*Myriophyllum aquaticum*) through introduction of the crysomelid beetle (*Lysathia sp*.) imported from Australia;
- and the water hyacinth (*Eichhornia crussipes*) through introduction of six species of exotic biological control agents (two weevil species: *Neochetina eichhorniae* and *N. bruchi*; one moth, *Niphograpta albiguttalis*; a leaf sucking mirid, *Eccritarsus catarinensis*; one mite species, *Orthogalumma terebrantis* and a pathogenic fungus, *Cercospora piaropi* (Coetzee et al. 2011).

However, as has been found with releases of exotic biological control agents targeting arthropod pests, not all releases targeting the aquatic weeds gave sustainable control following the initial introductions. Other studies have shown that on their own, exotic weevils do not have a large effect on the water hyacinth (Wilson et al., 2006). Ainsworth (2003) found that biological control of weeds using arthropod biological control agents was not completely effective and that the biological control agents need to be used in combination with herbicides.

Commercial use of biological control agents against crop and forest pests

In commercial settings, the most common use of biological control is the classical method, where natural enemies are purchased and released. Commercially available pest-control agents can be divided into two categories: those that must be registered with the national Environmental Protection Agency, and those that are exempt from registration. Agents that require registration include insect and plant growth regulators, and microbial biological-control agents such as viruses, bacteria, protozoa, and fungi. Authoritative information on efficacy, safety, etc., for these agents can be found on the label for a particular commercial product. Ordinarily, this information is the result of several years of research and considerable financial investment on the part of the company(ies) involved. Agents that are currently exempt from registration include multicellular animals, such as predaceous insects and mites, parasitic insects, entomopathogenic nematodes, predatory snails, insectivorous fish, etc. Because these organisms are exempt, there is no label that a potential user can turn to for authoritative information. For this reason, users should exercise an appropriate amount of caution when choosing such an agent for release. In other words, just because an exempted biological-control agent is commercially available, does not necessarily mean that the agent is effective or safe for use in the environment (Wilson et al., 2006).

To ensure success, users of commercially available predators and parasitoids are urged to adopt a "holistic" approach. Holism implies an understanding of the target system as a whole, including how the many components interact to produce the particular system that we observe. In a given ecosystem, it is important to consider not only the target pest population, but also the attributes of the natural enemy to be released, and the ecological structure of the target system. Each field or landscape should be viewed as a unique situation, such that recommendations for one particular site will not necessarily be appropriate for another. Any introduction of commercial natural enemies should respect the following phases:

A. Pre-introductory Phase

Prior to actual release of a natural enemy, some consideration should be given to choice of species, biological attributes of the chosen species, obtaining the agent, and quality of the purchased product. In choosing a species, it is critical to ask why this particular agent is available. Is it because the agent is effective? Easily collected and stored? Or easily cultured? Many commercially available predators and parasitoids have been shown to be effective in specific agro- ecosystems; however, this does not mean that the same agent will be effective in a new situation. Numerous factors in a target system can mitigate an otherwise effective species. To further complicate matters, for many target pest species; there are two or more commercially available agents for use (e.g., coccinellid beetles, syrphid flies and parasitic wasps against aphids). Unfortunately, we have insufficient data in most cases concerning the relative merits of a particular multiple-species release as opposed to a given single-species release.

The attributes of a given agent can be critical to success, particularly when there is a choice between two or more species for a given pest problem. For example, release of a predator that is predaceous in the adult stage could provide a greater immediate impact, compared to release of adult parasitoids that must first lay their eggs in hosts so as to allow their progeny to eventually kill the pest. Also, with such predators, both adult males and females can destroy numerous pest individuals, whereas only the female parasitoids actively seek and oviposit in hosts. Host-specific agents will be highly dependent on their prey, whereas less specialized or more generalist natural enemies may feed on a number of other species following release. In the latter case, the impact of the agent must be considered. Whether the agent is native or exotic (i.e., introduced) can be important. Exotic species may not be well adapted to the new conditions, particularly if they originated from a completely different environment. In recent years, pesticide-resistant parasitoids and predators have been developed in the laboratory and made available commercially. Such agents might be appropriate in certain situations, but unnecessary in others.

Obtaining enemies can be problematic at times. An agent that is listed as commercially available may not be available at a certain time, or in the numbers required for a given release. Thus, some advance preparation may be necessary. Legal requirements for importation should be investigated for exotic agents. Finally, the cost per unit should be compared among sellers, to help distinguish between producers/suppliers and companies which only supply agents. The price differential can be considerable.

Once the natural enemies have been received, some attention to quality of the biological control agents is required. It may even be necessary to determine if the correct species has been received. There are reports indicating that some companies have at times supplied the wrong species, either inadvertently or because their stock culture was misidentified to begin with. Intraspecific variation in an enemy can also be important, where different biotypes or races of a commercially available species exist, using the appropriate one can be critical to success. In parasitoids, body size can be a measure of quality (i.e., larger females generally have greater fecundity). Sex ratio should also be observed, especially in parasitoids because males do not kill pests. Ideally, the number of males in a shipment of parasitoids should approximate the number required to inseminate all of the females. Finally, viability should be checked whenever possible. For example, the rate of hatch (e.g., predator eggs) or emergence (e.g. hosts containing parasitoids) may be relatively low in some shipments.

B. Introductory Phase

Several factors must be considered for successful release of commercially available predators and parasitoids, including characteristics of the target pest population and the release strategy to be employed. The population density of the pest (i.e., number per unit of habitat) can be useful in determining how many agents to release. As the number of agents required will vary with the number of pests present, an enemy-to-pest ratio may be of value in standardizing release rates. Unfortunately, our current knowledge of the required ratios for most commercially available agents is limited at best. The dispersion or "spatial pattern" of the pest population can also influence release strategy, particularly where the pest is patchily distributed in a field or first appears at the edge. The age structure of the pest population should be assessed in those cases where parasitoids are to be released. Parasitoids are greatly restricted with respect to host stages in which they can successfully develop (i.e. egg, larval or pupal parasitoids). In some parasitic species, sex allocation is related to host size: unfertilized eggs (which give rise to males) tend to be deposited in smaller (younger) hosts, whereas fertilized eggs (which give rise to females) tend to be placed in larger (older) hosts. Thus, the distribution of body sizes in a pest population can be important; in some cases, it might be prudent (for example) to delay the release until a greater proportion of suitable hosts for the parasitoids are available.

C. Post-introductory Phase

Once the release has been made, it is critical to assess ecological impact of the agent on the pest population. This can be difficult, particularly where no untreated control or "check" plot is available. Even in replicated experimental plots designed to gather efficacy data, agents may spread from one plot to another, thereby compromising the experiment. Nevertheless, every effort should be made to determine efficacy of commercially available parasitoids and predators so that their use in biological control can become a more predictive science.

Users of biological control should also be cognizant of environmental impact of introduced agents. In this context, environmental impact is defined as any effect on a non-target organism brought about by the introduced predator, parasite or pathogen. Most commercially available biological-control agents can be expected to have an environmental impact of one sort or another. The critical issue is just how serious the impact will be. Enemies that are not host specific are of particular concern. For example, the mealy bug destroyer (Cryptolaemus montrouzieri) has interfered with a cochineal scale used for control of Opuntia cactus in South Africa, and Trichogramma minutum has parasitized eggs of a moth used to control purple nutsedge in Hawaii. Let us hope that such impacts will be minimal. Nevertheless, we cannot expect to replace broad-spectrum insecticides with broad-spectrum biological-control agents without some attendant environmental effects.

D. Conclusion

The "take home message" from this discussion is that users of commercially available predators and parasitoids can enhance their success by adopting a holistic approach, with proper attention to the attributes of the enemy, the characteristics of the pest population, and the nature of the target system. Frequent meetings of users, producers, researchers, and other interested parties to share information and personal experiences will help immensely during the critical phases in the development of augmentative release of commercially available biological-control agents.

Understanding the Risks Linked to Uncontrolled Introduction of Biological Control Agents

Release of a classical biological control agent is a type of irreversible action. If the agent becomes established, it is unlikely that it can be recalled (Bailey *et al*., 2010). The crucial variable of risk in biological control arises from the assumption that the agents cause potential damage to valued non-target species. The damage to a non-target species could be direct, for example feeding by a biological control agent on a valued native plant (Bailey *et al*., 2010); or indirect, for example, loss of a resource if biological control is successful.

Thus the effective use of biological control agents in pest management requires accurate identification of natural enemies that affect the pest species and accurate determination of the level of infection, parasitism or predation on the target pest (Van Driesce, 2004). African countries have a rich diversity of arthropods many of which are natural enemies of important pests of crops grown on the continent. Unfortunately, this rich fauna has not been studied adequately and as a result the indigenous natural enemies have not been exploited in pest management programmes (Ahangama and Gilstrap, 2007). Very few surveys aimed at identifying indigenous natural enemies of major pests of important crops grown in Africa have been conducted. The few studies that have been conducted in the past have focused on identification of species found and the degree of parasitism or predation on the pest (Youm et al. 1990; Drame-Yaye, 1998). Studies on the biology, ecology and host-parasite or host-predator interactions have been lacking. Thus although many indigenous natural enemies are observed to be active in vegetable and cucurbit crop fields for example, their roles in regulating pest populations and their potential for use in conservation and augmentation biological control has not been properly studied. Unfortunately, the increasing and intensive use of pesticides in many African countries has already eliminated many of the indigenous natural enemies from cropping systems before they can be exploited as biological control agents against their target pests.

Biological control, though one of the most effective methods that can be used to control major pests and diseases in Africa, is not the most widely used on the continent at present. This is because most farmers on the continent are more familiar with the use of pesticides. The few successes with the use of biological control in Africa have involved introduction of exotic natural enemies (See Boxes 19.1 and 19.2). There is no doubt that the use of classical biological control can achieve effective and sustainable control of exotic pests. This has been demonstrated in the control of some of the most destructive exotic arthropod pests, invasive plant species and aquatic weeds in Africa: The control of the mealy bug (*Phenacoccus manihoti*) on cassava, through the release of the exotic parasitoid, *Epidinocarsis lopezi* is regarded as the most successful classical biological control programme implemented against an arthropod pest in Africa (Zethner, 1995). The tremendous level of success in controlling the pest in several African countries and the high cost - benefit ratio of 1 to 178 in terms of the revenue returns achieved by the Africa-Wide Classical Biological Control of the Cassava Mealy bug is used as strong evidence in support of the theory that, once established, biological control is a self-sustaining strategy that only requires a single cost input (Zethner, 1995).

However, examination of other classical biological control programmes that have been carried out in Africa shows that not all releases of exotic biological control agents into Africa were as successful as that of E. lopezi: The introduction of two phytoseiid mites: *Typhrodromalus manihhoti* and *Typhrodromalus aripo* for the control of the other exotic pest of cassava, the cassava green mite (*Mononychellus tanajoa*) (Onzo *et al*., 2004) did not provide such spectacular results. The release of *T. manihoti* and *T. aripo* showed that unforeseen negative effects may affect performance of introduced natural enemies.

It is often assumed that when multiple introductions of natural enemies are carried out, the introduced species will complement each other; however, there might actually be predator-predator interactions that may affect the performance of one or of both species. It was discovered that the predatory species *T. manihoti* and *T. aripo* introduced and released to control the exotic pest, *Mononychellus tanajoa,* are potential competitors for the prey and that they feed on each other's young nymphs (Onzo *et al.*, 2004).

The multiple introductions of the natural enemies had a negative impact on one of the two predatory species that were released to control M. tanajoa. Apart from feeding on their prey species, many predatory natural enemies also feed on pollen from crops to meet their protein requirements. The two predatory mites that were introduced in Africa to control the cassava green mite also feed on maize pollen to meet their protein requirements (Onzo *et al.*, 2004). Maize is highly susceptible to drought conditions. The severe drought conditions that are being experienced in many countries of Africa as a result of climate change are adversely affecting maize production. This will reduce availability of maize pollen for these predators in those countries where both maize and cassava are grown.

The reduction or absence of maize pollen during the cropping season may have a negative impact on performance of one or both natural enemy species and may also have a negative impact on the intra-guild interactions of the species.

Climatic conditions can cause failure of an introduced biological control agent to control a target pest when there is poor climatic matching. This was suspected to explain the failure of the moth, P*arenchaetes pseudoinsulata* to control the invasive weed, *Chromolaena odorata* in South Africa although it had achieved complete control of the pest in Ghana (Zachariades et al. 2011).

The risks from introductions of exotic biological control have been a subject of serious concern in countries like South Africa where the largest numbers of biological control agents have been introduced since 1913. The catalogue produced by Klein (2011) shows that of 270 exotic biological control agents tested for host species specificity under quarantine in South Africa, only 106 species (representing 39%) were eventually released as biological control agents while 24% were rejected by the researchers because of doubts about their safety or about their efficacy.

Another worrying risk is the possibility of presence of exotic biological control agents, which were not intentionally introduced into the continent. Because of poor quarantine facilities, and little to virtually nonexistent research programmes on biological control in the majority of the underdeveloped African countries at present, there are risks of presence of exotic biological control agents that were not introduced intentionally into Africa and have not yet been detected. Evidence of this type of risk is demonstrated by information in the catalogue of exotic biological control agents in South Africa, compiled by Klein (2011); which shows that of the 284 exotic natural enemies introduced into South Africa since 1913, 270 were introduced intentionally while 14 were found to occur in the country, but had not been released there intentionally.

There is an emerging view that, although biological control agents have an important role to play in sustainable pest management strategies, exotic biological control agents should be evaluated more rigorously for the potential risks they might pose to non-target organisms (Warner et al., 2009). This is especially important in the light of the extreme changes in weather patterns that are being experienced in African cropping systems due to climate change. There are concerns about non-target impacts of introductions of exotic biological control agents. Some scientists are of the view that future releases of exotic natural enemies in classical biological control programmes should be treated in a similar way as invasive pest species. This view highlights the fact that there is little knowledge on the effects of the changes in the crop environment that are being caused by climate change and how these changes will impact on performance of the exotic natural enemies. The emerging view is advocating for more testing and monitoring protocols for introduction of biological control agents and more attention to the implementation practices and also improved methodologies for evaluating successes due to the released biological control agent; and for the economic analysis of classical biological control introductions; and a shift from project approaches that target individual species to concerns for impact of introduced biological control agents on the whole ecosystem.

Box 19.1: Case Study 1: Risks linked to Natural enemy introduction

The effective use of biological control agents in pest management requires accurate identification of natural enemies that affect the pest species and accurate determination of the level of parasitism or predation on the target pest. African countries have a rich diversity of arthropods many of which are natural enemies of important pests of crops grown on the continent. Unfortunately, this rich fauna has not been studied adequately and as a result the indigenous natural enemies have not been exploited in pest management programmes (Ahangama and Gilstrap, 2007). However, the use of biological control, particularly classical biological control can be subjected to some environmental risks that the present case study will illustrate. The aspect of learning that the case study is addressing include regulatory quarantine rules and laws, biological components of natural enemies that can influence their use, and risks associated with classical biological control.

The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) has been involved in the identification of biological control agents and development of Biological control measures against the insect pests of pearl millet *Pennisetum glaucum* in Niger since 1990. Insect pests like the millet stem borer *Coniesta ignefusalis* and the millet head miner *Heliocheilus albipunctella* regularly infested pearl millet plants (Drame-Yaye et al., 1998); often resulting in 100% crop loss. However up to the year 2000, no indigenous natural enemy agent, that could be used to successfully control these local pests, was found.

Very few surveys aimed at identifying indigenous natural enemies of major pests of important crops grown in Africa have been conducted. Part of the research conducted at ICRISAT Niger from 1990 - 2000 involved MSc and PhD students working on identification of successful biological control agents from other crops that could be useful against the pearl millet insect pests. The research project described in this case study dealt with the introduction to Niger, and testing, of the *Hymenoptera Cotesia* sesamiae active in Benin against maize stem borer, to fight *Coniesta ignefusalis*. For this to happen, ICRISAT signed an agreement with IITA Benin, to export cocoons of *Cotesia sesamiae* from Benin to Niger (Drame-Yaye, 1998)

The importation by plane of the parasitoid *Cotesia sesamiae* from Benin to Niger had to follow a long process of request for authorization from the legal authorities of Niger. The cocoons of *Cotesia sesamiae* do not enter diapause and require about 4 days to hatch. Another problem to face was the weather in Niger which was around an average of 430 C at the time of importation.

Through this case study, learners will be able to:

- Apply the key concepts of risks linked to biological control;
- Reflect on potential risks associated with classical biological control;
- Advise government and scientists on rules to follow for the introduction of biological control agents.

Study Questions:

1. What are the risks involved in this case?
2. How would you handle the process to avoid the risks associated with the importation of exotic parasitoids?

Box 19.2: Case study 2: The potential risk of indigenous and introduced natural enemies competing for prey species

One of the principles for use of Classical Biological Control is that an exotic pest does not have natural enemies in the new area and as a result you have to import its natural enemies from its home of origin. This principle has led to the assumption that an exotic pest cannot have indigenous natural enemies that can feed on it in the new habitat; and as a result indigenous natural enemies have been dismissed as not having a role to play in the biological control of exotic pest species. This case study aims to show that understanding activities of indigenous natural enemies while the classical biological control programme against an exotic pest is being implemented is important; that the role of indigenous natural enemies needs to be understood when exotic species have been introduced; and that their activity needs to be monitored together with those of the exotic natural enemy species.

The major crops grown in Africa have many pest species that are normally kept below the Economic Injury level by a wide range of indigenous natural enemies. Unfortunately, in most African countries many of the natural enemies that keep these species under controlled levels have not been identified. This is because most African countries have not prioritized the use of biological control as a key component of pest management strategies against major pests of important crops. Research on biological control is virtually non-existent in agricultural research programmes of many African countries. Because there is little or no information on indigenous natural enemy species, there is a real risk of introduced exotic natural enemy species having undesirable effects on the indigenous natural enemies that are unknown; or that the potential of the indigenous natural enemies, to be included in an integrated pest management programme of the exotic pets, is not exploited. This case study aims to show that some indigenous natural enemies can be used in combination with exotic natural enemies and have the potential to contribute to successful biological control of an exotic pets.

Cassava, *Manihot esculenta* (Euphobiaceae) is the staple crop of communities living in three lakeshore districts of Malawi: Karonga, Nkhatabay and Nkhotakota. The important pests of the crop in these districts in the 1970s and 1980s were the white fly (*Bemisia afer*), the elegant grasshopper (*Zonocerus elegans*), red spider mites (*Tetranychus spp.*), and termites (*Macrotermes spp.*) (Munthali, 1984, Munthali, 1992, Munthali *et al.*, 1999). The most destructive among these was the white fly, which caused huge yield reductions through feeding by the nymphs and transmission of the cassava mosaic virus by the adults. It was estimated that yield of cassava declined from 20,000 kg/ ha in the early 1970s to 2,000kg/ha in the 1980/81 cropping season (Sauti 1981). A number of indigenous natural enemies including two staphylinid predators (*Holobus fagelli* and *Holobus pallidicoris*) a predatory mite, Iphiseius degenerans provided some levels of control of the red spider mites and immature stages of the white fly while two parasitoids, *Encarsia sublutea* and Eretmocerus mundus, were also causing significant mortalities of white fly nymphs. However, following the accidental introduction of the cassava green mite (*Mononychellus tanajoa*) and the cassava mealybug (*Phenacoccus manihoti*), between 1982 and 1984; the exotic pests almost wiped out the cassava crop in Malawi. The most destructive of the two species was the cassava mealybug. Assessments conducted in 1984 revealed that the exotic pests had overtaken the cassava mosaic virus disease and became the most destructive pests of cassava in the country causing 98% yield losses (Munthali, 1984). In order to save the crop from total destruction, exotic biological control agents were introduced to control the two pests. Several species were released in the country, in collaboration with the International Institute of Tropical Agriculture (IITA), as part of the Africa-Wide Biological Control Programme. The species included coccinellid predators in the genera: *Exochomus, Hyperaspis*, and *Diomus sp.*, and the parasitoid *Epidinocarsis lopezi*. The monitoring of the released biological control agents, for establishment and effectiveness against the pests was done through a collaborative research effort between the scientists in the Ministry of Agriculture and the Entomologists at Chancellor College (University of Malawi). The data obtained from the monitoring programme showed that although the exotic predators had established in the release areas, control of the most destructive pest was achieved by the parasitoid *Epidinocarsis lopezi.* The cassava crop had recovered by the early 1990s. An interesting finding from assessments of the cassava crop during the monitoring period was that apart from the exotic natural enemies, the indigenous predatory mite, *Iphiseius degenerans*, also actively exploited the cassava green mite Munthali (1989) while activity of the other indigenous natural enemies seemed to have declined to negligible levels.

Through this case study, learners will be able to:

- Apply the key concepts of risks linked to biological control
- Conduct research on indigenous natural enemies of serious pests as a component of National Biological control programmes
- Monitor both exotic and indigenous biological control agents following releases of exotic natural enemies
- Reflect on potential risks associated with classical biological control
- Advise government and scientists on rules to follow for the introduction of biological control agents.

Study Questions:

1. What is your level of understanding of the role of indigenous natural enemies in the management of indigenous pests of important crops?
2. What are the potential risks posed to indigenous natural enemies that can result from introduction of exotic natural enemies?

Conclusion

Although classical biological control offers an effective and sustainable alternative to the use of pesticides against exotic pests, a convincing argument for its use can best be made if comprehensive records of previous introductions are used to demonstrate the economic benefits. Such comprehensive data can enable scientists, practitioners (farmers) and policy makers to determine the true impact of climate change on performance of introduced biological control agents over time.

There is evidence that the use of biological control agents against alien invasive plant species has resulted in great economic and environmental benefits in South Africa. Van Wilgen and De Lange (2011) estimated that the cost of economic losses in terms of impact of alien plant species on the environment and the economy was 6.5 billion Rands while the cost of implementation of the classical biological control against the alien species was only 700,000 to 17.3 million Rands depending on species. Unfortunately, documentation and compilation of data on performance of introduced biological control agents following their releases in other African countries have been lacking or tended to be unsystematic, resulting in incomplete data sets. Because of this it has not always been possible to attribute successful control of the exotic pests to the released biological control agents. This is especially true of many of the introductions made for the control of arthropod pests in agriculture.

Discussion Question

1. Should introductions of exotic biological control agents be encouraged wherever exotic pests have been reported, regardless of the research capacities of importing countries?
2. How can potential risks posed by exotic natural enemies be avoided?
3. What regulatory mechanisms and procedures should be in place in countries contemplating importation of exotic natural enemies?
4. How is climate change likely to affect performance of indigenous as well as exotic natural enemies of destructive crop pests?

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