Montpellier SupAgro,

2 Place Pierre Viala, 34060
Montpellier, France

École Doctorale SIBAGHE

Ecology, evolution, genetic resources
and paleontology (EERGP)

Caroline MWONGERA

HOW SMALLHOLDER FARMERS COPE WITH CLIMATE VARIABILITY

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Case study of the Eastern slope of Mount Kenya

Thesis director: Pr Françoise DOSBA
Co-director: Dr Christian LECLERC
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Jury:

Pr Jacques MAILLET	IRC Montpellier SupAgro, France	Examiner
Pr Pierre CAMBERLIN	Université de Bourgogne, France	Reviewer
Dr Richard JONES	IFDC, Kenya	Reviewer
Dr Christian PICHOT	INRA, France	Examiner
Dr Christian LECLERC	CIRAD, UMR AGAP, France	Co-director
Pr Françoise DOSBA	Montpellier SupAgro, UMR AGAP, France	Director

Abstract

Smallholder systems are fundamental to food security for many societies but have largely remained under considered. The aim of this study was to describe how farmers in smallholder farming systems cope with climate variability. The Eastern slope of Mount Kenya is characterized by high climate, social and cultural variability. Farmers practice rain-fed agriculture favouring multi-crops. A double comparative approach was implemented in order to isolate environmental and social factors, by comparing three altitudinal levels and two societies (Mwimbi and Tharaka). Crop diversity is both environmentally and socially structured. Farmers' climate knowledge is highly accurate in the light of climate rainfall records. Farming systems are also highly dynamic over time, in favor of maize and at the expense of sorghum and millet. This cropping system dynamic has induced an increasing risk of losing local farmers' varieties during drought from 1961 to 2006. However, rainfall variations and droughts do not cause seed losses homogenously, as societies interfere between crop and climate. Various sowing dates are practiced to favour the moisture conditions for the crop at germination. Seed genetic adaptability probably differs between communities, as some are usually exposed to droughts (Tharaka at 750 m) whereas others usually evolve in more favorable climatic environment (Mwimbi at 1100 m).Smallholder farmers thus cope with climatic variability with the crop genetic resources that they historically manage. Interaction between social, ecological, historical and genetic factors must be better reflected in crop genetic sampling strategies used in breeding programs to foster genetic adaptation to climate variability.

Keywords: Climate variability; drought; genetic erosion; Kenya, sorghum; maize, Mwimbi, Tharaka

Agricultures familiales et variabilité climatique sur le versant est du Mont Kenya

Résumé

Pour plusieurs sociétés de par le monde, la sécurité alimentaire repose encore aujourd'hui sur une agriculture familiale. L'objectif de cette thèse est de décrire et d'analyser comment les agriculteurs font face à la variabilité climatique. Le versant est du Mont Kenya est caractérisé par une forte variabilité climatique, sociale et culturelle. Les systèmes agricoles intègrent une diversité d'espèces et de variétés. Sans irrigation, ils dépendent exclusivement de la pluviométrie. Une double approche comparative a été utilisée pour isoler les facteurs sociaux et environnementaux dans notre analyse, en comparant trois altitudes (750 m, 950 m et 1100 m) et deux sociétés (Mwimbi et Tharaka). La diversité au niveau inter et intra spécifique est structurée en fonction de l'altitude et des communautés. Le savoir traditionnel des agriculteurs concernant les climats passés s'avère précis lorsqu'on le compare aux données pluviométriques. Avec l'adoption du maïs au détriment du sorgho et du mil, l'évolution des systèmes de cultures a induit un risque plus élevé aujourd'hui qu'auparavant de perdre des variétés lors des sécheresses. Cependant, l'effet négatif de la variabilité climatique n'est pas homogène; les agriculteurs, par leur savoir et leurs pratiques, atténuent l'effet de la variabilité climatique sur les plantes cultivées. Les dates de semis sont variables pour garantir l'humidité adéquate pour la germination des graines en début de saison des pluies. L'adaptabilité génétique des semences diffèrent fort probablement selon les communautés, certaines évoluant depuis plusieurs années en zones très arides (Tharaka à 750 m) alors que d'autres sont plus adaptées à des climats plus cléments (Mwimbi à 1100 m). Les agriculteurs font donc face à la variabilité climatique avec des ressources génétiques qu'ils gèrent et reproduisent historiquement. L'interaction des facteurs sociaux, écologiques, historiques et génétiques devraient davantage être considérée dans les programmes d'amélioration variétale pour faire face à la variabilité climatique.

Mots-clés : Variabilité climatique; sécheresses; érosion génétique; Kenya, sorgho; maïs, Mwimbi, Tharaka

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Dedication

I would like to dedicate this thesis to my wonderful husband and friend, Victor Mugambi Marete. Your love, support, encouragement and inspiration are highly appreciated.

Quote

"He, who is hoping for something, even though he has no strength, will not give up"

Meru proverb

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Introduction

Food security remains one of the main challenges currently facing the world not only in the developing but also in the developed countries. The worldwide demand for food is strongly increasing as a result of human population growth and changes in human diets towards higher consumption of milk and meat products (FAO, 2009a; Pinstrup-Andersen et al., 1999). By 2050, the human population is expected to increase by more than 41% (Jones and Thornton, 2009; Thornton et al., 2011), doubling the global food demand (Roberts, 2009). Many countries continue to experience inadequate food production, with over 835 million and 12 million people affected by food insecurity in developing and developed countries respectively. For the past decade, there has been a slow but steady rise in the number of people that do not have access to sufficient protein and energy from their diet, and even more suffer from micronutrient malnourishment (FAO, 2009b; FAO, 2010b). Sub-Saharan Africa has the highest prevalence of hunger in the world with nearly 1 out of 3 people affected (Sanchez and Swaminathan, 2005). In East Africa, over 86 million people suffer from hunger with Ethiopia and Kenya leading with 31 million and 10 million people affected respectively (FAO, 2010b).

In the past half century there was an increase in global food production reducing the number of hungry people despite doubling of the population (Godfray et al., 2010; Oram, 1995). Global food supply was supported by a technological revolution based on genetic improvement, expansion of irrigation infrastructure and adoption of fertilizers, pesticides and herbicides in industrialized countries. In developing nations, there was the ploughing of new land and development of irrigation (Borlaug and Dowswell, 2005; Firbank et al., 2008; Oram, 1995; Tilman et al., 2002). However, since the early 1980s, growth rates of intensified agriculture have began to decline mainly as a result of the growing competition for land, energy and water, soil erosion, desertification and salinization (Godfray et al., 2010; Kendall and Pimentel, 1994; Oram, 1995). Environmental impacts of intensified agriculture have challenged its sustainability. Intensified agriculture is considered as the most important driver of the observed biodiversity loss around the world, even before climate change, nitrogen deposition and invasions of exotic species (Chapin et al., 2000). The high use of inputs such as fertilizer and pesticides disrupts beneficial functions of biodiversity (e.g. natural pest control and pollination) and degrades environmental quality (Tscharntke et al., 2012). Intensified agriculture is also an important driver of climate change. In 2004, it caused about 14% of the worldwide human greenhouse gas emissions (mainly CH4 and N2O), and this does not include the CO2 emitted due to the use of fossil fuels. An additional 17% (mainly CO2) was contributed by land use change including the deforestation for agriculture (IPCC, 2007).

In the context of declining food production with increasing population growth, a major concern is the ability of agricultural systems to cope with climate variability. On one hand, the use of hybrids in intensified agriculture which usually favour monoculture imply genetic homogeneity. It is well known that the ability of agricultural systems to mitigate climate risk lies in genetic diversity (Kotschi, 2007; Lin, 2011; Sgrò et al., 2011). On the other hand, multi-cropping systems with high level of intra-specific diversity are still today managed by smallholder farmers around the world.

In their analysis of 21crop species in 18 countries, Jarvis et al., 2008 observed high level of intra- specific diversity. For instance farmers in the Amazon lowland of Peru managed up to 89 cassava varieties; 12 barley local varieties are managed in Ethiopian highlands and 18 pearl millet and 27 sorghum local varieties by the Pobe in Burkina. Smallholder multi-cropping systems thus could have potential of adaptability to climate variability that intensified agriculture is not able to provide. Cleveland et al., 1994 highlighted that local crop species can be adapted to climate risk prone areas. Farmer varieties can be locally (Frankel et al 1995) or widely geographically adapted (Witcombe, 1999; Zeven, 1998). As farmer varieties are widespread in exchange, wide adaptation is suggested (Wood and Lenné, 1997). However, there is no empirical evidence of how smallholder rainfall systems cope with climate variability.

The aim of this PhD is to describe how smallholder farming systems cope with climate variability. Such a system has remained under considered whereas can be fundamental to food security for many societies; they can provide innovative approach based on ancestral and experienced ways to mitigate negative effects of climate variability. In Africa, unreliable rainfall with strong interannual variability has been experienced over the Sahel. Drought starting in 1970s is considered as the most important drought of the 20th century worldwide, in term of spatial and time extension as well as in term of intensity (Ali and Lebel, 2009). In East Africa, farmers are faced with high rainfall variability between and within the seasons such as variations in onset, rain day occurrence, rainfall intensity and cessation date (Camberlin et al., 2009). Future climate projections for most areas in Sub-Saharan Africa, highlight difficulties for agriculture production, with loss in the length of the growing season that will reduce the crop productivity and enhance water stress (Mertz et al., 2009; Thornton et al., 2011). Both past rainfall variability and projections reveal how crucial describing ways by which smallholders cope with climate variability is.

0.1 Farmer strategy to cope with climate variability

Farmer resources to cope with climate variability are biological, technological, as well as social in nature. They have developed a great diversity of tools and strategies to cope with many acute and simultaneous changes.

Among the most important resources that farmers have is the diverse and constantly evolving agrobiodiversity that they own, manage, and use. The general hypothesis that is usually proposed is that the diverse crop varieties that smallholders commonly combine in their gardens, fields and agroforests have long helped them to adapt to a broad range of natural, economic and social changes. This diversity offers flexibility and resilience that could confer an advantage to the small farmer in times of stress, agrobiodiversity driving the processes of adaptation. Some studies have shown higher levels of productivity in smallholder systems than in large monocultures, if total output is considered rather than yield from a single crop. A large farm may produce more maize per hectare than a small farm in which the crop is grown as part of a multi-cropping system that also includes beans, squash, potatoes, and fodder. But, productivity in terms of harvestable products per unit area of multi-crops developed by smallholders is higher than under a single crop with the same level of management (Altieri, 2009). This phenomena is referred to as the ‘paradox of the scale’ or the ‘inverse productivity-size relationship’ (Altieri, 2009; Barrett et al., 2010; Horlings and Marsden, 2011). Africa has approximately 33 million small farms, representing 80 percent of all farms in the region (Altieri, 2009). In Sub-Saharan Africa, nearly 90% of staple food production is dependent on rain-fed agriculture (Cooper and Coe, 2011). In Kenya, these smallholder systems (averaging 0.2–0.3 ha in size) dominate food production, accounting for 75% of the total agricultural output and 70 % of marketed agricultural products (Hickey et al., 2012). For most smallholders in Africa, agricultural biodiversity is a coping strategy. At the local level, farmers adapt their cropping patterns, diversify and mix many crops and varieties in the same field in order to enhance resilience of their farming systems. This also includes the use of a wide range of wild plants which play a significant role in the subsistence economy. For example the Tswana are able to survive at the peak of the drought in the Kalahari by use of a diversified food base with emphasis on wild food plants (Grivetti, 1979). In yet another study, Natarajan and Willey (Natarajan and Willey, 1986), demonstrated that mixed cropping systems of sorghum/peanut and millet/peanut exhibited greater yield than in the case of mono-cropping. The differences in productivity between monocultures and mixed cropping systems became more accentuated with water stress. This suggests that more diverse plant communities are more resilient to environmental perturbations. Multi-cropping systems can thus be considered as a strategy of smallholders to cope with climate variability. Describing how smallholder farming systems cope with climate variability implies that all crops are considered in the analysis.

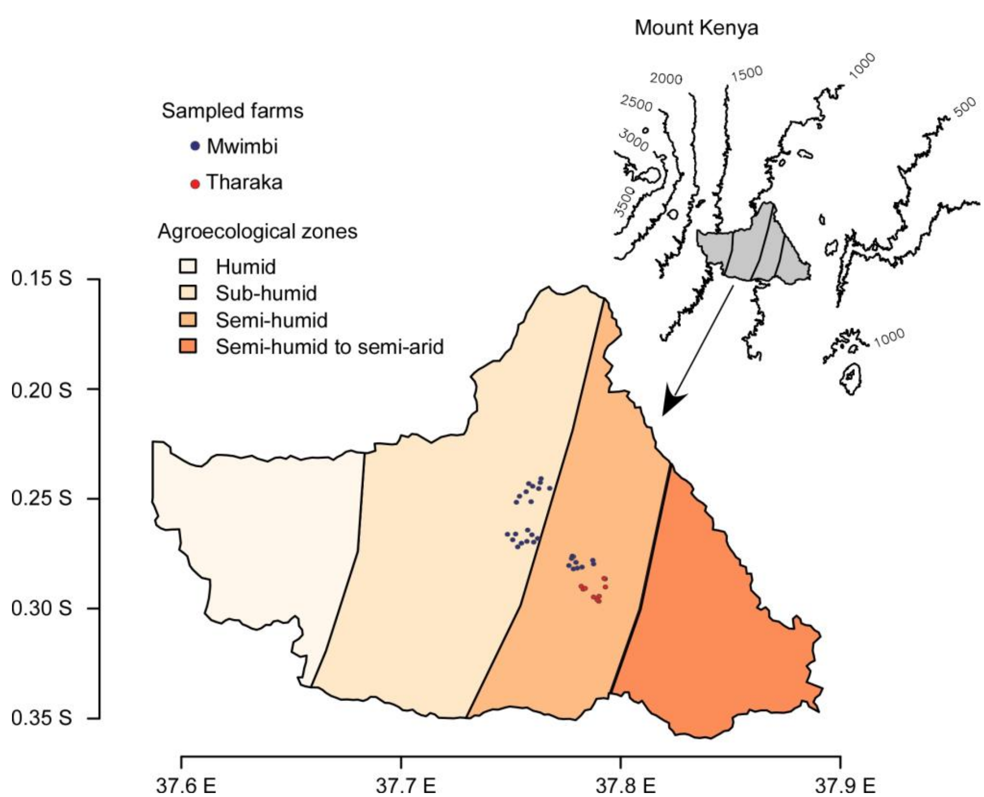
Traditional knowledge and practices is unique to a given culture or society and they are usually considered together. Knowledge is orally passed on from one generation to another, and it is valuable in adjusting to local-level climate variability (Nyong et al., 2007; Pareek and Trivedi, 2011; Stigter et al., 2005). Traditional knowledge systems are developed over centuries, and include observing natural phenomena such as the growth of shoots on particular plants at certain times in the year, observation of the moon and stars and insects and animal behaviour (Aklilu and Wekesa, 2001; IRIN, 2011). Traditional management of risk through agrobiodiversity, and associated knowledge, are found among smallholders around the world. There is “memory” of risks as well as agronomic and environmental knowledge built into their agricultural systems. Traditional knowledge has played a significant part in solving problems, including problems related to climate variability and change. Describing how smallholder farming systems cope with climate variability implies the use of a social comparative approach, as knowledge is embedded into a given culture.

0.2 Study site and scientific strategy

Kenya is particularly relevant for describing how smallholders cope with climate variability, as farmers favour multi-cropping systems, and farmer communities are usually socially and/or culturally differentiated. This allows the implementation of a comparative approach.

In the arid and semi-arid regions of Kenya, droughts are common and occur on average one in every three seasons (Hickey et al., 2012). A wider range of adaptation options are already required for adapting to current substantial season-to-season weather ranges that farmers are experiencing. For example over a 45 year climate analysis in a semi-arid location in Kenya, for the Short Rains season, the length of the growing season varied from 50 to 175 days and rainfall from 125 to 810 mm (Cooper et al., 2008). Kenya has consistently been classified as one of the 20 most food-insecure countries in the world (Maplecroft, 2011). The eastern slope of Mount Kenya is suited and relevant for studies aimed at describing how smallholders cope with climate variability (Figure 1).

Figure 1. Map showing the localization of the study site on the Eastern slope of Mount Kenya, sampled farms and associated agroecological zones



The study site is on the eastern most limit of the Meru South administrative district. Selection of the site was motivated by its high cultural and ecological heterogeneity which allows us to analyze social and environmental factors at work in structuring crop diversity and coping with climate variability. The site is home to three ethno-linguistic groups, namely the Tharaka, Mwimbi, and Muthambi.

We focused on an altitudinal gradient, i.e. from the maize-tobacco zone to the sorghum-pearl millet zone and selected three altitudinal levels, i) Lowlands (750 m ASL), ii) midlands (950m ASL) and iii) highlands (1100m ASL). The Mwimbi occupy the high and mid altitude, whereas the Tharaka are predominantly at the low altitude with smaller numbers at the mid altitude.

On the eastern slope of Mount Kenya, crop production is primarily rain-fed, favouring multi-cropping. Droughts are frequent with high climate variability between and within seasons. Crop genetic diversity managed by farmer communities is a key component, and there is also great environmental and cultural variability. The context allows the implementation of multidisciplinary methods in order to consider in our study that historical, social, biological and environmental processes can interfere in coping with climate variability. This PhD was led at the interface of biological and social sciences.

Rainfall is bi-modal with the long rains from March to May and short rains October to December (Camberlin and Okoola, 2003; Camberlin et al., 2009; Camberlin et al., 2012). Considerable interannual variations of seasonal rainfall have been showed over East Africa and the Mount Kenya region, particularly for the Short Rains (Black et al., 2003; Camberlin, 2010; Nicholson, 1996). For the long rains, intra-annual rainfall variations are much more related to the frequency of the rain events than to the daily rain intensity (Moron et al., 2007). According to Camberlin et al., 2009, the onset is more variable than the cessation for both seasons in equatorial East Africa. Climate is closely interrelated with landforms. In the highlands, the mountain not only mitigates high temperatures and rates of evapotranspiration, but also force rain bearing winds upward and causes them to lose a much greater amount of moisture than over the low lying plains. The study site is characterized by sub-humid to semi-arid agro-ecologies. An agro-ecological zone has been classified by its relevant agro-climatic factors (mainly moisture supply) and differentiated by soil pattern (Jaetzold et al., 2007). Availability of rainfall data of the study site is a great advantage to achieve the aims of our studies.

For most local varieties that farmers are cultivating along the eastern slope, seed is sourced through what is referred to as the “traditional/local seed system”. Farming systems are locally integrated and organized and farmers themselves produce, disseminate and procure their seeds. Seeds are procured directly from their own harvest, through exchange among friends, neighbours and relatives, or through local grain markets. The cultivation of several crop varieties on the eastern slope of Mount Kenya also constituted a condition for the site selection.

Many communities are distinguished on the eastern slope of Mount Kenya and this cultural diversity was integrated in our comparative setting and scientific strategy. The Meru speaking communities are part of the highland Bantu. The Meru is made up of eight sub-tribes, based on dialectal differences, variations in cultural traits and differences in traditions. These include: Tigania, Igembe, Imenti, Igoji, Mwimbi, Tharaka, Muthambi and Chuka (Lambert, 1956; Bernardi 1959) and is currently estimated to have a population of about 1.3 million people (KNBS, 2009).

Mount Kenya Meru communities have been described as "ridge top communities" (Fadiman, 1993) because each community lives on an interfluves, being separated by rivers. Different communities live on different interfluves, whereas farmers from the same communities exploit different altitudes. The context allows the implementing of a double comparative approach as proposed by Leclerc and Coppens d'Eeeckenbrugge (2012) to isolate social and environmental factors in the analysis (Table 1).

Farmers from the same community, at different altitudinal levels were compared to highlight the effect of the environmental factor, and farmers from two different communities at the same altitudinal level compared to highlight the social factor.

Table 1. Double comparative setting of the study site. At 950 m elevation, Mwimbi and Tharaka live in the same agro-ecological zone. Environmental conditions being controlled; this zone was used to test effects of social communities on seed management and on response of their crop to climate variability. Mwimbi farmers at midlands and highlands and Tharaka farmers at lowlands and midlands live in different agro-ecological zones. In this case, the social identity of farmers is controlled, and the two zones were used to test how different environments influence crop response to climate variability

1100 m ASL (highlands)	Mwimbi 5 Km		Sub-humid agro-ecology
950 m ASL (midlands)	2 Km Tharaka 5 Km	Mwimbi	Semi-humid agro-ecology
750 m ASL (lowlands)	Tharaka		Semi-humid to Semi-arid agro-ecology

0.3 Historical setting of the Eastern slope of Mount Kenya

The Swynnerton plan which was a colonial agricultural policy appeared in 1954 in Kenya, aiming to intensify the development of agricultural practice. The main objective of the plan was to create family holdings large enough to keep the family self-sufficient in food and also enable them to practice alternate husbandry and thus develop a cash income. On the Eastern slope of Mount Kenya, movement occurred upslope and down to newly established farms in the midlands (Bernard, 1972). Around 1960, Mwimbi farmers began to move from 1100 m (highland climatic zone) to 950 m (midland climatic zone), whereas, about ten years later, Tharaka farmers began to move up from 750 m (lowland climatic zone). The two communities, originating from different climatic environments, are today geographically close to each other in the midlands. The historical setting allows us to compare the change in space in ecological context corresponding to that which in time is induced by global environmental changes, to analyze ecological and crop genetic factors at work in the social process of adaptation to climate changes. We avoid the use of long term and scale studies that would have been costly and challenging to conduct.

0.4 Specific questions and structure of the PhD

After a detailed literature review in chapter 1 and description of crop variety diversity in chapter 2 (used as background for following chapters), my PhD is structured in two parts. The first, based on a diachronic approach deals with farmers' past climate knowledge and how they coped with past interannual rainfall variation, using a retrospective survey from 1961 to 2006 (chapter 3 and 4). The second, based on a synchronic approach, concerns farmers' strategies at present day (chapter 5). Favouring empirical approach with automatic weather stations installed on farmer fields, we focus on intra annual (inter season) rainfall variability and how farmers cope with climate variability by adopting different sowing dates to reduce the length of dry spells after germinations. The link between these two time scales, obviously complementary in the analysis, is discussed. The three last chapters (chapter 3-5) deal with crop-society-climate interactions, through the prism of seed losses and crop failures. The thesis is based on a multidisciplinary study encompassing the fields of biology, sociology and climatology.

Food security can be defined as the success of local livelihoods to guarantee access to adequate food at the household level through trade as well as production (Devereux and Edwards, 2004). The importance of agricultural biodiversity has widely been recognized as a biological basis for food security. Crop diversity in smallholder systems has enabled farmers to cope with the natural, economic and social changes. In drought-prone areas where rain-fed agriculture is solely practiced such as on the eastern slope of Mount Kenya, the reliance on crop genetic diversity is particularly important. The cultivation of diverse crops can decrease the vulnerability of farmers to climate variability as different crops respond differently to climate variations (FAO, 2011b; Fraser et al., 2005; Reidsma and Ewert, 2008). These crucial issues are reviewed in detail in chapter 1.

Studies on crop diversity and dynamics have primarily focused on the overall diversity of the species at the local and regional level without taking into account the social context. In chapter 2, we will show how crop diversity distribution is influenced by environmental and cultural differences and the seed exchange networks. The specific question we address in this chapter is: how is crop diversity structured in an environmentally and socially contrasted site? Cultivated crop and variety diversity among smallholder farms on the eastern slope of Mount Kenya is empirically estimated within and between communities. Using a field comparative setting, a double comparative approach was used to assess the amount and the distribution of crop variety diversity over the altitudinal gradient and among different communities. Farmer's seed access and exchange networks is described in order to understand *in situ* conservation of the community and the role that this diversity can play in helping farmers cope with climate variability.

How humans perceive the environment and the language used to categorize and describe it should not the same depending on the society under consideration. Environmental knowledge thus is culturally defined, and can only be assessed by referring to other cultural aspects within the same society. Among many small holder farmers around the world, local concepts used by farmers to describe past drought do not inform us about the severity of a given drought, as compared to others. In chapter 3 we aim to show the association between traditional knowledge, which is culturally built-in, and western climatic knowledge (based on rainfall records). The specific questions we address are: how accurate is farmers past climate knowledge? Is there a link between frequency of loss and past rainfall variations? Valuating farmer traditional climate knowledge, and integrating it into a multicultural research project, could help to mitigate negative effects of droughts, which have become more severe and frequent, according to farmers.

Smallholder rain-fed agriculture systems especially in Africa are today increasingly dynamic (Cooper and Coe, 2011), notably under the impulsion of agricultural policies that promote the cultivation of maize in place of traditionally cultivated crops such as sorghum and millets. However, the dynamic of the farming system itself has never been considered as a factor having the potential to increase in the future the impacts of climate variability on smallholder rain-fed multi-cropping systems. Models simulating the crop response to climate often consider only one crop at a time, whereas smallholder rain-fed agriculture usually favours multi-cropping systems, but also assumed in the future, continued use of current varieties with unchanged cultural practices (Jones and Thornton, 2003; Thornton et al., 2009).

In chapter 4, combining ecological anthropology and climatology, we analyze the impact of past rainfall variation on variety loss over time in rain-fed agriculture systems managed by East African smallholders, considering their dynamic. While usual approaches consider present day characteristics of agricultural systems to assess its adaptability to hypothetical rainfall variability (projection into the future), assuming unchanged crop varieties and a single crop at a time, our study is based on farmer knowledge using a retrospective survey (looking into the past), thence, past rainfall variability is known, not hypothetical and we in addition consider the dynamic of the farming system. The specific questions we address are: how agricultural policies modified crop assemblage in rain-fed farming system from 1961 to 2006? For the different crop species, is the probability to lose a variety the same when faced with drought? How do the different components of the rainy seasons contribute to variety losses? Has the farming system capacity to mitigate the risks of variety losses due to drought been reduced over the period with the increasing popularity of maize cultivated in place of sorghum and pearl millet?

Rainfall is a key input to the success of a crop's growing cycle and to realize yields. Prolonged dry spells during the wet season are common and can cause crop failures and seed losses (Araya et al., 2010; Barron et al., 2003; Segele and Lamb, 2005). However rainfall variation and droughts do not cause seed losses homogenously as farmers by use of their cultural knowledge and practices interfere between crop and climate. In chapter 5, we will attempt to identify factors used in coping with climate variability by considering farmers' cultural practices and the crop genetic resources they use to mitigate negative drought effects. Our specific research question is: how do farmers interfere between crop and climate? What cultural practices and the crop genetic resources do they use to mitigate negative drought effects? Using a space-and-time substitution design we compare two communities that have moved into a new climatic environment, representing rapid and global environmental changes. The context allows us, using a smaller region during four cropping seasons, to analyze ecological and crop genetic factors at work in the social process of adaptation to climate changes. We thereby avoid the use of a long-term scale study that would have been costly and challenging to conduct.

Our research, based on a multidisciplinary approach integrating social and historical components, should be very useful at larger scale to analyze global change that many local societies around the world are facing and will face in the future. If food security remains for the present day a challenge, vis-à-vis climate variability, smallholders' agriculture with its high level of crop genetic diversity could provide useful strategies, which were historically experienced and improved by farmers. Diversified cropping systems is what many smallholders farmers try to do around the world, and we can hope that these local initiatives will provide innovative solutions to global issues of food security, notably to cope with climate variability.

0.5 References cited in introduction

Aklilu Y., Wekesa M. (2001) *Livestock and livelihoods in emergencies: lessons learnt from the 1999-2001 emergency response in the pastoral sector in Kenya*. H. P. N. Paper, Nairobi and Medford. pp. 40.

Ali A., Lebel T. (2009) The Sahelian standardized rainfall index revisited. *International Journal of Climatology* 29 (12),1705-1714.

Altieri M.A. (2009) Agroecology, small farms, and food sovereignty. *Monthly Review* 61 (3),102-113.

Araya A., Keesstra S.D., Stroosnijder L. (2010) A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. *Agricultural and Forest Meteorology* 150,1047–1064.

Barrett C.B., Bellemare M.F., Hou J.Y. (2010) Reconsidering conventional explanations of the inverse productivity–size relationship. *World Development* 38 (1),88-97.

Barron J., Rockstrom J., Gichuki F., Hatibu N. (2003) Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural and Forest Meteorology* 117,23-37.

Bernard F.E. (1972) *East of mount Kenya : Meru agriculture in transition*. Weltforum Verlag, München. pp. 176.

Bernardi B. (1959) *The Mugwe: a failing prophet*. Oxford University Press for the International African Institute, London.

Black E., Slingo J.M., K.R. S. (2003) An observational study of the relationship between excessively strong short rains in coastal east Africa and indian ocean SST. *Monthly Weather Review* 103,74–94.

Borlaug N.E., Dowswell C.R. (2005) Feeding a world of ten billion people: a 21st century challenge, in: *International Congress "In the Wake of the Double Helix: From the Green Revolution to the Gene Revolution"*, 27–31 May 2003,Bologna, Italy,3–23.

Camberlin P. (2010) More variable tropical climates have a slower demographic growth. *Climate Research* 41,157-167.

Camberlin P., Okoola R.E. (2003) The onset and cessation of the ‘long rains’ in eastern Africa and their interannual variability. *Theoretical and Applied Climatology* 75,43–54.

Camberlin P., Moron V., Okoola R., Philippon N., Gitau W. (2009) Components of rainy seasons’ variability in equatorial east Africa: onset, cessation, rainfall frequency and intensity. *Theoretical and Applied Climatology* 98,237-249. DOI: 10.1007/s00704-009-0113-1.

Camberlin P., Boyard J.-M., Philippon N., Baron C., Leclerc C., Mwongera C. (2012) Climatic gradients along the windward slopes of mount Kenya and their implication for crop risks. Part 1: climate variability. *International Journal of Climatology* [online] 17. DOI: 10.1002/joc.3427.

Chapin F.S., Zavaleta E.S., Eviner V.T., Naylor R.L., Vitousek P.M., Reynolds H.L., Hooper D.U., Lavorel S., SalaI O.E., Hobbie S.E., Mack M.C., Díaz S. (2000) Consequences of changing biodiversity. *Nature* 405,234-242.

Cleveland D.A., Soleri D., Smith S.E. (1994) Do folk crop varieties have a role in sustainable agriculture? *BioScience* 44 (11),740-751.

Cooper P.J.M., Coe R. (2011) Assessing and addressing climate-induced risk in sub-Saharan rainfed agriculture. *Experimental Agriculture* 47 (02),179-184. DOI: 10.1017/s0014479711000019.

Cooper P.J.M., Dimes J., Rao K.P.C., Shapiro B., Shiferaw B., Twomlow S. (2008) Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: an essential first step in adapting to future climate change? *Agriculture, Ecosystems & Environment* 126 (1-2),24-35. DOI: 10.1016/j.agee.2008.01.007.

Devereux S., Edwards J. (2004) Climate change and food security. *IDS Bulletin* 35 (3),22-30.

Fadiman, J.A. (1993) When we began, there were witchmen. An oral history of Mount Kenya. University of California Press, London, England. pp. 395.

FAO. (2008) *Diversity of experiences. Understanding change in crop and seed diversity*. FAO, Rome, Italy. pp. 42.

FAO. (2009a) *How to feed the world in 2050*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 35.

FAO. (2009b) *The state of food insecurity in the world 2009. Economic crises – impacts and lessons learned*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 61.

FAO. (2010) *The state of food insecurity in the world 2010. Addressing food insecurity in protracted crises*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 62.

FAO. (2011) *Potential effects of climate change on crop pollination*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 40.

Firbank L.G., Petit S., Smart S., Blain A., Fuller R.J. (2008) Assessing the impacts of agricultural intensification on biodiversity: a British perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences* 1492,777-787.

Fraser E., Mabee W., Figge F. (2005) A framework for assessing the vulnerability of food systems to future shocks. *Futures* 37 (6),465-479.

Godfray H.C.J., Beddington J.R., Crute I.R., Haddad L., Lawrence D., Muir J.F., Pretty J., Robinson S., Thomas S.M., Toulmin C. (2010) Food security: the challenge of feeding 9 billion people. *Science* 327,812-818.

Grivetti L.E. (1979) Kalahari agro-pastoral hunter-gatherers: the Tswana example. *Ecology of Food and Nutrition* 7 (4),235–256.

Hickey G.M., Pelletier B., Brownhill L., Kamau G.M., Maina I.N. (2012) Preface: challenges and opportunities for enhancing food security in Kenya. *Food Security* 4,333–340. DOI: 10.1007/s12571-012-0203-2.

Horlings L.G., Marsden T.K. (2011) Towards the real green revolution? Exploring the conceptual dimensions of a new ecological modernisation of agriculture that could 'feed the world'. *Global Environmental Change* 21 (2),441-452.

IPCC. (2007) *Climate change 2007.Mitigation of climate change: working group III contribution to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, UK. pp. 862.

IRIN. (2011) Ethiopia: Borena zone braced for more failed rains. *Humanitarian news and analysis*.http://www.irinnews.org/report.aspx?reportid=93247. [March 23, 2012].

Jaetzold R., Schmidt H., Hornetz B., Shisanya C. (2007) *Farm management handbook of Kenya. Vol. II/C. East Kenya*. Ministry of Agriculture, Nairobi, Kenya. pp. 406.

Jarvis D.I., Brown A.H.D., Cuong P.H., Collado-Panduro L., Latournerie-Moreno L., Gyawali S., Tanto T., Sawadogo M., Mar I., Sadiki M., Hue N.T.N., Arias-Reyes L., Balma D., Bajracharya J., Castillo F., Rijal D., Belqadi L., Rana R., Saidi S., Ouedraogo J., Zangre R., Rhrib K., Chavez J.L., Schoen D., Sthapit B., De Santis P., Fadda C., Hodgkin T.

(2008) A global perspective of the richness and evenness of traditional crop-variety diversity maintained by farming communities. *Proceedings of the National Academy of Sciences* 105 (14),5326-5331. DOI: 10.1073/pnas.0800607105.

Jones P.G., Thornton P.K. (2003) The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change* 13,51-59.

Jones P.G., Thornton P.K. (2009) Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to climate change. *Environmental Science & Policy* 12 (4),427-437. DOI: 10.1016/j.envsci.2008.08.006.

Kendall H.W., Pimentel D. (1994) Constraints on the expansion of the global food supply. *Ambio* 23 (3),198-205.

KNBS. (2009) 2009 population and housing census results http://www.knbs.or.ke. [March 12, 2012].

Kotschi J. (2007) Agricultural biodiversity is essential for adapting to climate change. *GAIA-Ecological perspectives for science and society* 16 (2),98-101.

Lambert H.E. (1956) *Kikuyu Social and Political Institutions*. Oxford University Press, London. pp. 149.

Leclerc, C., Coppens D'eeckenbrugge, G. (2012) Social organization of crop genetic diversity The G x E x S interaction model Diversity 4, 1-32.

Lin B. (2011) Resilience in Agriculture through crop diversification: adaptive management for environmental change. *BioScience* 61 (3),183-193. DOI: 10.1525/bio.2011.61.3.4.

Maplecroft. (2011) Maplecroft food security index and interactive global map.http://maps.maplecroft.com. [February 2, 2012].

Mertz O., Halsnæs K., Olesen J.E., Rasmussen K. (2009) Adaptation to climate change in developing countries. *Environmental Management* 43 (5),743-752. DOI: 10.1007/s00267-008-9259-3.

Moron V., Robertson A.W., Ward M.N., Camberlin P. (2007) Spatial coherence of tropical rainfall at regional scale. *Journal of Climate* 20,5244–5263.

Natarajan M., Willey R.W. (1986) The effects of water stress on yield advantages of intercropping systems. *Field Crops Research* 13,117–131.

Nicholson S.E. (1996) A review of climate dynamics and climate variability in eastern Africa, in: J. T.C. and O. E.O (Ed.), *The limnology, climatology and paleoclimatology of the east african lakes*, Gordon and Breach. pp. 25-56.

Nyong A., Adesina F., Osman Elasha B. (2007) The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change* 12 (5),787-797. DOI: 10.1007/s11027-007-9099-0.

Oram P. (1995) *The potential of technology to meet world food needs in 2020*. International Food Policy Research Institute, Washington, DC. pp. 2.

Pareek A., Trivedi P.C. (2011) Cultural values and indigenous knowledge of climate change and disaster prediction in Rajasthan, India. *Indian Journal of Traditional Knowledge* 10 (1),183-189.

Pinstrup-Andersen P., Pandya-Lorch R., Rosegrant M.W. (1999) *World food prospects: critical issues for the early twenty-first century*. International Food Policy Research Institute, Washington, DC. pp. 30.

Reidsma P., Ewert F. (2008) Regional farm diversity can reduce vulnerability of food production to climate change. *Ecology and Society* 13(1) (38),13-16.

Roberts T.L. (2009) The role of fertilizer in growing the world's food. *Better Crops* 93 (2),12-15.

Segele Z.T., Lamb P.J. (2005) Characterization and variability of Kiremt rainy season over Ethiopia. *Meteorology and Atmospheric Physics* 89,153-180.

Sgrò C.M., Lowe A.J., Hoffmann A.A. (2011) Building evolutionary resilience for conserving biodiversity under climate change. *Evolutionary Applications* 4 (2),326-337.

Stigter C.J., Dawei Z., Onyewotu L.O.Z., Xurong M. (2005) Using traditional methods and indigenous technologies for coping with climate variability. *Climatic change* 70,255-271.

Thornton P.K., Jones P.G., Alagarswamy G., Andresen J. (2009) Spatial variation of crop yield response to climate change in East Africa. *Global Environmental Change* 19,54–65.

Thornton P.K., Jones P.G., Ericksen P.J., Challinor A.J. (2011) Agriculture and food systems in sub-Saharan Africa in a 4°C+ world. *Philosophical Transactions of the Royal Society, Series A* 369,117-136.

Tilman D., Cassman K.G., Matson P.A., Naylor R., Polasky.S. (2002) Agricultural sustainability and intensive production practices. *Nature* 418 (6898),671-677. DOI: 10.1038/nature01014.

Tscharntke T., Clough Y., Wanger T.C., Jackson L., Motzke I., Perfecto I., Vandermeer J., Whitbread A. (2012) Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation* 151,53-59.

Wood D., Lenné J.M. (1997) The conservation of agrobiodiversity on-farm: questioning the emerging paradigm. *Biodiversity and Conservation* 6,109-129.

Witcombe J.R. (1999) Do farmer-participatory methods apply more to high potential areas than to marginal ones? *Outlook on Agriculture* 28,43-49.

Zeven A.C. (1998) Landraces: a review of definitions and classifications. *Euphytica* 104,127-139.

1 Literature review

1.1 Food security: intensified versus smallholder agriculture

Food security can be defined as the success of local livelihoods to guarantee access to adequate food at the household level through trade as well as production (Devereux and Edwards, 2004). Grain is the primary source of nutrition for most of the world, although there is a rise in the demand for meat and milk driven by population growth and rising incomes especially in the developing countries (Thornton, 2010).

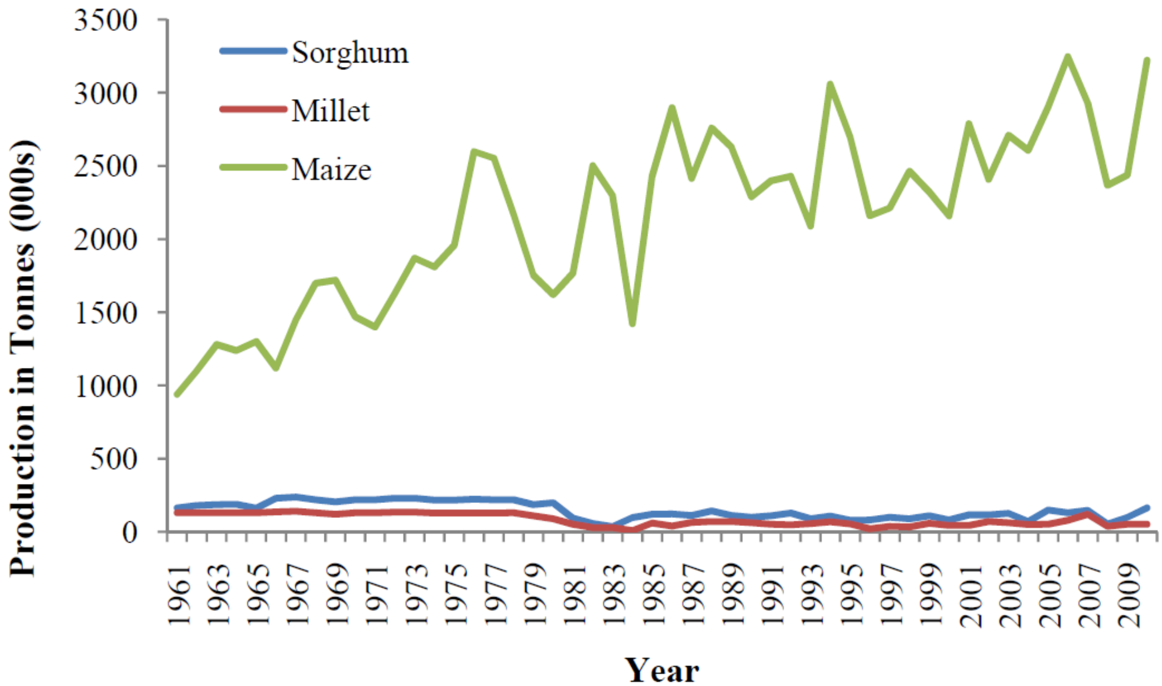
Some of the increases in food production in the 18th- and 19th-century can be attributed to the Industrial and Agricultural Revolutions and the 20th-century Green Revolution. Agricultural Revolution was marked by a massive increase in agricultural productivity and improvement in farm technology whereas the Green revolution which played the greatest part in increasing agricultural production involved the development of high-yielding varieties of cereal grains, expansion of irrigation infrastructure, modernization of management techniques, distribution of hybridized seeds, synthetic fertilizers, and pesticides to farmers (Borlaug and Dowswell, 2005; Firbank et al., 2008; Oram, 1995; Tilman et al., 2002). However since the early 1980s growth rates of food production have began to decline mainly as a result of the growing competition for land, energy and water, soil erosion, desertification, salinization and the effects of climate change (Godfray et al., 2010; Kendall and Pimentel, 1994; Oram, 1995).

Previous attempts to promote increased food production led to the onset of agricultural intensification and the development of large scale farms as defining features of modern agriculture. More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850 (Millennium Ecosystem Assessment, 2005). These high-intensity land-use systems are the main cause of global change and biodiversity loss (Darkoh, 2003; Tscharntke et al., 2005). In the cradle areas of crop domestication, loss of traditional cultivars can be tied in with the specialization and intensification that comes with the introduction and dissemination of modern, high-yielding varieties (FAO, 1996; FAO, 2010a).The commercialization of a relatively small number of crops species and varieties such as rice, maize and wheat) has led to several commercial farms globally approaching monocultures. As well as on smallholder farms, the negative consequence of this is the replacement of locally adapted crop species in highly climate risk prone areas, with less adaptable commercial varieties (Almekinders, 2001; Ceccarelli et al., 1995; Cleveland et al., 1994) leading to a continuous cycle of food insecurity. Government policies that promote highly productive crop species play an important role in the loss of biodiversity and have led to the abandonment of traditional crop species (Darkoh, 2003). The loss of these crop species in particular is not only a loss of biodiversity, but also has implications with increasing climate variability and for climate change because these are highly adapted to the local biological and physical environment and enhance the community's resilience (Altieri and Koohafkan, 2008; Berkes et al., 1995). For example, the agronomically important, high-intensity pastures in Germany (Lolio-Cynosuretum) lost around half of the plant species (Tscharntke et al., 2005). In a study carried out in eight European countries (Flohre et al., 2011) have demonstrated a decrease in the diversity of vascular plants and birds with agricultural intensification. In a Latin America, ant and bird richness declined in coffee agrosystems with management intensification (Philpott et al., 2008). Agricultural intensification in The Netherlands in the 1960s also contributed to the conversion of species-rich heathlands first into low-diversity stands of a weedy grass (Molinia) and then into shrubby forest (Tilman and Lehman, 2001). In Argentina and Bolivia, the Chaco thorn forest is being felled at a rate considered among the highest in the world to give way to soybean cultivation while in Borneo, the Dypterocarp forest, one of the species-richest in the world, is being replaced by oil palm plantations. Many animal and plant populations have also been dramatically reduced by changing land use patterns, to the point that they could be considered functionally extinct, such as the maned wolf and the giant anteater in the Chaco plains, and the orangutan and several species of pitcher plants in the Bornean rainforest (Díaz et al., 2006). To date most diversity loss studies have focused on birds which are thought to be good indicators of farmland biodiversity (Donald et al., 2001) and they have attributed the substantial decrease in bird diversity with the process of agricultural intensification. In a study in the Pampas of Argentina, loss of bird diversity and associated ecosystem services that benefit crop production was demonstrated with intensification and expansion of row crop agriculture (Gavier-Pizarro et al., 2011; Schrag et al., 2009). In Europe, severe and widespread decline in the population of farmland bird species has also been attributed to agriculture intensification (Donald et al., 2001; Donald et al., 2006; Gregory et al., 2005). Several cases of this negative correlation have also been reported such as in Africa (Bolwig et al., 2006; Buchanan et al., 2009; Sinclair et al., 2002) and South America (Tscharntke et al., 2008).

1.1.1 An example of maize introduction and food security in Africa

Since the introduction of maize in Africa in the 1500s (McCann, 2001; Miracle, 1965), a large part of the population has become dependent on it as the main staple starch. 'Food security' in most African countries is now mainly equated with the availability and affordability of maize (Jayne and Jones, 1997; Mazunda and Droppelmann, 2012; Nyoro et al., 2007; Orr et al., 2001). Consequently, maize production and access drives national food and agricultural policies leading to the extension of maize as the dominant pathway for food security. In Eastern Africa, maize accounts for 30−50% of low-income household expenditures (IITA, 2009). In Kenya and Tanzania for instance it represents 36% and 44% respectively of the daily caloric intake (De Groote et al., 2002). Maize has become the pre-eminent staple crop in Kenya over the past 100 years, prior to which sorghum and millet were the staple cereals (Brooks et al., 2009). Figure 1.1 illustrates the trend in the production of the three major cereals cultivated in Kenya from 1961-2009.

Figure 1.1: Trends in the production of the major cereal crops in Kenya (1961-2009). Maize production (green line) has generally been increasing from 1961-2009, while that of sorghum (blue line) and millet (red line) has been declining from 1981-2009. Source: FAOSTAT (FAO, 2012).



It reveals that overall the production of maize has been on an increase whereas that of sorghum and millet has been declining from 1965-2009. During these 44 years, the decline in sorghum and millet production may mainly be attributed to state policies that supported maize markets and prices. The past food policies in Kenya overemphasized the role of maize in ensuring food security (Nyoro et al., 2007). Thereby this can be considered as influencing the increase in the production of maize as compared to that of sorghum and millets which were previously the more common crops. Policies to encourage farmers to boost maize production may be contradicted by policies to promote the cultivation of crops adapted to local growing conditions, more so in arid and semi-arid areas which account for two-thirds of the country's land (Nkonya et al., 2011). Maize is highly sensitive to deprivation of water, nitrogen and sunlight (McCann, 2001; Qin et al., 2004). With frequent and more severe droughts over the horn of Africa in recent years (FAO, 2011; Haile, 2005; Meiera et al., 2007), compounded with the fact that most of the farmers are subsistence smallholders who cannot afford the use of fertilizers (Bashir and Gonzalo, 2008; Wichelns, 2003), farmers are often faced with maize famine resulting in recurrent food shortages. Sub-Saharan Africa has seen a deterioration of its food security status since the 1970, when most countries were self-sufficient or even had an agricultural surplus, till the current situation where food shortages are frequent (De Groote et al., 2002). Over Eastern Kenya maize became the dominant crop during the 1900-1965 period occupying over 75% of the cereal area (Smale and Jayne, 2003); it replaced sorghum and millets which were dominant up to the early 1980s when their production sharply declined by over 50% (FAO, 2012). The prevalent food shortage situations especially in the lower drylands may be attributed to the high dependence on maize which is more sensitive to water stress. More recently, famine situations have been experienced for most seasons in the past three years (FAO, 2011), consequently this led to the government calling for relief efforts as well as the expensive partial importation of maize.

The challenge of modern agriculture is thus to forestall or reverse its negative impact on biodiversity while increasing its productivity on the short and long term. These aims are often considered contradictory. Increasing agricultural production would either require: increasing crop land which would imply deforestation and loss in diversity, or the adoption of intensive agriculture implying the use of external inputs (Kendall and Pimentel, 1994; Vandermeer and Perfecto, 2007).

Smallholder agriculture plays an important role in producing more than half of the world's food supply, and is the backbone of African agriculture and food security. Over 75% of the farms worldwide are small farms and these produce the majority of the staple crops needed to feed the world's rural and urban populations (Altieri, 2008). Of the two-thirds of sub-Saharan Africa's population that resides in the rural areas, the majority can be considered as smallholder farmers. The term 'smallholder' refers to their limited resource endowments relative to other farmers in the sector. (Dixon et al., 2004). Thus, the definition of a smallholder differs between countries and between agro-ecological zones. Smallholders in many developing countries are responsible for very high proportions of food and cash crop production, for example in Nigeria they account for 90% of rice, wheat, cotton, cocoa and other food crops (Jazaïry et al., 1992). In Kenya, smallholder systems average 0.2–0.3 ha in size, account for 75% of the total agricultural output and 70 % of marketed agricultural products (Hickey et al., 2012). Smallholder systems are characterized by livelihood strategies that have been evolved to adapt and cope with high rainfall variability, especially in marginal environments. There is consensus of its multiple functional roles arising from multiple benefits from food, fibre and medicines, cultural heritage, water and environmental services. This promotes the ability of smallholders to build more resilient and sustainable agriculture systems as a crucial response to the global food, water and climate crisis.

To achieve food security especially with the additional challenge of climate change, attention is imperative towards smallholder farming, its practices and technologies for adaptation and mitigation. It is now recognized that investment in smallholder agriculture is essential to ending poverty and hunger (UN, 2008; World Bank, 2008), especially as they account for over 75% of global food production (Altieri, 2008). An important feature of small and diversified farms is their high productivity per unit area as compared to large monocultures given the same level of management (Altieri, 2009; Barrett et al., 2010; Horlings and Marsden, 2011). For instance, studies in Mexico found that a 1.73 ha plot of land has to be planted with maize monoculture to produce as much food as one hectare planted with a mixture of maize, squash and beans (Altieri and Toledo, 2011). With low level of external inputs, especially in Africa (Bashir, 2008), the diminishing availability of agriculturally productive land, and the need to minimize further loss and degradation of natural habitats such as forests, wetlands, and long-term pastures, calls for strategies that have the capacity of achieving higher yields per unit, which small farms can provide. Not only do small-medium-sized farms exhibit higher yields than conventional farmers, but are more efficient, conserve natural resources and biodiversity better and contribute more to economic development than do large farms (Altieri, 2008).

Traditional knowledge and technology exhibited by farmers in smallholder systems has in the past enabled them produce sustained yields with minimal external inputs and faced with climate variability. This can serve as a key source of information on adaptive capacity and resilient capabilities exhibited by small farms, features of strategic importance for world farmers to cope with climatic change. While industrial agriculture contributes directly to climate change through green house gas emissions, small farms on the converse increase sequestration of carbon in soils and most significantly use less fossil fuels (Altieri, 2008).

As compared to intensified agriculture, smallholder agricultural systems have remained under considered; yet, they are fundamental to food security for many societies and can provide innovative approach based on ancestral and experienced ways to mitigate negative effects of an increasing climatic variability. Many have considerable resources with which they manage the increased risks that climate change brings. These resources are biological, technological, as well as social in nature and have developed a great diversity of tools and strategies to cope with many acute and simultaneous changes. Among the most important resources farmers have is the diverse and constantly evolving agro biodiversity that they own, manage, and use (Jackson et al., 2007). The diverse crop varieties that smallholders commonly combine in their gardens, fields and agro forests have long helped them to adapt to a broad range of natural, economic and social changes. This diversity and the processes of adaptation of these agro biodiversity resources offer flexibility and resilience that larger and more specialized farms often do not have, and can confer an advantage on the small farmer in times of stress.

Understanding the dynamics of these farming systems especially those under rain-fed agriculture is critical in improving their production and in achieving food security. If food security remains for the present day a challenge, vis-à-vis climate variability, smallholders' agriculture with its high level of crop genetic diversity could provide useful strategies, which were historically experienced and improved by farmers.

The challenge of intensified agriculture is not different from smallholder agriculture as both have to forestall or reverse the negative impact of climate variability on crop diversity while increasing the productivity on the short and long term. With climate change, climate variability is expected to increase having a significant consequence on both intensified and smallholders' food production. The impacts of a changing climate on agricultural production in a world that warms by 4◦C or more are likely to be severe, if not critical. For most areas in Sub-Saharan Africa, the outcome is bleak with loss in the length of the growing season, reduced crop productivity and enhanced water stress (Mertz et al., 2009; Thornton et al., 2011). Few studies have been dedicated to smallholder agricultural systems as possible source of innovation for worldwide agricultural economy.

1.2 The role of biodiversity for food security and human well-being

Biodiversity is a term that is used to define the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 1992; CBD, 2003; IUCN, 1990; WWF et al., 1993). The erosion of diversity comprising genes, species and ecosystems which play a crucial role in feeding the population is of great concern. McNeely notes that since the beginning of the 20th century alone, in traditional agrosystems, about 75% of genetic diversity of the most important crops has disappeared from farmers' fields (McNeely, 1995). With the loss of biodiversity, communities will become more vulnerable because options for change may be diminished (Huq and Reid, 2005; WEHAB, 2002).

The human population depends on biodiversity in the mitigation and adaptation of the effects of climate change. The Global Crop Diversity Trust recognizes crop diversity as being fundamental to protecting the environment, defeating hunger and achieving food security and the only way to guarantee that farmers and plant breeders will have the raw materials needed to improve and adapt their crops to meet challenges of a changing climate and a growing population (Global crop diversity trust, 2012). The prevalence of complex and diversified cropping systems is usually highlighted as of key importance to the stability of the farming systems (Chapin et al., 2000; Cleveland et al., 1994; Kotschi, 2006; Schiere et al., 2006; Walker et al., 1999). A survey conducted in Central American hillsides after Hurricane Mitch showed that farmers using diversification practices such as cover crops, intercropping and agroforestry suffered less damage than their conventional monoculture neighbors (Altieri and Toledo, 2011). Diversified cropping systems allow crops to reach acceptable productivity levels in the midst of environmentally stressful conditions. As different crops respond differently to climate variability, cultivating diverse crops can decrease the vulnerability of farmers to climate variability (Fraser et al., 2005; Reidsma and Ewert, 2008). At the same time, it stabilizes yields over the long term, even with low levels of technology and limited resources (Altieri, 2009; Altieri and Toledo, 2011). High-diversity systems provide important ecosystem services such as pollination and pest and disease control (Fadda et al., 2011; Tonhasca and Byrne, 1994a; Tscharntke et al., 2005). The degree of genetic variability within species is also important for maintaining ecosystem performance and for allowing continued adaptation to changing conditions (CBD, 2003). Therefore, the possibility exists that the loss of within-species genetic variation could also lead to instability in the face of a changing environment. Biodiversity may guarantee ecological resilience, i.e., the capacity to recover after disruption of functions, and the mitigation of risks caused by disturbance (Tschakert, 2007; Tscharntke et al., 2005; Tscharntke et al., 2012). One example is the use of diverse traditional varieties of crops. In many agro ecosystems throughout the world, particularly in developing countries, farmers continue to use traditional local varieties (or landraces) of both major and minor crops (Jackson et al., 2007). In the drylands of Africa, there are a wide range of wild plants which play a significant role in the subsistence economy. The Tswana are able to survive at the peak of the drought in the Kalahari by use of a diversified food base with emphasis on wild food plants (Grivetti, 1979). It was expected that traditional crop varieties would rapidly disappear in the face of new high yielding cultivars, but these have continued to dominate production especially in smallholder farms grown together with modern cultivars (Cleveland et al., 1994). It has been suggested inter alia that traditional varieties provide yield stability, are resistant to biotic and abiotic stress, have good resilience, and are adapted to low input agriculture (Altieri, 2004; Frison et al., 2011; Jackson et al., 2007). Local crop varieties provide about 39% of the resistant varieties used in the breeding programmes of major crops such as maize, wheat, soybean, sorghum and barley (Fadda et al., 2011). In addition, intra-specific diversity especially of local crop varieties provides resistant varieties, and has been employed by small scale farmers as a disease management strategy in genetically diverse systems (Platform for Agrobiodiversity Research, 2012). Hence, they constitute a key component of the natural resources assets in many parts of the world.

People most vulnerable to climate change are also those that greatly depend on biodiversity. First, they are the ones who rely the most on the biodiversity of natural ecosystems in terms of food security and sustained access to medicinal products, fuel, construction materials, and protection from natural hazards. Second, because of their low economic and political power, they cannot substitute purchased goods and services for the lost ecosystem benefits (Díaz et al., 2006).

Achieving efficient and productive agricultural land use while conserving biodiversity represents one of the greatest scientific challenges facing humankind because of the trade-offs among competing economic and environmental goals, and inadequate knowledge of the key biological, biogeochemical and ecological processes (Tilman et al., 2002; Tscharntke et al., 2012). Increasing food production must be complemented by polices to enhance food access and promote environmental sustainability (FAO, 2009). Future increases in food production must be done in an environmentally safe manner through ecological intensification (Horlings and Marsden, 2011; Roberts, 2009). For resilient and productive smallholder systems, focus must be on intensifying production with preservation of functional diversity, reduction in external inputs such as pesticides and fertilizers and the promotion of use of locally available materials such as crop residues, farm manure, and compost to improve soil fertility (Pinstrup-Andersen et al., 1999).

1.3 Food security and climate variability

Agriculture is highly dependent on climate conditions, and obvious impacts on food security are expected with climatic changes (Scialabba and Müller-Lindenlauf, 2010). The most relevant climate change-related factors to agriculture are the rise in temperature, changes in precipitation patterns, increase in greenhouse gases and increased incidence of extreme weather events (Kotschi, 2006; Kotschi, 2007).

Although the distinction between ‘climate change’ and ‘climate variability’ has been brought out in many different ways, the common distinction is based on time scale. The IPCC (IPCC, 2007), distinguishes ‘climate variability’ as variations in the climate system over short time scales such as months, years or decades, and ‘climate change’ as longer term trends in mean climate variables of periods of several decades or longer. An alternative definition by United Nations Framework for the Convention of Climate Change focuses on causes of variation in the climate and posits that ‘climate variability’ relates to natural variations in the climate and ‘climate change' relates to human induced variations in the climate. Climate variability can also be understood as variations in the prevailing state of the climate on all temporal and spatial scales beyond that of individual weather events (O'Brien and Leichenko, 2000). For Africa, it is determined by prevailing patterns of sea surface temperature, atmospheric winds, regional climate fluctuations in the Indian and Atlantic Oceans, and by the El Niño Southern Oscillation (ENSO) phenomenon; the natural shift in ocean currents and winds off the coast of South America which occurs every two to seven years. ENSO events bring above average rainfall to some regions and reduced rainfall to others (UNEP, 2002).

Expected repercussions of climate change are twofold, biophysical and socio-economic. Bio-physical impacts include rising sea waters, more frequent and intense storms, the extinction of species, worsening droughts and crop failure (Mubaya et al., 2010). Socio-economic impacts include effects on agriculture and food security, fresh water supply and quality, tourism, human health, human settlement and financial services such as increasing levels of poverty (IPCC, 2001; UNFCCC, 2007). The social-economic and bio-physical impacts have multiple linkages aggravating critical stress levels. For instance, access to food can be linked to rising temperatures, drought and environmental degradation (FAO, 2010b; Koch et al., 2006). Many authors report of an average increase in surface temperatures over most of Africa, Asia and Latin America (Kotschi, 2007; UNFCCC, 2007), and more intense and longer droughts have been observed in the dry tropics and subtropics (Kotschi, 2007; O'Brien and Leichenko, 2000). Rising temperatures will cause changes in the distribution of disease vectors putting more people at risk from diseases such as malaria and dengue fever (UNFCCC, 2007; World Bank, 2012).

Climate variability and change are a major threat to food security in many regions especially in the developing world, where agriculture is dependent on rainfall (IPCC, 2001; Parry et al., 2004; Ziervogel et al., 2006). The anticipated impact of global warming by 2080 on crop yields is expected to have far reaching effects especially in developing countries that have less capacity to adapt as opposed to the richer countries. A number of regional and national studies have highlighted the possible negative impacts of current climate variability and future change on agricultural productivity (Rao et al., 2011).Countries closer to the equator will experience a greater decline in agricultural productivity, with expected losses over eastern Africa ranging 5 to 25 percent (Cline, 2008). In Africa, climate change will affect food and water resources, much agricultural land will be lost with shorter growing seasons and lower yields (UNFCCC, 2007). In subtropical Eastern Africa, warming temperatures are projected to cause more frequent and more intense extreme weather events, such as heavy rain storms, flooding, fires, hurricanes, tropical storms and El Niño events (IPCC, 2001). In Tanzania and East Africa at large, there has already been observed a decline in long-cycle crops and rainfall between March and May from 1996 to 2003 (Funk et al., 2005). Effects of climate change will further adversely affect food security and exacerbate malnutrition in the affected areas. Because of the lack of economic, development, and institutional capacity, African countries are likely among the most vulnerable to the impacts of climate change (O'Brien and Leichenko, 2000).

Climate change, biodiversity and human well being are inextricably linked. Climate change has an impact on reducing biodiversity, and on the other hand, the effects of climate change on the human population can be reduced by the use of biodiversity (CBD, 2009). Climate change impacts on biodiversity has been identified with the IPCC (IPCC, 2007) concluding that temperature increases exceeding 1.5-2.5^{0}C will likely expose 20-30% of plant and animal species to extinction. Approximately 10% of species assessed so far will be at an increasingly high risk of extinction for every 1°C rise in global mean temperature, within the range of future scenarios (typically <5°C global temperature rise) modelled in impacts assessments (CBD, 2009). Biodiversity plays a role in the long term ability of the ecosystems to regulate climate, biodiversity loss may amplify climate warming leading to unforeseen shifts in earth systems.

Rainfall is a critical input to the success of a crop's growing cycle and to realize yields. Crops require adequate soil moisture for seedling emergence and throughout the vegetative and reproductive phases. The important characteristics of rainfall influencing production are the date of onset, the duration and frequency of wet spells and the dates of occurrence and of intervening dry spells (Maracchi et al., 1993). Dry spells induce water stress to the newly emerging seedlings contributing to seedling mortality forcing a re-sowing and possibly the choice of another variety (Araya and Stroosnijder, 2011). At the time of flowering dry spells result in poor seed filling and significant yield losses (Kouressy et al., 2008; Sultan et al., 2005). The performance of a given rainy season, for optimal crop growth, does not only lie in the overall total amount, but requires an adequate distribution of the rains (Camberlin et al., 2009). Rains that are considered to be "bad" by farmers from an agricultural point of view are; low total precipitation amounts for the season, prolonged dry spells separating the wet spells, high number of dry spells, delayed onset of rains and an early cessation of rainfall. Prolonged dry spells during the wet season are common and are a significant cause of seed losses. Studies carried in north eastern Ethiopia reported that frequent dry spells of about 10 days length is a major cause of crop failure (Araya et al., 2010; Segele and Lamb, 2005). Barron et al., 2003, further reported that dry spells longer than five days are seasonal occurrences in semi-arid locations in east Africa affecting yields negatively.

1.4 Adaptation of human societies to climate change and variability

Throughout the history of society, communities have adapted to climate variability through different ways. Adaptation has been defined by various authors as follows: adaptation to climate change and variability includes changes in management activities to enable effective response to the changes in climate that may occur (Cooper et al., 2008); adaptation refers also to adjustment in practices, processes or structures of systems to projected or actual changes in climate. It can be spontaneous or planned (Watson et al., 1996); yet, adaptation is an adjustment in the use of resources in relation to climate stress (Eriksen and Lind, 2009); or, adaptation is an adjustment in social or economic systems made in response to actual or expected climate to reduce the vulnerability of society to change in climate system (Galvin et al., 2004); end, adaptation refers to any adjustment in natural or human systems that take place in response to actual or expected impacts of climate change, and intended either to moderate harm or to exploit beneficial opportunities (IPCC, 2001).

Individuals, communities and nations have over years adapted in varying degrees to climate uncertainties. Their coping and adaptation strategies include approaches such as livelihood diversification, altering the crop calendar, diversifying crop production, improved water management, planting trees, adjusting livestock stocking rates and migration of livestock (Jarvis et al., 2011; Kristjanson et al., 2012; Mortimore and Adams, 2001; Thomas et al., 2007b). For most smallholders, especially in Africa, crop diversity is an indispensable resource as a coping strategy. At the local level, farmers adapt their cropping patterns, in the context of diversified mix of crops and varieties which are crucial as a base for enhancing resilience. This also includes the use of a wide range of wild plants which play a significant role in the subsistence economy. For example the Tswana are able to survive at the peak of the drought in the Kalahari by use of a diversified food base with emphasis on wild food plants (Grivetti, 1979). In yet another study, Natarajan and Willey (1986) demonstrated that mixed cropping systems of sorghum/peanut and millet/peanut exhibited greater yield than in the case of mono-cropping, and that the relative differences in productivity between monocultures and polycultures became more accentuated with water stress. Kotschi, reported how acquiring camels which are more drought-resistant than cattle for labour, and growing minor millets which are more drought tolerant was adapted by farmers in the drylands of Ethiopia and India respectively to deal with drought (Kotschi, 2006).

The most common adaptation strategy employed in Kenya is the diversification of crops cultivated. Others include protection and planting of trees, moving livestock to other areas, irrigation and water harvesting, mulching, fertilizer and manure application and varying of planting dates (Nkonya et al., 2011). For instance, Rubyogo (1999) investigated farmers' crop variety ranking criteria in Kenya and reports the use of the following criteria : i) early maturity, ii) drought tolerant, iii) stable and if possible high yield, iv) pest/disease and weed tolerance and v) socio-economic criteria such as market production or household consumption. Farmers maintain different varieties of maize, sorghum and other crops for each of these objectives and value having agricultural biodiversity in their farming systems. Promotion of crop genetic diversity is part of farmer's coping strategies for mitigating weather unpredictability; it also reduces the so-called "hunger period" by spreading availability of food products over time. For example, in mixed farming, green leaves from cowpeas may be harvested as early as 21 days after sowing, whereas early green maize harvest is done at 60 days and late material at 120 days (Bonkoungou, 2001).

These studies suggest that more diverse plant communities are, more resilient to environmental perturbations. Maintaining the world's crop diversity, which was selected and improved by farmers over generations, is therefore extremely valuable in the light of on-going and anticipated climate change as well as in addressing future challenges in achieving food security for a population expected to double by 2050.

Traditional knowledge and practices, that is unique to a given culture or society and passed on from one generation to another by word of mouth and observation, is valuable in adjusting to climate variability (Nyong et al., 2007; Pareek and Trivedi, 2011; Stigter et al., 2005).

Traditional knowledge systems are developed over centuries, and include observing natural phenomena such as the growth of shoots on particular plants at certain times in the year, observation of moon and stars and insects and animal behavior (Aklilu and Wekesa, 2001; IRIN, 2011). For example, elders so-called *Hayyuu* of Borana pastoralists in Ethiopia using the phases of the moon and position of the stars, correctly forecasted the worst drought that devastated the Horn of Africa in 2011 (IRIN, 2011). Those pastoralists who followed the advices of *Hayyuu* sold a part of their herd before the drought and were able to minimize their herd loss. In the Rajasthan region of India, indigenous rain forecasters predict the nature of rainfall in the entire season by observing clouds for the monsoon and inform people about prospects for agriculture. This information is used for example in making decisions such as not to plough when heavy rains are predicted and converting hillsides to level terraces during a floods forecast (Pareek and Trivedi, 2011). In southern Uganda, farmers observe signs such as the flowering of trees, arrival of migratory birds, nighttime temperatures and the wind direction to predict the start of the rains for decisions about the crops that they select and the area and timing of planting (Orlove et al., 2010).

1.5 References cited in chapter 1

Aklilu Y., Wekesa M. (2001) *Livestock and livelihoods in emergencies: lessons learnt from the 1999-2001 emergency response in the pastoral sector in Kenya*. H. P. N. Paper, Nairobi and Medford. pp. 40.

Almekinders C. (2001) *Management of crop genetic diversity at community level. Conceptual elements and practical implementation*. GTZ, Eschborn. pp. 53.

Altieri M.A. (2004) Linking ecologists and traditional farmers in the search for sustainable agriculture. *Ecological Society of America* 2 (1),35-42.

Altieri M.A. (2008) *Small farms as a planetary ecological asset: five key reasons why we should support the revitalisation of small farms in the global south*. Third World Network, Penang, Malaysia. pp. 26.

Altieri M.A. (2009) Agroecology, small farms, and food sovereignty. *Monthly Review* 61 (3),102-113.

Altieri M.A., Koohafkan P. (2008) *Enduring farms: climate change, smallholders and traditional farming communities*. Third World Network, Penang, Malaysia. pp. 72.

Altieri M.A., Toledo V.M. (2011) The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. *Journal of Peasant Studies* 38 (3),587-612.

Araya A., Stroosnijder L. (2011) Assessing drought risk and irrigation need in northern Ethiopia. *Agricultural and Forest Meteorology* 151 (4),425-436. DOI: 10.1016/j.agrformet.2010.11.014.

Araya A., Keesstra S.D., Stroosnijder L. (2010) A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. *Agricultural and Forest Meteorology* 150,1047–1064.

Barrett C.B., Bellemare M.F., Hou J.Y. (2010) Reconsidering conventional explanations of the inverse productivity–size relationship. *World Development* 38 (1),88-97.

Barron J., Rockstrom J., Gichuki F., Hatibu N. (2003) Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural and Forest Meteorology* 117,23-37.

Bashir J., Gonzalo P. (2008) Agriculture in Africa: strategies to improve and sustain smallholder production systems. *Annals of the New York Academy of Sciences* 1136,218-232.

Berkes F., Folke C., Gadgil M. (1995) Traditional ecological knowledge, biodiversity, resilience and sustainability in: C. A. Perring (Ed.), Biodiversity Conservation, Kluwer Academic Publishers, Netherlands. pp. 281-299.

Bolwig S., Pomeroy D., Tushabe H., Mushabe D. (2006) Crops, trees, and birds: biodiversity change under agricultural intensification in Uganda’s farmed landscapes. *Danish Journal of Geography* 106 (2),115-130.

Bonkoungou E.G. (2001) *Biodiversity in drylands: challenges and opportunities for conservation and sustainable use*. IUCN-The Global Drylands Partnership, Lusaka, Zambia. pp. 20.

Borlaug N.E., Dowswell C.R. (2005) Feeding a world of ten billion people: a 21st century challenge, in: *International Congress "In the Wake of the Double Helix: From the Green Revolution to the Gene Revolution"*, 27–31 May 2003,Bologna, Italy,3–23.

Brooks S., Thompson J., Odame H., Kibaara B., Nderitu S., Karin F., Millstone E. (2009) *Environmental change and maize innovation in Kenya: exploring pathways in and out of maize*, Brighton. pp. 67.

Buchanan G.M., Donald P.F., Fishpool L.D.C., Arinaitwe J.A., Balman M., Mayaux P. (2009) An assessment of land cover and threats in important bird areas in Africa. *Bird Conservation International* 19 (1),49-61.

Camberlin P., Moron V., Okoola R., Philippon N., Gitau W. (2009) Components of rainy seasons' variability in equatorial east Africa: onset, cessation, rainfall frequency and intensity. *Theoretical and Applied Climatology* 98,237-249. DOI: 10.1007/s00704-009-0113-1.

CBD. (1992) Article 2. Use of Terms.http://www.biodiv.org/convention/articles.asp. [April 3, 2012].

CBD. (2003) *Interlinkages between biological diversity and climate change*. Secretariat of the Convention on Biological Diversity, Montreal. pp. 143.

CBD. (2009) *Connecting biodiversity and climate change mitigation and adaptation: report of the second ad hoc technical expert group on biodiversity and climate change*. Secretariat of the Convention on Biological Diversity, Montreal. pp. 126.

Ceccarelli S., Grando S., Booth R.H. (1995) International breeding programmes and resource-poor farmers: crop improvement in difficult environments,in: *Participatory Plant Breeding*, 26–29 July,Wageningen, The Netherlands,99–116.

Chapin F.S., Zavaleta E.S., Eviner V.T., Naylor R.L., Vitousek P.M., Reynolds H.L., Hooper D.U., Lavorel S., SalaI O.E., Hobbie S.E., Mack M.C., Díaz S. (2000) Consequences of changing biodiversity. *Nature* 405,234-242.

Cleveland D.A., Soleri D., Smith S.E. (1994) Do folk crop varieties have a role in sustainable agriculture? *BioScience* 44 (11),740-751.

Cline W.R. (2008) "Global warming and agriculture ", *Finance and Development (*March, 2008*)*. International Monetary Fund. 45 (1),23-27.

Cooper P.J.M., Dimes J., Rao K.P.C., Shapiro B., Shiferaw B., Twomlow S. (2008) Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: an essential first step in adapting to future climate change? *Agriculture, Ecosystems & Environment* 126 (1-2),24-35. DOI: 10.1016/j.agee.2008.01.007.

Darkoh M.B.K. (2003) Regional perspectives on agriculture and biodiversity in the drylands of Africa. *Arid Environments* 54,261–279.

De Groote H., Doss C., Lyimo S.D., W. M. (2002) Adoption of maize technologies in east Africa - what happened to Africa's emerging maize revolution?, in: *FASID Forum V, "Green revolution in Asia and its transferability to Africa"*, December 8-10,Tokyo,1-18.

Devereux S., Edwards J. (2004) Climate change and food security. *IDS Bulletin* 35 (3),22-30.

Díaz S., Fargione J., Stuart C.F., Tilman D. (2006) Biodiversity loss threatens human well-being. *PLoS Biology* 4 (8),1300-1305.

Dixon J., Taniguchi K., Wattenbach H., Tanyeri-Arbur A. (2004) *Smallholders,globalization and policy analysis*. Food and Agriculture Organization of the United Nations, Rome. pp. 98.

Donald P.F., Green R.E., Heath M.F. (2001) Agricultural intensification and the collapse of Europe's farmland bird populations. *Philosophical Transactions of the Royal Society B: Biological Sciences* 268,25-29.

Donald P.F., Sanderson F.J., Burfield I.J., van Bommel F.P.J. (2006) Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990-2000. *Agriculture, Ecosystems & Environment* 116,189-196.

Eriksen S., Lind J. (2009) Adaptation as a political process: adjusting to drought and conflict in Kenya's drylands. *Environmental Management* 43,817-835. DOI: 10.1007/s00267-008-9189-0.

Fadda C., De Santis P., Jarvis D. (2011) Can agrobiodiversity be part of pest and disease management? Asking the right questions. *Crop Biodiversity to Reduce Pest and Disease Damage*.http://agrobiodiversityplatform.org/cropbiodiversity/2011/07/28/can-biodiversity-be-part-of-pest-and-disease-manage-asking-the-right-questions/. [February 07, 2012].

FAO. (1996) *Report on the state of the world's plant genetic resources for food and agriculture*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 29.

FAO. (2009) *How to feed the world in 2050*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 35.

FAO. (2010a) CF p40? *Gardens of Biodiversity. Conservation of genetic resources and their use in traditional food production systems by small farmers of the southern caucasus*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 391.

FAO. (2010b) cfp40? *Analysis of climate change and variability risks in the smallholder sector. Case studies of the Laikipia and Narok districts representing major agro-ecological zones in Kenya*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 84.

FAO. (2011) Drought-related food insecurity: a focus on the horn of Africa, in: *Emergency in the horn of Africa: Follow-up and response actions*, 18 August,Rome, Italy,1-7.

FAO. (2012) *FAOSTAT database on agriculture*.Food and Agriculture Organisation of United Nations. http://faostat.fao.org/site/567/default.aspx#ancor. [July 25, 2012].

Firbank L.G., Petit S., Smart S., Blain A., Fuller R.J. (2008) Assessing the impacts of agricultural intensification on biodiversity: a British perspective. *Philosophical Transactions of the Royal Society B: Biological Sciences* 1492,777-787.

Flohre A., Fischer C., Aavik T., Bengtsson J., Berendse F., Bommarco R., Ceryngier P., Clement L.W., Dennis C., Eggers S., Emmerson M., Geiger F., Guerrero I., Hawro V., Inchausti P., Liira J., Morales M.B., Oñate J.J., Pärt T., Weisser W.W., Winqvist C., Thies C., Tscharntke T. (2011) Agricultural intensification and biodiversity partitioning in European landscapes comparing plants, carabids, and birds. *Ecological Applications* 5,1772-1781.

Fraser E., Mabee W., Figge F. (2005) A framework for assessing the vulnerability of food systems to future shocks. *Futures* 37 (6),465-479.

Frison E.A., Cherfas J., Hodgkin T. (2011) Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability* 3,238-253.

Funk C., Senay G., Asfaw A., Verdin J., Rowland J., Michaelson J., Eilerts G., Korecha D., Choularton R. (2005) *Recent drought tendencies in Ethiopia and Equatorial - subtropical eastern Africa*. FEWS-NET, Washington, DC. pp. 15.

Galvin K.A., Thornton P.K., Boone R.B., Sunderland J. (2004) Climate variability and impacts on east African livestock herders: the Maasai of Ngorongoro conservation area, Tanzania. *African Journal of Range and Forage Science* 21 (3),183-189.

Gavier-Pizarro G.I., Calamari N.C., Thompson J.J., Canavelli S.B., Solari L.M., Decarre J., Goijman A.P., Suarez R.P., Bernardos J.N., Zaccagnini M.E. (2011) Expansion and intensification of row crop agriculture in the Pampas and Espinal of Argentina can reduce ecosystem service provision by changing avian density. *Agriculture, Ecosystems & Environment* 154,44-55.

Global Crop Diversity Trust. (2012) Crop Diversity. *Our mission*.http://www.croptrust.org/main/ldiversity.php. [February 1, 2012].

Godfray H.C.J., Beddington J.R., Crute I.R., Haddad L., Lawrence D., Muir J.F., Pretty J., Robinson S., Thomas S.M., Toulmin C. (2010) Food security: the challenge of feeding 9 billion people. *Science* 327,812-818.

Gregory R.D., van Strien A.J., Vorisek P., Gmelig Meyling A.W., Noble D.G., Foppen R.P.B., Gibbons D.W. (2005) Developing indicators for European birds. *Philosophical Transactions of the Royal Society B: Biological Sciences* 360,269-288.

Grivetti L.E. (1979) Kalahari agro-pastoral hunter-gatherers: the Tswana example. *Ecology of Food and Nutrition* 7 (4),235–256.

Haile M. (2005) Weather patterns, food security and humanitarian response in sub-Saharan Africa. *Philosophical Transactions of the Royal Society B: Biological Sciences* 360,2169-2182.

Hickey G.M., Pelletier B., Brownhill L., Kamau G.M., Maina I.N. (2012) Preface: challenges and opportunities for enhancing food security in Kenya. *Food Security* 4,333–340. DOI: 10.1007/s12571-012-0203-2.

Horlings L.G., Marsden T.K. (2011) Towards the real green revolution? Exploring the conceptual dimensions of a new ecological modernisation of agriculture that could 'feed the world'. *Global Environmental Change* 21 (2),441-452.

Huq S., Reid H. (2005) *Climate change and development: consultation on key researchable issues*. International Institute for Environment and Development, London, UK. pp. 33.

IITA. (2009) Maize.http://www.iita.org/maize. [June 11, 2012].

IPCC. (2001) *Climate change 2001: impacts, adaptation, and vulnerability. Contribution of working group II to the third assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, UK. pp. 1032.

IPCC. (2007) *Climate change 2007.Mitigation of climate change: working group III contribution to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, UK. pp. 862.

IRIN. (2011) Ethiopia: Borena zone braced for more failed rains. *Humanitarian news and analysis*.http://www.irinnews.org/report.aspx?reportid=93247. [March 23, 2012].

IUCN. (1990) *Biodiversity in sub-Saharan Africa and Its Islands: conservation, management, and sustainable use*, Gland, Switzerland. pp. 277.

Jackson L.E., Pascual U., Hodgkin T. (2007) Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agriculture, Ecosystems and Environment* 121 (3),196-210. DOI: 10.1016/j.agee.2006.12.017.

Jarvis A., Lau C., Cook S., Wollenberg E.V.A., Hansen J., Bonilla O., Challinor A. (2011) An integrated adaptation and mitigation framework for developing agricultural research: synergies and trade-offs. *Experimental Agriculture* 47 (02),185-203. DOI: 10.1017/s0014479711000123.

Jayne T.S., Jones S. (1997) Food marketing and pricing policy in Eastern and Southern Africa: a survey. *World Development* 25 (9),1505-1527.

Jazaïry I., Alamgir M., Panuccio T. (1992) *The State of world rural poverty: an inquiry into its causes and consequences*. International Fund for Agricultural Development, Rome, Italy.

Kendall H.W., Pimentel D. (1994) Constraints on the expansion of the global food supply. *Ambio* 23 (3),198-205.

Koch I.C., Vogel C., Patel Z. (2006) Institutional dynamics and climate change adaptation in South Africa. *Mitigation and Adaptation Strategies for Global Change* 12,1323–1339.

Kotschi J. (2006) Coping with climate change and the role of agrobiodiversity,in: *Conference on International Agricultural Research for Development*, October 11-13,University of Bonn, Tropentag,1-7.

Kotschi J. (2007) Agricultural biodiversity is essential for adapting to climate change. *GAIA-Ecological perspectives for science and society* 16 (2),98-101.

Kouressy M., Dingkuhn M., Vaksmann M., Heinemann A.B. (2008) Adaptation to diverse semi-arid environments of sorghum genotypes having different plant type and sensitivity to photoperiod. *Agricultural and Forest Meteorology* 148 (3),357-371. DOI: 10.1016/j.agrformet.2007.09.009.

Kristjanson P., Neufeldt H., Gassner A., Mango J., Kyazze F.B., Desta S., Sayula G., Thiede B., Forch W., Thornton P.K., Coe R. (2012) Are food insecure smallholder households making changes in their farming practices? Evidence from east Africa. *Food Security* 4 (3). DOI: 10.1007/s12571-012-0194-z.

Maracchi G., Bacci L., Cantini C., Haimanot M.T. (1993) Effect of water deficit in vegetative and post-flowering phases on pearl millet grown in controller environment. *Agricoltura Mediterranea* 123,65-71.

Mazunda J., Droppelmann K. (2012) *Maize consumption estimation and dietary diversity assessment methods in Malawi*. International Food Policy Research Institute. pp. 4.

McCann J. (2001) Maize and grace: history, corn, and africa's new landscapes, 1500–1999. *Comparative Studies in Society and History* 43 (2),246-272. DOI: 0010-4175/01/246–272.

McNeely J.A. (1995) Biodiversity conservation and traditional agrosystems, in: R. E. Saunier and R. A. Meganck (Ed.), *Conservation of Biodiversity and the New Regional Planning*, Organization of American States and the IUCN (The World Conservation Union), Gland, Switzerland. pp. 21–31.

Meiera P., Bond D., Bond J. (2007) Environmental influences on pastoral conflict in the horn of Africa *Political Geography* 26 (6),716–735.

Mertz O., Halsnæs K., Olesen J.E., Rasmussen K. (2009) Adaptation to climate change in developing countries. *Environmental Management* 43 (5),743-752. DOI: 10.1007/s00267-008-9259-3.

Millennium Ecosystem Assessment. (2005) *Ecosystems and human well-being: biodiversity synthesis*. World Resources Institute, Washington, DC. pp. 100.

Miracle M.P. (1965) The Introduction and spread of maize in Africa. *Journal of African History* 6 (1),39-55.

Mortimore M.J., Adams W.M. (2001) Farmer adaptation, change and 'crisis' in the Sahel. *Global Environmental Change* 11,49-57.

Mubaya C.P., Njuki J., Liwenga E., Mutsvangwa E.P., Mugabe F.T. (2010) Perceived impacts of climate related parameters on smallholder farmers in Zambia and Zimbabwe *Sustainable Development* 12 (5),170-186.

Natarajan M., Willey R.W. (1986) The effects of water stress on yield advantages of intercropping systems. *Field Crops Research* 13,117–131.

Nkonya E., Place F., Pender J., Mwanjololo M., Okhimamhe A., Kato E., Crespo S., Ndjeunga J., Traore S. (2011) *Climate risk management through sustainable land management in sub-Saharan Africa*. International Food Policy Research Institute, Washington DC. pp. 88.

Nyong A., Adesina F., Osman Elasha B. (2007) The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change* 12 (5),787-797. DOI: 10.1007/s11027-007-9099-0.

Nyoro J.K., Ayieko M., Muyanga M. (2007) The compatibility of trade policy with domestic policy interventions affecting the grains sector in Kenya,in: *FAO's workshop on trade and policy for food products conducive to development in eastern Africa*, March,1-2 Rome, Italy,1-24.

O'Brien K.L., Leichenko R.M. (2000) Double exposure: assessing the impacts of climate change within the context of economic globalization. *Global Environmental Change* 10,221-232.

Oram P. (1995) *The potential of technology to meet world food needs in 2020*. International Food Policy Research Institute, Washington, DC. pp. 2.

Orlove B., Roncoli C., Kabugo M., Majugu A. (2010) Indigenous climate knowledge in southern Uganda: the multiple components of a dynamic regional system. *Climatic change* 100,243–265.

Orr A., Mwale B., Saiti D. (2001) Market liberalisation, household food security and the rural poor in Malawi. *European Journal of Development Research* 13 (1),47-69.

Pareek A., Trivedi P.C. (2011) Cultural values and indigenous knowledge of climate change and disaster prediction in Rajasthan, India. *Indian Journal of Traditional Knowledge* 10 (1),183-189.

Parry M.L., Rosenzweig A., Iglesias M.L., Fischer G. (2004) Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change* 14,53-67.

Philpott S.M., Arendt W.J., Armbrecht I., Bichier P., Diestch T.V., Gordon C., Greenberg R., Perfecto I., Reynoso-Santos R., Soto-Pinto L., Tejeda-Cruz C., Williams-Linera G., Valenzuela J., Zolotoff J.M. (2008) Biodiversity loss in latin American coffee landscapes: review of the evidence on ants, birds, and trees. *Conservation Biology* 22 (5),1093-1105.

Pinstrup-Andersen P., Pandya-Lorch R., Rosegrant M.W. (1999) *World food prospects: critical issues for the early twenty-first century*. International Food Policy Research Institute, Washington, DC. pp. 30.

Platform for Agrobiodiversity Research. (2012) Crop biodiversity to reduce pest and disease damage.http://agrobiodiversityplatform.org/cropbiodiversity/about-2/the-project/. [February 3, 2012].

Qin L., Trouverie J., Chateau-Joubert S., Simond-Côte E., Thévenot C., Prioul J.-L. (2004) Involvement of the Ivr2-invertase in the perianth during maize kernel development under water stress. *Plant Science* 166 (2),371-379.

Rao K.P.C., Ndegwa W.G., Kizito K., Oyoo A. (2011) Climate variability and change: farmer perceptions and understanding of intra-seasonal variability in rainfall and associated risk in semi-arid Kenya. *Experimental Agriculture* 47 (2),267-291.

Reidsma P., Ewert F. (2008) Regional farm diversity can reduce vulnerability of food production to climate change. *Ecology and Society* 13(1) (38),13-16.

Roberts T.L. (2009) The role of fertilizer in growing the world's food. *Better Crops* 93 (2),12-15.

Rubyogo J.C. (1999) The role of farmers' seed management systems in developing a sustainable seed sector, in: *National Workshop on Agrobiodiversity* April, 16-17,Nairobi, Kenya,7-13.

Schiere J.B., Baumhardt A.L., Van Keulen H., Whitbread A.M., Bruinsma A.S., Goodchild A.V., Gregorini P., Slingerland M.A., Wiedemann-Hartwell B. (2006) Mixed crop-livestock systems in semi-arid regions, in: G. A. Peterson, et al. (Ed.), *Dryland Agriculture*, ASA, CSSA, and SSSA, Madison, WI. pp. 227-292.

Schrag A.M., Zaccagnini M.E., Calamari N., Canavelli S. (2009) Climate and land-use influences on avifauna in central Argentina: broad-scale patterns and implications of agricultural conversion for biodiversity. *Agriculture, Ecosystems & Environment* 132,135–142.

Scialabba N.E.-H., Müller-Lindenlauf M. (2010) Organic agriculture and climate change. *Renewable Agriculture and Food Systems* 25 (2),158-169. DOI: 10.1017/s1742170510000116.

Segele Z.T., Lamb P.J. (2005) Characterization and variability of Kiremt rainy season over Ethiopia. *Meteorology and Atmospheric Physics* 89,153–180.

Sinclair A.R.E., Mduma S.A.R., Arcese P. (2002) Protected areas as biodiversity benchmarks for human impact: agriculture and the Serengeti avifauna. *Proceedings of the Royal Society B: Biological Sciences* 269,2401-2405.

Smale M., Jayne T.S. (2003) *Maize in eastern and southern Africa: 'seeds' of success in retrospect*. International Food Policy Research Institute. pp. 90.

Stigter C.J., Dawei Z., Onyewotu L.O.Z., Xurong M. (2005) Using traditional methods and indigenous technologies for coping with climate variability. *Climatic change* 70,255-271.

Sultan B., Baron C., Dingkuhn M., Sarr B., Janicot S. (2005) Agricultural impacts of large-scale variability of the west African monsoon. *Agricultural and Forest Meteorology* 128 (1-2),93-110. DOI: 10.1016/j.agrformet.2004.08.005.

Thomas D.S.G., Twyman C., Osbahr H., Hewitson B. (2007) Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic change* 83 (3),301-322. DOI: 10.1007/s10584-006-9205-4.

Thornton P.K. (2010) Livestock production: recent trends, future prospects. *Philosophical Transactions of the Royal Society B* 365 (1554),2853-2867.

Thornton P.K., Jones P.G., Ericksen P.J., Challinor A.J. (2011) Agriculture and food systems in sub-Saharan Africa in a 4°C+ world. *Philosophical Transactions of the Royal Society, Series A* 369,117-136.

Tilman D., Lehman C. (2001) Human-caused environmental change: impacts on plant diversity and evolution. *Proceedings of the National Academy of Sciences* 98 (10),5433-5440.

Tilman D., Cassman K.G., Matson P.A., Naylor R., Polasky.S. (2002) Agricultural sustainability and intensive production practices. *Nature* 418 (6898),671-677. DOI: 10.1038/nature01014.

Tonhasca A., Byrne D.N. (1994) The effects of crop diversification on herbivorous insects: a metaanalysis approach. *Ecological Entomology* 19 (3),239-244.

Tschakert P. (2007) Views from the vulnerable: understanding climatic and other stressors in the Sahel. *Global Environmental Change* 17 (3-4),381-396. DOI: 10.1016/j.gloenvcha.2006.11.008.

Tscharntke T., Klein A.M., Kruess A., Steffan-Dewenter I., Thies C. (2005) Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. *Ecology Letters* 8,857–874.

Tscharntke T., Sekercioglu C.H., Dietsch T.V., Sodhi N.S., Hoehn P., Tylianakis J.M. (2008) Landscape constraints on functional diversity of birds and insects in tropical agroecosystems. *Ecology* 89 (4),944–951.

Tscharntke T., Clough Y., Wanger T.C., Jackson L., Motzke I., Perfecto I., Vandermeer J., Whitbread A. (2012) Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation* 151,53-59.

UN. (2008) High-Level task force on the global food security crisis.http://www.un.org/issues/food/taskforce/Documentation/CFA%20Web.pdf. [September 21, 2012].

UNEP. (2002) *Africa environment outlook: past, present and future perspectives*. Earthprint for and on behalf of the United Nations Environment Programme, Stevenage, Hertfordshire pp. 422.

UNFCCC. (2007) *Climate change: impacts, vulnerability and adaptation in developing countries*. United Nations Framework Convention on Climate Change, Bonn, Germany. pp. 68.

Vandermeer J., Perfecto I. (2007) The agricultural matrix and a future paradigm for conservation. *Conservation Biology* 21 (1),274–277.

Walker B., Kinzig A., Langridge J. (1999) Plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. *Ecosystems* 2,95-113.

Watson R.T., Zinyowera M.C., Moss R.H. (1996) (Ed.) *Climate change 1995: Impacts,adaptation and Mitigation of climate change: Scientific -Technical analysis.*

Contribution of working group II to the second Assessment Report of the Intergovernmental Panel on Climate change, Cambridge University Press, Cambridge, UK. pp. 889.

WEHAB. (2002) A framework for action on biodiversity and ecosystem management, in: *World summit on sustainable development*, 26 August - 4 September 2002,Johannesburg, South Africa,1-36.

Wichelns D. (2003) Policy recommendations to enhance farm-level use of fertilizer and irrigation water in sub-Saharan Africa. *Journal of Sustainable Agriculture* 23 (2),53-77.

World Bank. (2008) *World development report 2008: agriculture for development*. World Bank, Washington, DC. pp. 386.

World Bank. (2012) Adaptation to climate change in agriculture and natural resource management.http://climatechange.worldbank.org/climatechange/content/adaptation-climate-change-agriculture-and-natural-resource-management. [May 23, 2012].

WWF, The Nature Conservancy, USAID. (1993) *African Biodiversity: Foundation for the Future*. Professional Printing Inc, Beltsville, Maryland. pp. 149.

Ziervogel G., Nyong A., Osman B., Conde C., Cortes S., Downing T. (2006) *Climate variability and change:implications for household food security*. International START Secretariat, Washington, DC. pp. 34.

2 Crop diversity in an environmentally and socially contrasted site

Abstract

To consider crop diversity as offering an opportunity for the mitigation of climatic variability, we have to understand how several factors determine its distribution. This chapter identifies and measures crop and varietal diversity in an environmentally and socially contrasted site on the eastern slope of Mount Kenya, in order to draw policy implication for *in situ* conservation and management of genetic resources. Richness, evenness, effective number of species and Shannon-Wiener index are used to measure the on farm crop and varietal diversity of the studied area. In a survey of crop species among 243 smallholder farms, a total of 13 cultivated crop species, 53 varieties were recorded; there were on average 6.23 crop species per farm. Diversity evaluated based on the number of named varieties grown by the farmers varied and was significant along an altitudinal gradient. Cultural identity and age class did not significantly classify richness. Our data demonstrates that overall farm diversity is correlated to seed source. Social factors and the seed exchange networks should receive attention in biodiversity conservation efforts in the local farming systems. Maintaining varied seed sources and cultivating higher species diversity is necessary to support adaptation to the heterogeneous environment and in mitigating climate variability. This documentation is important information for scientists to monitor the crop genetic resources on-farm and for policy managers to develop long-term conservation strategies.

Introduction

The importance of agricultural biodiversity has widely been recognized as a biological basis for food security (chapter 1). The International Treaty on Plant Genetic Resources (2001), the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture (1996), and the Convention on Biological Diversity (1992), are international agreements that recognize the important role that genetic diversity conservation plays in current and future food and agriculture production. The Global Crop Diversity Trust also recognizes crop diversity as being fundamental to protecting the environment, defeating hunger and achieving food security and the only way to guarantee that farmers and plant breeders will have the raw materials needed to improve and adapt their crops to meet challenges of a changing climate and a growing population (Global crop diversity trust, 2012).In smallholder farms, representing 80% of all farms in Africa (Altieri, 2008), the diverse crop varieties in the gardens, fields and agro forests have long helped farmers adapt to a broad range of natural, economic and social changes. Crop diversity contributes to resilience in the farming system (Lin, 2011; Malézieux et al., 2009; Shava et al., 2009; Sthapit et al., 2006) and gives stability to ecosystems in the face of human induced environmental change (Heal, 1999). In addition, intra-specific diversity especially of local crop varieties provides resistant varieties, and has been employed by small scale farmers as a disease management strategy in genetically diverse systems (Platform for Agrobiodiversity Research, 2012). The main purpose of mixtures of varieties of the same crop, for pest and disease management is to slow down pest and pathogen spread (Fadda et al., 2011; Wolfe, 1985) through breaking the evolution of pest populations (Heisey *et al.*, 1997). In drought-prone areas where rain-fed agriculture is solely practiced, the reliance on crop genetic diversity is particularly important. As different crops respond differently to climate variability, cultivating diverse crops can decrease the vulnerability of farmers to climate variability (FAO, 2011b; Fraser et al., 2005; Reidsma and Ewert, 2008). Temporal stability of a natural ecosystem increases with increasing species diversity (Clarence and Tilman, 2000; Cleland, 2011; Tilman et al., 2006). Biodiversity is increasingly recognized as an essential resource on which families, communities, nations, and future generations depend (Cil and Jones-Walters, 2011; Cocks, 2006).

In the Kenyan dry-lands, farmers practice a multi-crops system with majority of the crops grown being landraces and this contributes to the farmer's livelihood strategies due to their adaptation to the local environment. A landrace has been defined as 'variable plant populations adapted to local agro climatic conditions which are named, selected and maintained by the traditional farmers to meet their social, economic, cultural and ecological needs' (Teshome et al., 1997).Farmers recognize the need to cultivate diverse crop species as a way to cope with environmental constraints that they are faced with from one season to another.

The conservation of crop diversity in farmers' fields, *in situ*, is necessary to cope with future production scenarios resulting from climate change. *In situ* conservation outweighs established ex situ collections in that the crop species is exposed and over time gets adapted to varying factors in the agricultural ecosystem, thereby may provide a solution to coping with climate change.

Crop genetic diversity can be measured at the level of crop varieties, agro-morphological traits, and genetic markers (Pham et al., 2011; Sthapit et al., 2006; Sthapit et al., 2004). Ecologists differentiate between alpha (the diversity in a particular area or ecosystem), beta (the change of species diversity between ecosystems) and gamma (the overall species diversity for different ecosystems within a region) (Houston, 1994; Magurran, 1988).On-farm crop diversity (alpha diversity) is often measured in terms of counting farmer-named varieties (Tripp, 1996) and reflects diversity in agro-morphological and adaptive traits of the named landraces (Sthapit et al., 2006).

Research on the crop diversity and dynamics has primarily focused on the overall diversity of the species at the local and regional level without taking into account the social context, and how crop diversity distribution is influenced by cultural differences and the seed exchange networks.

The approach we adopt in this study is to estimate empirically the distribution of landrace diversity in rain-fed agricultural systems among smallholder farms on the Eastern slope of Mount Kenya. Using a contrasted environment as defined by altitude and among different cultural groups we assess the amount and distribution of crop variety diversity over an altitudinal gradient and among different social groups, evaluate farmer's seed access and exchange networks and how their diversity can play a role in mitigation of climate variability. The analysis examines the diversity between the farmer's social groups and the environment in which they are living. Assessment of crop diversity, both principal crops and rare crops, helps us understand *in situ* conservation of the community and the role that this diversity can play in fostering resilience of the farming system to climatic shocks. It also helps us indentify crops which are most likely to be lost in the process of genetic erosion. The role is to represent an overview of crop diversity and explore the relation of observed diversity to environmental and social factors. Dynamic of diversity, notably caused by variety losses over time after drought, will be analyzed in following chapters

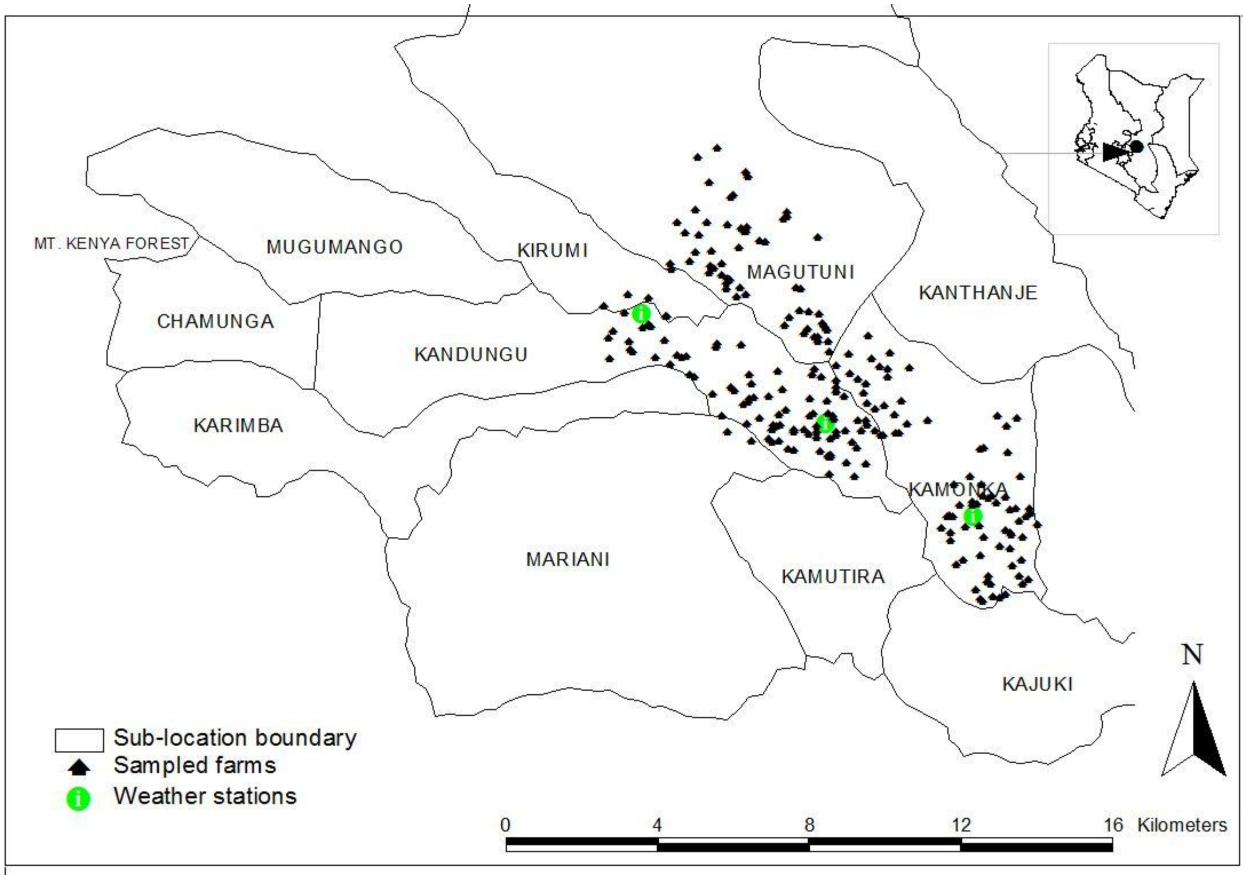
This knowledge gathered from a small scale will be essential to achieve a better understanding at a global scale of plant diversity patterns and in evaluating how crop diversity that is available to farmers can be useful in coping with climate variability. It will also help in informing conservation management decisions aimed at preserving biodiversity. Our aim was not to evaluate species similarity or differences between the communities, but to estimate empirically the distribution of crop and varietal diversity among smallholders on the Eastern slope of Mount Kenya. We assess diversity based on the variability of plant populations as reflected in their naming system (see section 2.3 for details).

2.2 Material and Methods

2.2.1 Crop surveys

On the eastern slope of Mount Kenya, farmers manage two cropping seasons per year corresponding to the Long Rains and to the Short Rains from March to May and from October to December, respectively (Camberlin et al., 2012).We conducted the crop surveys in 2009 at three altitudinal levels; 750, 950 and 1100 m (hereafter referred to as lowlands, midlands and highlands) along the Eastern slopes of Mount Kenya. A total of 243 households were sampled in 4 sub-locations. Farmer sampling strategy at midlands aimed at having a favourable representation of the two farmers' cultural communities, namely Mwimbi and Tharaka. At lowlands and highlands, we sampled the Tharaka and Mwimbi communities respectively. Within each sub-location households were selected at random. Crop named varieties distinguished by farmers and cultivated by each household during the two main crop growing rainy seasons were inventoried, including their seed source. Social information (age, origin and ethnic affiliation) of the respondent was also collected. Seed sources for all varieties mentioned by each respondent were recorded to gain a general picture and understanding of farmer seed management and crop genetic resources conservation. The location of each household (Figure 2.1) was recorded using a GPS (Trimble GeoXM ^{TM}).

Figure 2.1. Map showing location of the study site with households surveyed. An automatic weather station was installed at each of the three altitudinal levels.



2.3 Data analysis

Basic data were summarized as lists of crop species. To characterize the community crop composition, we adopted several measures: (1) species richness (number of species, i.e. alpha diversity); (2) species diversity according to Shannon index (Shannon, 1948); (3) species evenness (as a complement of the Shannon index, i.e. alpha diversity); (4) effective number of species;

To apply the concepts of richness and evenness on local varieties names, a further investigation in a participatory way was held with farmers to determine the identity of their varieties and consistency of the names. During farm visits verification of named varieties was carried out based on plant morphological traits or seed characteristics from farmer's samples. Discussions were held with the household members and in farmer groups to evaluate consistency in naming and describing varieties by comparing information from farmer households and different groups (gender, ethnic and age classes). This aimed at ascertaining the presence of synonyms (different names among the different cultural groups for the same variety) and categorical names (same name for different varieties), and control this effect into the analysis. For synonyms, we used the most prevalent name in our analysis, while varieties with categorical names were eliminated from the analysis.

2.3.1 Richness

Richness, *S*, was obtained by taking into count of the number of varieties for each crop species found in the community. At the farm level, the average species richness was calculated by obtaining an average of the sum of richness for all farms by the number of farms that were cultivating the crop in consideration.

$\mathrm{S = count\ of\ varieties}$

2.3.2 Shannon diversity Index (H')

This is an index that combines both richness (count) and relative abundance (or evenness) concepts and sometimes called heterogeneity index for this reason (Benin et al., 2004; Peet, 1974).

The Shannon-Wiener index was calculated as: $H' = -\sum_{i=1}^{s}(pi)(\ln pi)$ (Magurran, 1988), where

p_i = proportion of individuals of species *i* in community (= n_i /N; where n is the number of individuals of a given species and N is the total number of individuals in a sample).

2.3.3 Evenness

Using species richness (***S***) and the Shannon-Wiener index (*H'*), the measure of evenness, which is the ratio of observed diversity to maximum diversity, is calculated as: $\mathbf{E = \boldsymbol{H'} / \ln(\boldsymbol{S})}$,

(Magurran, 1988). Evenness (*E*) is a measure of how similar the abundances of different species are. When there are similar proportions of all subspecies then evenness is one, but when the abundances are very dissimilar (some rare and some common species) then the value increases (Heip, 1974).

2.3.4 Effective number of species

The effective number of species of a diversity index is the number of equally-likely elements needed to produce the given value of the diversity index (Hill, 1973; Jost, 2006). It has been argued that the effective number of species should be taken as the true measure of species diversity. The Shannon index is converted to effective number of species by taking its exponential; $\mathrm{D}(H') = \exp(-\sum_{i=1}^{s} pi \ln pi)$, (Jost, 2006; Jost, 2007; MacArthur, 1965).

2.3.5 Comparison of diversity between different communities

Differences in diversity between categories were evaluated using ANOVA. In making our interpretations we focus mainly on the effective number of species as it gives the "true" diversity of the community in question, with common behaviours and properties (Jost, 2006; Jost, 2009; Jost et al., 2010), and also takes into account differences in species frequencies between the communities. Further statistical analyses were performed with R, an open-source software package (http://cran.r-project.org/) and JMP version 9 (SAS Institute Inc., Cary, NC, USA

2.4 Results

2.4.1 Overall crop diversity

Within the 243 surveyed households, a total of 13 cultivated crop species and 53 varieties were recorded (Table 2.1).The key crop species sorghum and maize are present in over 94% of the farms and an additional 4 crop species occur in 50% of the gardens. The most common legumes are beans and cowpea. Sunflower, finger millet, soybean, tobacco, cassava and black bean are rare crops occurring in less than 5% of the farms. The average number of crop species per farm is 6.23 (SD = 1.67), with a minimum of 2 and a maximum of 10 crops. Out of the 13 crop species, tobacco and sunflower are grown as cash crops while for the others, majority are legumes (46%), followed by cereals (31%). Across all crops, each farmer on average grew more than one variety, as indicated by the overall richness per farm which is 1.19. The household’s effective number of species ranges from 2.0 to 9.7 species. The community’s farming system has a high level of inter-specific diversity which includes the cultivation of minor crops (cultivated by less than 5% of the households) such as soybean, cassava and black bean.

Table 2.1. Household and community estimates of diversity for the observed cultivated crops

Crop	Botanical name	Number of farms (N = 243)	Average farm richness	Community effective no of species	Community richness	Community evenness†	Community Shannon index
Sorghum	*Sorghum bicolor*	230	1.64	5.79	10	0.76	1.76
Pearl millet	*Pennisetum glaucum*	105	1.05	4.35	6	0.82	1.47
Cowpea	*Vigna unguiculata*	204	1.16	3.15	5	0.71	1.15
Green gram	*Vigna radiata*	139	1.05	1.98	2	0.98	0.68
Maize	*Zea mays*	234	1.59	5.81	12	0.71	1.76
Beans	*Phaseolus vulgaris*	198	1.7	3.81	7	0.69	1.34
Pigeon pea	*Cajanus cajan*	198	1.07	2.48	3	0.83	0.91
Sunflower	*Helianthus annuus*	76	1.13	1.67	2	0.74	0.51
Finger millet	*Eleusine coracana*	35	1	1	1	0	0
Soybean	*Glycine max*	2	1	1	1	0	0
Tobacco	*Nicotiana tabacum*	87	1.02	1.55	2	0.63	0.44
Cassava	*Manihot esculenta*	3	1	1	1	0	0
Black bean	*Lablab purpureus*	3	1	1	1	0	0
Overall			1.19	2.66	4.08	0.53	0.77

H' = Shannon-Wiener index;

† This is complement of the relevant Shannon-Wiener indices (H')

For the study site, the effective number of species is less than the species richness for most of the crops apart from finger millet, soybean, cassava and black bean. This reflects a degree of dominance, the greater the dominance in the community the greater the differences (Jost, 2006). Low species diversity is indicative of few varieties in the community or a few that are very abundant.

2.4.2 Diversity along the altitudinal gradient

Richness, Shannon index and the effective number of species were greatest at the midlands followed by lowlands and highlands (Table 2.2). The richness significantly varied between altitudes (ANOVA, F= 26.0; P < 0.001). At altitudinal level, the highest number of total species richness (45) was recorded at midlands, while the lowest (31) was in lowlands. Significant differences were also obtained between altitudes for the Shannon index (ANOVA, F= 29.7; P < 0.001), evenness (ANOVA, F= 10.5; P < 0.001) and effective number of species (ANOVA, F= 34.7; P < 0.001). The evenness index indicates that the proportions of the crop species are more similar at the lowlands, followed by midlands and that dominance of some crop species is higher at the highlands. Farms at the highlands where maize is dominant, showed the least uniform composition of crop species with evenness value of (0.96) which differed significantly from the other two altitudes (Table 2.2). There was no significant difference in the evenness index between the midlands and lowlands meaning that they are equally uniform in their crop compositions.

Table 2.2. Total and average richness *(S)*, mean values of Shannon (*H'*), Evenness and Effective number of species at three altitudinal levels over the Eastern slope of Mount Kenya

	Richness *(S)*			Shannon Index (H')		Evenness Index (E)		Effective no of species	
Altitude	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Highlands	40	5.54^{b}	1.61	1.59^{c}	0.28	0.96^{b}	0.03	5.11^{c}	1.34
Midlands	45	7.08^{a}	1.56	1.88^{a}	0.24	0.97^{a}	0.02	6.71^{a}	1.42
Lowlands	31	5.96^{b}	1.19	1.72^{b}	0.23	0.98^{a}	0.03	5.73^{b}	1.15
Significance		***		***		***		***	

Note: Differences between altitudes are analyzed using ANOVA, followed by Duncan's multiple range test. Means in a column followed by different letters indicate significant differences at $P < 0.05$
*** indicate significant differences at $P < 0.001$ (*F* test)

2.4.3 Crop diversity distribution among cultural groups

Controlling altitudinal effect, in order to analyze the social effect (Table 2.3), the values of crop diversity parameters between the Mwimbi and Tharaka communities at midlands were not statistically significant ($p<0.05$). The Tharaka as compared to the Mwimbi are cultivating 1.1 times more effective number of species.

Table 2.3. Total and average richness *(S)*, mean values of Shannon (*H'*), Evenness and Effective number of species between Tharaka and Mwimbi farmer cultural communities living at midlands

	Number of crop species			Shannon Index		Evenness Index		Effective no of species	
Dialect	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tharaka	38	7.33[a]	1.62	1.92[a]	0.24	0.98[a]	0.02	7.00[a]	1.47
Mwimbi	39	6.86[a]	1.48	1.84[a]	0.23	0.97[a]	0.03	6.44[a]	1.33
Significance		NS		NS		NS		NS	

Note: Differences between altitudes are analyzed using ANOVA, followed by Duncan's multiple range test. Means in a column followed by different letters indicate significant differences at $P < 0.05$
* indicate significant differences at $P < 0.05$ and NS = Not Significant, (*F* test)

2.4.4 Crop diversity distribution among the age classes

There were no significant differences in the richness, Shannon index, evenness and effective number of species between the two age classes ($P < 0.05$) (Table 2.4). . Comparing the effective number of species, we can draw that older farmers are cultivating 1.05 times more diversity than younger farmers.

Table 2.4. Total and average richness *(S)*, mean values of Shannon (*H'*), Evenness and Effective number of species between farmers grouped as old (> 50 years) and young (< 50 years) over the study site along the Eastern slopes of Mount Kenya

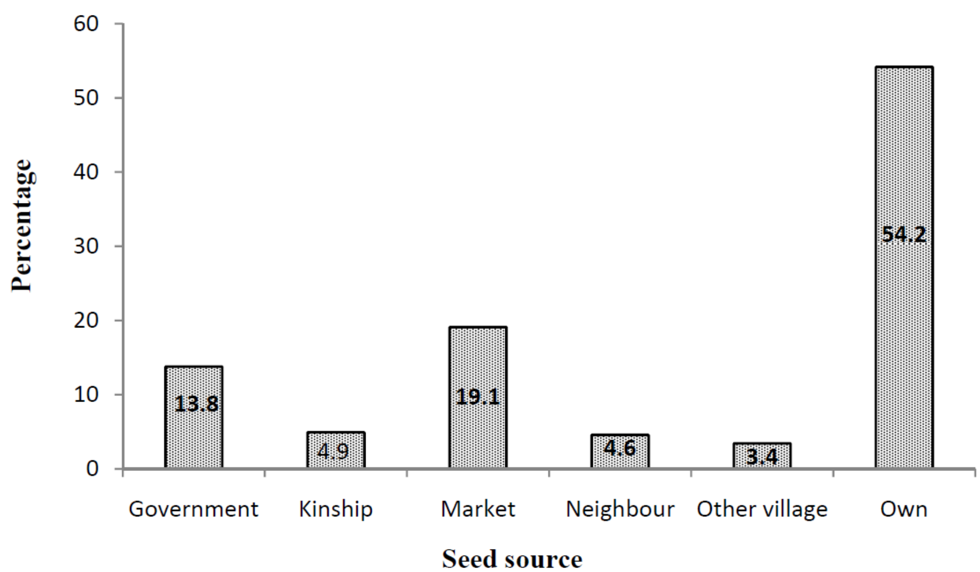
	Number of crop species			Shannon Index		Evenness Index		Effective no of species	
Dialect	Total	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Old	53	6.44[a]	1.81	1.76[a]	0.32	0.97[a]	0.03	6.06[a]	1.67
Young	52	6.13[a]	1.59	1.72[a]	0.26	0.97[a]	0.03	5.76[a]	1.42
Significance		ns		ns		ns		ns	

Note: Differences between altitudes are analyzed using ANOVA, followed by Duncan's multiple range test. Means in a column followed by different letters indicate significant differences at $P < 0.05$
ns = not significant, (F test)
Old (age above 50 years); Young (age below 50 years)

2.4.5 Seed acquisition and exchange

Generally farmers over the study mainly obtain seed to plant at the onset of the season from own seed stocks (54.2%), followed by seed purchased from the markets (19.1%), government (13.8%), kinship members (4.9%), neighbours and friends within the same village (4.6%) and members of different villages (3.4%), (Figure 2.2). The high reliance on own seed stocks is an indication of the role played by farmers as principal managers of crop diversity, producing and maintaining crop genetic resources. Farmers have a high dependence on the local seed supply channels (own seed, local markets, relatives and neighbours), from which they obtain about 80% of their seed. This can be explained by the absence of a formal seed system for local landraces cultivated in the Kenyan dry lands (Nagarajan *et al.*, 2007). This confirms the importance of own seed stocks in meeting the individual farm's seed needs within the local farming system.

Figure 2.2. Percentage of farmers obtaining seed to cultivate from a given seed source. Labels indicate percentages. Own seed is the most important source of seed.

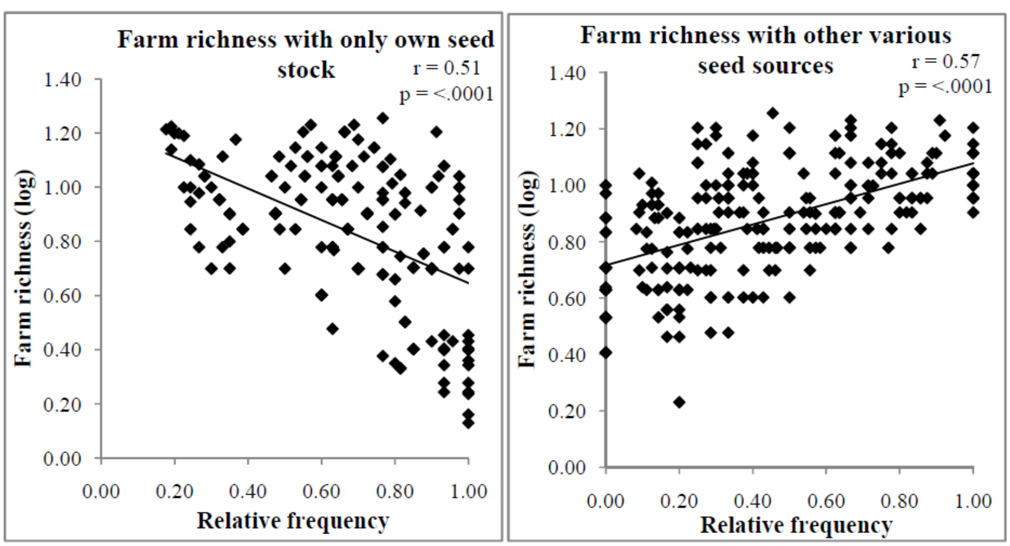


Existing farmers' social networks act as vital seed distribution channels and are significant in maintaining crop diversity. Farmers' seed exchange is greater with those that they are with close social ties (4.9% for kinship) and in close proximity (and 4.6% among neighbours, friends, and members of the same community) and thereafter with those of different communities (3.4%). Stronger ties are present with members of the same cultural community than with those from a different community. This has an impact on the overall diversity available to farmers especially to recover lost varieties following drought.

2.4.6 Seed source and overall crop diversity

We categorized the seed source for each variety cultivated by the farmer into two; own seed (exclusively from within the farm) and other (seed obtained outside the farm). Results in figure 2.3, comparing the farm's overall diversity (which is expressed using the effective number of species) to the relative frequency of the seed source, show that farmers who depend mainly on their own saved seed cultivate a lower number of crop varieties. Possible explanations for this is that that the transaction costs of acquiring each new seed (since markets are the second alternative source of seed) means that less varieties get planted. The opposite trend is observed for the category of other sources of seed (other than own), whereby the higher the frequency of a farmer obtaining seed from outside, the greater his overall crop diversity. This shows the importance of other seed sources in acquiring additional varieties by a household. Seed networks therefore play a vital role in the household's and community's crop diversity.

Figure 2.3. Correlation of the relative frequency of seed lots obtained from the farmers own seed stocks and other seed sources (outside the farm) with overall farm diversity



Focus on strengthening and understanding these networks is crucial for crop genetic resources conservation and in dissemination of new varieties or in cases of variety replacement following loss.

2.5 Conclusion

The high crop diversity both at species and intra species level that we observed is important for farmers to cope with climate variability. Crop diversity is not randomly distributed but rather is a function of the environment as determined by altitude. This is consistent with results that have been shown in other studies (Quiroz et al., 2002; Stevens, 1992). Crop diversity is also not homogenous among the different, cultural groups and age classes. The high heterogeneity at the highlands could indicate a higher introduction of new crop species based on more favorable climatic conditions. Higher species diversity is an indication of a more complex and healthier community because a greater variety of species allows for more species interaction and indicates good environmental conditions (Zargaran *et al.*, 2011) . Also a greater diversity infers stability to the system.

Social and cultural rules within the cultural community that can act to promote loss of the variety by impeding on its exchange and access need to be regarded. We propose that for biodiversity management and conservation strategies, resources cannot be allocated uniformly and factors such as the crop species, the cultural community itself as well as environmental and social factors within the community must be considered.

2.6 References cited in chapter 2

Altieri M.A. (2008) *Small farms as a planetary ecological asset: five key reasons why we should support the revitalisation of small farms in the global south*. Third World Network, Penang, Malaysia. pp. 26.

Benin S., Smale M., Pender J., Gebremedhin B., Ehui S. (2004) The economic determinants of cereal crop diversity on farms in the Ethiopian highlands. *Agricultural Economics* 31 (2-3),197-208.

Camberlin P., Boyard-Micheau J., Philippon N., Baron C., Leclerc C., Mwongera C. (2012) Climatic gradients along the windward slopes of Mount Kenya and their implication for crop risks. Part 1: Climate Variability. *International Journal of Climatology* wileyonlinelibrary.com,1-17.

Cil A., Jones-Walters L. (2011) Biodiversity action plans as a way towards local sustainable development. *Innovation: The European Journal of Social Science Research* 24 (4),467-479. DOI: 10.1080/13511610.2011.593897.

Clarence L.L., Tilman D. (2000) Biodiversity, stability, and productivity in competitive communities. *The American Naturalist* 156 (5),534-552.

Cleland E.E. (2011) Biodiversity and ecosystem stability. *Scitable by Nature Education*.http://www.nature.com/scitable/knowledge/library/biodiversity-and-ecosystem-stability-17059965. [March 5, 2011].

Cocks M.L. (2006) Biocultural diversity: moving beyond the realm of ‘indigenous’ and ‘local’ people *Human Ecology* 34 (2),185-200.

Fadda C., De Santis P., Jarvis D. (2011) Can agrobiodiversity be part of pest and disease management? Asking the right questions. *Crop Biodiversity to Reduce Pest and Disease Damage*.http://agrobiodiversityplatform.org/cropbiodiversity/2011/07/28/can-biodiversity-be-part-of-pest-and-disease-manage-asking-the-right-questions/. [February 07, 2012].

FAO. (2011) *Potential effects of climate change on crop pollination*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 40.

Fraser E., Mabee W., Figge F. (2005) A framework for assessing the vulnerability of food systems to future shocks. *Futures* 37 (6),465-479.

Global crop diversity trust. (2012) Crop Diversity. *Our mission*.http://www.croptrust.org/main/ldiversity.php. [February 1, 2012].

Heal G.M. (1999) Biodiversity as a commodity. *Finance* 1 (July, Publisher),1-26.

Heip C. (1974) A new index of measuring evenness. *Journal of Marine Biology Association* 54,555-557.

Heisey P., Smale M., Byerlee D., Souza E. (1997) Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan. *American Journal of Agricultural Economics* 79,726-737.

Hickey G.M., Pelletier B., Brownhill L., Kamau G.M., Maina I.N. (2012) Preface: challenges and opportunities for enhancing food security in Kenya. *Food Security* 4,333–340. DOI: 10.1007/s12571-012-0203-2.

Hill M.O. (1973) Diversity and evenness: a unifying notation and its consequences. *Ecology* 54 (2),427-432.

Houston M.A. (1994) *Biological diversity: the coexistence of species on changing landscapes*. Cambridge University Press, Cambridge. pp. 681.

Jost L. (2006) Entropy and diversity. *Oikos* 113 (2),363-375.

Jost L. (2007) Partitioning diversity into independent alpha and beta components. *Ecology* 88,2427–2439.

Jost L. (2009) Mismeasuring biological diversity: response to Hoffmann and Hoffmann (2008). *Ecological Economics* 68,925-928.

Jost L., DeVries P., Walla T., Greeney H., Chao A., Ricotta C. (2010) Partitioning diversity for conservation analyses. *Diversity and Distributions* 16 (1),65-76. DOI: 10.1111/j.1472-4642.2009.00626.x.

Lin B. (2011) Resilience in Agriculture through crop diversification: adaptive management for environmental change. *BioScience* 61 (3),183-193. DOI: 10.1525/bio.2011.61.3.4.

MacArthur R. (1965) Patterns of species diversity. *Biology Revised* 40,510-533.

Magurran A.E. (1988) *Ecological diversity and its measurement*. Croom Helm, London. pp. 179.

Malézieux E., Crozat Y., Dupraz C., Laurans M., Makowski D., Ozier-Lafontaine H., Rapidel B., Tourdonnet S., Valantin-Morison M. (2009) Mixing plant species in cropping systems: concepts, tools and models. A review. *Agronomy for Sustainable Development* 29 (1),43-62. DOI: 10.1051/agro:2007057.

Nagarajan L., Audi P., Jones R., Smale M. (2007) *Seed provision and Dryland crops in the semi-arid regions of Eastern Kenya*. International Food Policy Research Institute, Washington, DC.

Peet R.K. (1974) The Measurement of Species Diversity. *Annual Review of Ecology and Systematics* 5,285-307.

Pham T.D., Geleta M., Bui T.M., Bui T.C., Merker A., Carlsson A.S. (2011) Comparative analysis of genetic diversity of sesame (Sesamum indicum L.) from Vietnam and Cambodia using agro-morphological and molecular markers. *Hereditas* 148 (1),28-35. DOI: 10.1111/j.1601-5223.2010.02196.x.

Platform for Agrobiodiversity Research. (2012) Crop biodiversity to reduce pest and disease damage http://agrobiodiversityplatform.org/cropbiodiversity/about-2/the-project/. [February 3, 2012].

Quiroz C., Gutiérrez M., Rodríguez D., Pérez D., Ynfante J., Gámez J., Pérez de Fernandez T., Marques A., Pacheco W. (2002) Home gardens and in situ conservation of agrobiodiversity—Venezuelan component in: *Home gardens and in situ conservation of plant genetic resources in farming systems*, 17–19 July 2001,Witzenhausen, Federal Republic of Germany,73-82.

Reidsma P., Ewert F. (2008) Regional farm diversity can reduce vulnerability of food production to climate change. *Ecology and Society* 13(1) (38),13-16.

Shannon C. (1948) A mathematical theory of communication. . *Bell System Technical Journal 27* 27,379-423, 623-656.

Shava S., O'Donoghue R., Krasny M.E., Zazu C. (2009) Traditional food crops as a source of community resilience in Zimbabwe. *International Journal of African Renaissance Studies* 4 (1),31-48.

Stevens G.C. (1992) The Elevational Gradient in Altitudinal Range: An Extension of Rapoport's Latitudinal Rule to Altitude. *The American Naturalist* 140 (6),893-911.

Sthapit B.R., Shrestha P.K., Upadhyay M.P. (2006) On-farm management of agricultural biodiversity in Nepal: Lessons Learned,in: *National Symposium on In-Situ Conservation of Agricultural Biodiversity on-Farm*, 18-19 July Kathmandu, Nepal,267.

Sthapit B.R., Upadhyay M.P., Shrestha P.K., Jarvis D.I. (2004) On-farm conservation of agricultural biodiversity in Nepal: Volume 1. Assessing the amount and distribution of genetic diversity on-farm,in: *Second National Workshop*, 25–27 August,Nagarkot, Nepal,191.

Teshome A., Baum B.R., Fahrig L., Torrance J.K., Arnason T.J., Lambert J.D. (1997) Sorghum [Sorghum bicolor (L.) Moench] landrace variation and classification in North Shewa and South Welo, Ethiopia. *Euphytica* 97,255–263.

Tilman D., Reich P.B., Knops J.M.H. (2006) Biodiversity and ecosystem stability in a decade-long grassland experiment. *Nature* 441 (7093),629-632. DOI: 10.1038/nature04742.

Tripp R. (1996) Biodiversity and modern crop varieties: sharpening the debate. *Agriculture and Human Values* 13 (4),48-63.

Wolfe M. (1985) The current status and prospects of multiline cultivars and variety mixtures for disease resistance. *Annual Reviews in Phytopatholy* 23,251–273.

Zargaran M.-R., Odisho S., Babakhani F.-T., Hoseinpour B. (2011) Oak gall wasps (Hymenoptera: Cynipidae) species composition using diversity and similarity indexes across different locations of Oak forest, West-Azerbaijan, Iran. *International Journal of Biodiversity and Conservation* 3 (12),637-649.

3 Farmers' traditional climate knowledge as a cultural built-in object and its high accuracy in the light of climatological rainfall records

Abstract

In studying traditional knowledge about climate, two approaches can be distinguished. In the first, traditional knowledge is a 'cultural built-in object'; it is conceived as a whole, and its relevance can be assessed by referring to other cultural aspects within the same society that climate knowledge refers to. In the second approach, the accuracy of traditional knowledge can be assessed by comparing it to western academic knowledge used as an external reference. The aim of this chapter is to show how the two approaches are complementary in studying farmers' past climate knowledge. To do so, it describes how climate knowledge of Meru farmers (Kenya) is culturally built-in, and how it is highly accurate in the light of rainfall records. A retrospective survey was carried-out individually and randomly among 195 Eastern African farmers on climatic reasons for loss of on-farm crop diversity from 1961 to 2006. More than 3000 crop loss events were recorded, and reasons given by farmers were mainly related to droughts or heavy rainfall. Chi square statistic computed by Monte Carlo simulation based on 999 replicates was used to test how farmers' past climate knowledge was associated to rainfall records. Independence between traditional knowledge and western climatic knowledge was clearly rejected. Indeed, both for drought and for heavy rainfall, there was a highly significant association between Meru farmers' climate knowledge, which is culturally built-in, and rainfall records. We discuss how the cultural built-in knowledge helps farmers in perceiving and remembering past climate variations. Meru society was divided in two sections, namely rain cycle and sun cycle. The alternate succession of political authority between rain and sun cycles corresponds, for Meru farmers, to the return of drought or of heavy rainfall, respectively. Ecological anthropology and climatology could be used in a multidisciplinary and inter-cultural

approach linking traditional and academic climate knowledge, each one shedding light on the other.

3.1 Introduction

The ways that human societies conceive natural phenomena and interact with them have become a common place in anthropology, where nature is treated as a cultural concept (Descola and Pálsson, 1996, for overview). Nature should not be the same depending on societies under consideration. In many societies, the concept of nature does not exist at all, for instance among Baka Pygmies in Cameroon where logically death cannot be conceived as a 'natural' phenomena; the border between what is human and what is not is accordingly ambiguous. A human can be an animal, or an animal human, and in such a society we usually do not know who is who, with specific terms in the language to identify the entities living between the two categories (Joiris, 1993; Leclerc, 1999).

In studying traditional ecological knowledge, two approaches can be distinguished. In the first, the relativist position in anthropology conceives the environment as a continuum, where separated thing cannot be intrinsically or *a priori* defined: environmental components are "culturally defined" (Ellen and Fukui, 1996, for summary). Thus, there is a close interaction between how humans perceive the environment and the language used to categorize and describe it. Anthropologists favor the "in-side" point of view in apprehending folk environmental knowledge as a cultural built-in object. The approach consists of describing cultural aspects separately, and then, from relations to relations, to include them in a whole, following Mauss's sociological concept of totality. Nothing is exclusively environmental and/or exclusively cultural as the environment itself is culturally defined. Environmental knowledge thus is conceived as a whole, and can only be assessed by referring to other cultural aspects within the same society.

In studying traditional knowledge, a second approach has been used, where the accuracy of knowledge can be assessed by comparing it to western academic knowledge as an external reference. Thus, following Berlin's work (Berlin, 1973; Berlin et al., 1973; Berlin et al., 1974), ethno-biological studies have aimed at comparing different societies for the number and the definition of categories in use to describe biological species, as compared to those that are recognized in western science, used as an external reference (Berlin, 1999; Diamond and Bishop, 1999; Medin and Atran, 1999, for overview). Others, like Martin (1975), have argued against such analyses, underlining the incongruity of the comparison, which finally consists in detecting in folk classifications the hierarchical, Linnaean or varietal, system developed in western cultures. Indeed, the reference to an external system neglects the essential link of the folk classification to the group involved, i.e. the fact that the objects only exist as such because they take a place into a culturally defined system of oppositions, which makes sense to the group (Leclerc and Coppens d'Eeckenbrugge, 2012 for details on crop intra-specific classification and naming).

Such a critique is valid when categories are well defined and named. However, past climatic variation cannot be easily studied in such a way. Among many smallholder farmers around the world, where subsistence economy is based on rain-fed farming systems, local concepts used by farmers to describe drought in the past usually do not inform us about the severity of a given drought, as compared to others. Comparison between farmers' knowledge on drought and climatic records cannot therefore be implemented. How thus can knowledge of past climatic rainfall variation be built, and shared within a local, small-scale, society? How can this knowledge be described and analyzed without the use of explicitly named categories that reflect past drought severity?

Applied to farmers' past climatic knowledge, the aim of this paper is to show how the two approaches, culturally built-in and externally assessed, are complementary. An external reference, with meteorological data, is needed to describe traditional farmer's knowledge concerning past rainfall variations.

The cultural, economical and climatic context of the eastern slope of Mount Kenya is particularly relevant for implementing such an approach. The agriculture of Meru communities established along the mountain is mainly rain-fed. Rainfall is bi-modal with the long rain season (long rains hereafter) from March to May and short rain season (short rains) from October to December (Camberlin et al., 2009; Camberlin et al., 2012). Eastern Kenya has a long history of climate stress events, and farmers remember well periods of drought and famine. The great famine at the end of the 19th century described in detail by Ambler (1988) using farmers' oral tradition is a good illustration. More than one hundred years later, the key challenge for farmers remains ensuring success of their rain-fed farming systems by preserving the diversity of their crop varieties, well adapted to their homeland. Memory of past rainfall variation and patterns is thus crucial to aid in coping with future climate variations.

A retrospective survey was implemented to inventory farmers' crop varieties that had been lost in the past, and the reasons for loss recorded. Among reasons mentioned by farmers, there were two contrasted ones related to past rainfall patterns, "drought" being opposed to "heavy rainfall". Meru farmers have a drought nomenclature that allows remembrance of past rainfall variations. Past climate knowledge is also embedded within their social organization, with grouping of farmers into strong, well defined, age and generation classes. Political power is transmitted between generations according to a rain and sun cycle, which corresponds to the return of drought or heavy rainfall.

Association between Meru climate knowledge, which is culturally built-in, and rainfall records, used as external reference, was tested in two complementary ways. In the first one, the question was whether reasons mentioned by farmers were associated to (or independent from) climatic rainfall records. In the second, the proportion of farmers mentioning drought when drought conditions had occurred in the past was considered. Doing so, the group was used as a reference to test agreement between the farmer climate knowledge and past rainfall records, and to identity the number of implicit unnamed categories that farmers used to conceptualize and remember past rainfall patterns. Thus, the higher the proportion of farmers mentioning drought (or heavy rainfall) that concur with past rainfall records, the higher the agreement.

Valuating farmer traditional climate knowledge into a multicultural research project could help to assess how they mitigate the negative effects of droughts, which have become more severe and frequent, according to Meru farmers.

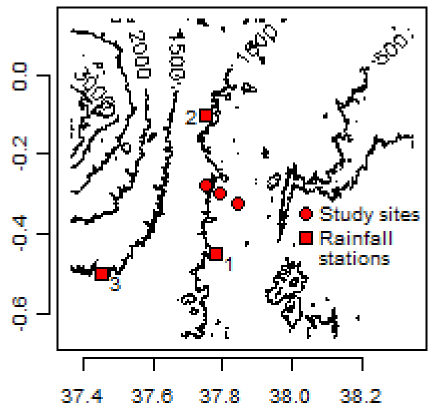
3.2 Materials and methods

3.2.1 Rainfall data

The Kenya Meteorological Department provided rainfall data from three stations in the neighborhood of surveyed farmers. The three stations, namely Ishiara (S 0.45, E 37.78, alt. 872 m), Mitunguu (S 0.10, E 37.78, alt. 1189 m), and Embu (S 0.50, E 37.45, alt. 1433 m), are located at three different altitudinal levels (hereafter, lower, mid and higher levels, respectively).

Farmers surveyed were randomly sampled along a similar three-level altitudinal gradient in order to ensure correlation between the altitudes of study sites and of rainfall stations (Figure 3.1).

Figure 3.1. Study site, Eastern slope of Mount Kenya. Farmers surveyed (solid circles) and rainfall stations (solid squares) 1. Ishiara (872 m); 2. Mintunguu (1189 m); 3. Embu (1433 m)



The stations monthly and daily rainfall records encompassed the period 1961-2006. These records have been the object of a recent analysis by Camberlin et al (2012, for details). To assess farmer knowledge accuracy, analysis was limited to the long rains season that was more impacted by intra-specific crop diversity loss over time than the short rains (see chapter 5). The onset and cessation of the long rains seasons in each year were determined by considering the February-June sub-period. The seasonal precipitation amount (Ptot), frequency of rainy days (FRE), rainfall intensity (INT), seasonal duration (DUR), and the number of rainy days (NRD) were computed between the onset and the cessation of the seasons. All these variables were sorted in an ascending order and percentiles used to define rainfall categories.

Two surveys were carried out following two different methods to assess farmers' knowledge of past rainfall variations. First, a retrospective survey assessing climatic reasons given by farmers to explain crop variety losses over time was carried out in October 2009. Independent interview technique was used: each farmer was interviewed individually and not in a group setting. The responses given by an individual farmer were not influenced by those given by others. A total of 195 farmers were surveyed at three altitudinal levels across three Meru communities: 45 at 700 m, 89 at 950 m, and 61 at 1100 m above sea-level (asl). For each crop variety, the years of loss, and, for each loss, reasons for loss were recorded.

Second, a survey on farmers' drought nomenclature and history was carried out in September 2011. Interviews were done individually as well as in group settings. A total of 36 individual farmers (23 men and 13 women) were interviewed at three altitudinal levels. A second field visit was carried out to confirm the years that correspond to drought nomenclature used by the Meru to remember past climatic events. The second group of interviews involved 12 elderly farmers who were selected based on their sound knowledge of relations between past climate variations, and the Meru social and political organizations.

3.2.2 Data analysis

More than 3200 crop variety losses were orally reported by farmers in retrospect from 1961 to 2006, and reasons for loss recorded. The following two-way contingency table (Table 3.1) cross-classifies these declarations by reasons (lines) and by seasonal rainfall categories (from 1 to 6 in ascending order in columns).

Table 3.1. Variety losses from 1961 to 2006 as function of reason given by farmers and six categories of seasonal rainfall amount in ascending order

Reasons given by farmers		Ordered rainfall categories						Total	%
		1	2	3	4	5	6		
Drought		1086	365	151	394	322	35	2353	73.49
Heavy rainfall		71	28	26	46	97	4	272	8.49
Consummed-sold		51	24	23	23	33	19	173	5.4
Pest-disease		51	37	22	21	22	17	170	5.31
Variety changed		43	19	13	30	23	7	135	4.22
Other		23	7	10	35	12	12	99	3.09
	Total	1325	480	245	549	509	94	3202	100
	%	41.38	14.99	7.65	17.15	15.9	2.94	100	

Rainfall amounts and frequency depend on altitude and seasons (Camberlin et al., 2012). In order to control this interaction, and to allow chi square analyses, the precipitation amounts were transformed into equally weighted ordered categories. This transformation was done separately for each altitudinal level. Ranked into the same number of ordered categories, rainfall from different altitudes can be compared.

Monte Carlo Chi-squared statistic computed with 999 replicates was used to test how farmers' past climate knowledge was associated to rainfall records. The Chi-squared statistic was also used to identify the number of implicit unnamed categories that farmers used to conceptualize and remember past rainfall patterns. The method is based on cell Pearson's residuals computed from the two-way contingency table cross-classifying climatic reasons given by farmer and rainfall amount. This method allows identifying a cell that individually contributes to reject the (independence) null hypothesis. The Pearson’s residual for a cell (C_{ij}) is given as:

$$C_{ij} = \frac{\text{observed}_{ij} - \text{expected}_{ij}}{\sqrt{\text{expected}_{ij}}}$$

Pearson's residuals approximately follow a standard normal distribution. That implies that cells with a Pearson's residual of ±2 or ±4, for instance, are those that are *individually* significant at approximately the $\alpha = 0.05$ and $\alpha = 0.0001$ levels (Meyer et al., 2005). Pearson's residuals thus measure for each cell how far (positively or negatively) observed frequencies deviated from expected frequencies. This method was usefully applied to rainfall data treated as ordered qualitative variable by considering conditional distributions (Agresti, 2007). It was used to measure farmer knowledge accuracy, i.e. how far (positively or negatively), according to rainfall values, frequencies of droughts mentioned by farmers were from expected frequencies, i.e. the probability to mention any reasons by guessing.

Contingency table was computed to cross-classify farmer climatic reasons (in rows) by ordered rainfall categories (in columns). To confirm farmer knowledge accuracy about past rainfall patterns, the proportion of farmers mentioning drought for low rainfall values should be significantly higher (cell Pearson residuals exceeding 2) than that expected randomly (guessing). Pearson residuals should progressively decrease from first to second rainfall categories, from second to third, and so forth, progressively becoming close to 0 and more and more negative as rainfall increases. On the contrary, proportion of farmers mentioning heavy rainfall should be negatively associated with the lower rainfall values, and positively with the higher. If past rainfall knowledge of farmers is accurate, conditional Pearson residuals for drought should decrease linearly as rainfall values increase (negative linear regression), and it should increase linearly for heavy rainfall (positive linear regression). This linear hypothesis was tested using different numbers of rainfall ordered categories, to identify the one corresponding to the lower residual mean square (RMS). Thus, the number of rainfall categories that better fits with farmer climate reasons was considered as components of the farmers' culturally built-in climate knowledge itself. It corresponds to the number of implicit unnamed categories used by farmers to conceptualize past rainfall variation and drought severity. The procedure was applied to the five rainfall indicators used to climatologically characterize the rainy seasons performance.

3.3 Results

Beginning in late 1897, drought and hunger spread across central Kenya. For much of Eastern Africa, the 1890s was a period of erratic and inadequate rainfall – a time of troubles. (...) By early 1899 central Kenya was in the grip of a famine more serious than any recalled in living memory (C. Ambler, 1988, *The great famine,* 1897-1901).

3.3.1 Climatic knowledge as a cultural built-in object

Drought in Meru language is referred to as yuura, a term which evokes the sense of crisis caused by extreme and general scarcity of food. According to farmers, in 1928, the drought came to be known as yuura ria kwara mururu, the drought of the empty granaries. The 1940 drought is referred to as yuura ria KEA, an acronym for the British King's African Rifles army battalion that arrived to contain the Mau Mau rebellion. In 1943, drought was named yuura ria Kithioro, which means the circles drought. Because of construction of the road linking the towns of Meru and Embu, people had to use diversions and travel long distances to obtain food. In 1948, the drought was called Yuura ria Taribo, the drought of Taribo, named after a white man who donated food to the local people. In 1954, drought was referred to as Yuura ria miuu (the drought of miuu). Miuu is a local tree whose bark was scrapped producing a powder that was cooked and eaten. In 1965, this drought was named as Yuura ria Tigania, the drought of the Tigania, a Meru group where people went to provide labor to earn food or money. In 1967, the drought was called Yuura ria Kaburia in reference to a wealthy business man who owned a shop in the upland. People traveled from the lowlands to purchase food, as he was the only one with stocks. In 1979, this was called Yuura ria kithukio. The term Kuthukio refers to something in large pieces such as meat. There were no grains to eat and people slaughtered their animals for food. In 1982, the drought is known as Yuura ria ngakwa ngwete, meaning the drought of “I will die holding”. This is because during that period, people had money to buy food but could not find anything to buy. Therefore they said that they will die with money in their hands. The 1984 drought was referred to as Yuura ria T9, meaning the “drought of the T9”. There were trained dogs named T9 attached to the 9th battalion of the Tanzania Army used to fight the Government of Dictator Idi Amin Dada of Uganda. The drought came to be referred to as T9, being equated to the aggressiveness of the T9 dogs. In 2000, drought was referred to as Yuura ria nkari tawe, the drought of “I am as you are”. This is because when one went to borrow food from his neighbor, or any other person in the region, they would tell them that they were also experiencing a similar situation, without any food.

Figure 3.2. Frequency of droughts according to farmers (1961-2006). Names reported on the figure are those used in Meru drought nomenclature

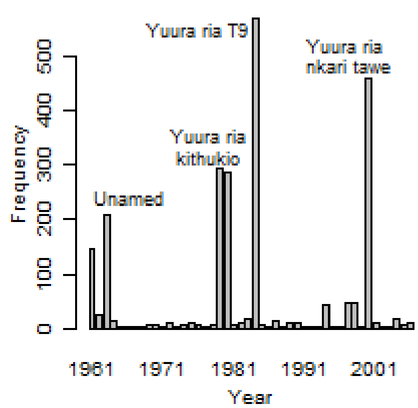


Figure 3.2 shows the years where droughts were associated with crop diversity losses by farmers. Their distribution is far from random, consisting of six major drought years. Meru drought names were reported on this figure, which summarizes the combined perceptions of the past rainfall variations by all individual farmers. These years correspond to major droughts inventoried by

several authors for Kenya (Mbithi and Wisner, 1973; Newman, 1975; Nyamwange, 1995; Ogallo et al., 2005), the 1984 drought being considered as the worst in the last century.

3.3.2 Farmer past climate knowledge accuracy

Contrary to studies applied to crop and animals, where many categories are distinguished, two categories only can be used, namely "drought" and "heavy rainfall", to assess accuracy of Meru farmers' climate knowledge. But, being culturally built-in, this knowledge is more accurate than what these two terms allow us to think.

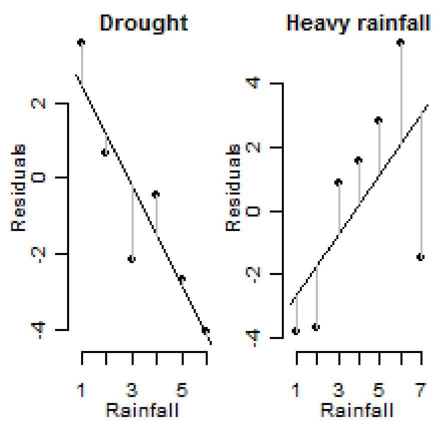
According to farmers, 82% of variety losses were due to rainfall anomalies, as compared to 5.4 % and 5.3 % due to grain consumption or diseases, respectively. "Drought" was mentioned 73.5 % of the times whereas 8.5 % of the losses were caused by heavy rainfall. For drought, figure 3 shows decreasing values of cells Pearson residuals from lower to higher rainfall values, and the reverse for heavy rainfall.

Figure 3.3 shows how farmers' past climatic knowledge agrees with rainfall variations. The proportion of farmers mentioning drought (left panel) agrees with drought conditions represented on the x axis by the rainfall ordered categories. The number of farmers mentioning drought is high for the low rainfall categories, and is significantly lower at higher rainfall values. The zero Pearson residual value on y axis corresponds to guessing. Accuracy of farmer knowledge on drought was thus suggested both at lower (residual: +3.6) and higher rainfall values (residual: −4.1). In these cases, the proportion of responses significantly deviates from guessing.

Farmers accuracy was also suggested when they mentioned heavy rainfall (right panel). The number of farmers mentioning heavy rainfall increased as rainfall values increased, and was significantly higher (residual at +5.3 for category 6) at higher rainfall values than at lower values (which correspond to drought conditions, with a highly negative residuals at −3.9). Similarly to what was observed with drought, the proportion of responses significantly deviates from guessing. Chi square statistic computed by Monte Carlo simulation clearly rejected conditional independence (p= 0.001) between reasons given by farmers and rain gauge recorded rainfall, both for drought and heavy rainfall.

Under the linear hypothesis, this result allows identification of the number of implicit unnamed categories that farmers use to perceive past rainfall variations and drought severity. Indeed, the conditional residuals for drought follow a negative linear regression (*r*= −0.91, *p*= 0.012) as function of rainfall, whereas it follows a positive linear regression for heavy rainfall (*r*= +0.62, *p*= 0.14). Heavy rainfall was under-mentioned for the rainfall level 7 as compared to linear expectation. However, grouping levels 6 and 7 by summing their residuals significantly increases the correlation (*r*= +0.95, *p*= 0.003). This also suggests the high accuracy of farmers' knowledge concerning past seasonal rainfall variations. Farmers refer to six unnamed categories to conceptualize past drought severity, and seven to order episodes of heavy rainfall.

Figure 3.3. Pearson's residuals as function of of seasonal rainfall categories sorted in ascending order. Left panel: residuals are conditioned by the frequency of farmers mentioning drought, and residuals decrease as rainfall values increase (six rainfall categories); Right panel: residuals are conditioned by frequency of farmers mentioning heavy rainfall, and residuals increases as rainfall values increase (seven rainfall categories)



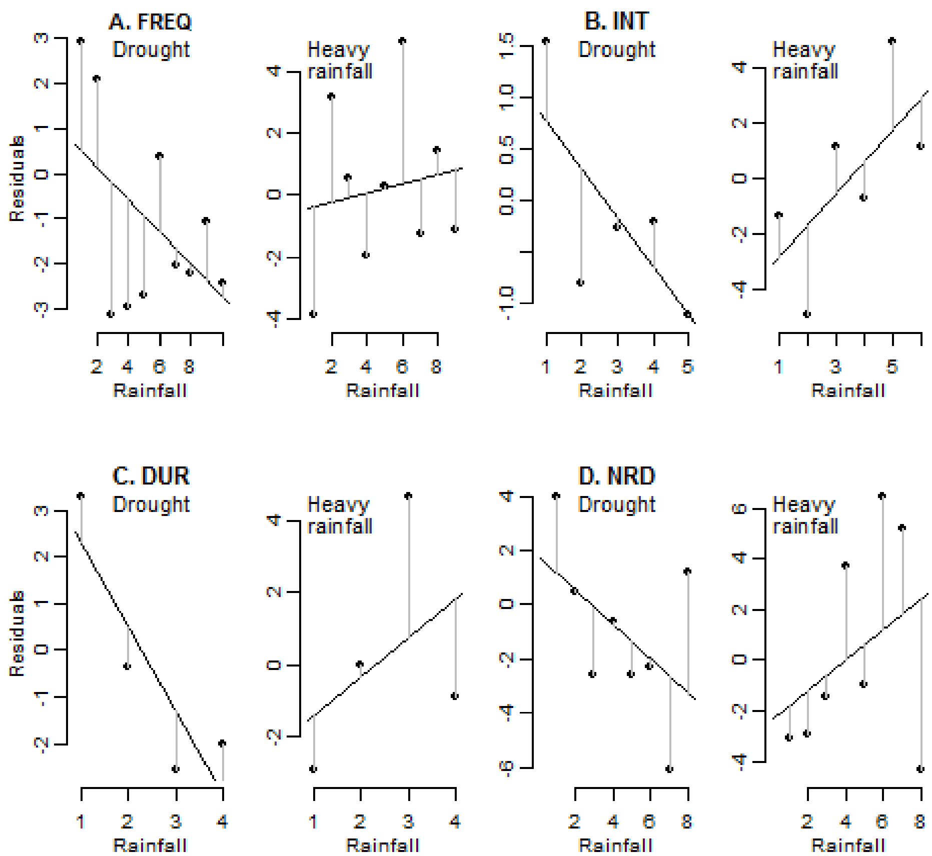
The number of farmers' implicit unnamed rainfall categories was determined for other rainfall descriptors (table 3.2). This was done for each number of rainfall categories by considering residual mean squares, as well as correlation coefficients between Pearson’s residuals and the rainfall categories. For seasonal precipitation amounts (Ptot) for example, six categories better explained climatic reason given by farmers, as the residual mean square was lower (better fit to linear hypothesis).

Table 3.2. Pearson's residuals and ordered rainfall categories. For each rainfall indicator, correlation (*r*) and residual mean squares (RMS) were reported. A. When "drought" was mentioned by farmers. B. When "heavy rainfall" was mentioned by farmers. P-values (*p*) were reported only for the lowest RMS used to identify the number of farmers' unnamed rainfall categories.

A. Drought		Number of unnamed rainfall categories						
		4	5	6	7	8	9	10
Ptot	*r*	−0.6	−0.62	−0.91	−0.8	−0.62	−0.55	−0.59
	RMS	-9.9	-5.74	-1.64	-3.02	-6.55	-7.34	-4.59
	p			0.001				
Freq	*r*	−0.51	−0.53	−0.38	−0.38	−0.37	−0.38	−0.5
	RMS	-11.21	-8.89	-9.68	-6.43	-8.23	-4.77	-3.97
	p							0.13
Int	*r*	−0.21	−0.72	−0.55	−0.25	−0.2	−0.29	−0.22
	RMS	-9.11	-0.67	-1.66	-6.45	-5.73	-3.87	-4.45
	p		0.17					
Dur	*r*	−0.88	−0.63	−0.65	−0.53	−0.59	−0.53	−0.46
	RMS	-2.26	-6.55	-3.97	-8.99	-4.92	-4	-7.24
	p	0.11						
Nrd	*r*	−0.81	−0.59	−0.6	−0.55	−0.51	−0.41	−0.44
	RMS	-5.33	-7.77	-5.85	-8.1	-7.98	-7.5	-6.9
	p	0.19						
B. Heavy rainfall		Number of unnamed rainfall categories						
		4	5	6	7	8	9	10
Ptot	*r*	0.19	0.32	0.53	0.62	0.24	0.3	0.33
	RMS	-60.98	-45.26	-15.97	-8.67	-53.24	-39.97	-24.28
	p				0.14			
Freq	*r*	0.55	0.53	0.23	0.22	0.28	0.15	0.26
	RMS	-10.46	-9.42	-9.68	-13.03	-11.82	-8.21	-10.08
	p						0.69	
Int	*r*	0.45	0.7	0.65	0.3	0.32	0.37	0.26
	RMS	-27.69	-4.29	-7.61	-24.04	-20.34	-13.28	-20.74
	p		0.16					
Dur	*r*	0.43	0.19	0.21	0.33	0.3	0.13	0.17
	RMS	-12.68	-32.49	-26.29	-50.04	-14.17	-19.11	-38.3
	p	0.56						
Nrd	*r*	0.4	0.22	0.28	0.34	0.35	0.17	0.17
	RMS	-21.32	-36.16	-29.74	-18.02	-17.75	-19.47	-21.07
	p					0.39		

The number of implicit unnamed categories varied depending on climatological rainfall indicators considered. While six implicit unnamed categories better explain association between drought farmer knowledge and seasonal rainfall (p= 0.01), ten were observed for frequency of rainy days (p= 0.13), five for rainfall intensity (p= 0.17), and four for both seasonal duration (p= 0.11) and number of rainy days (p= 0.19). Agreement between past farmer knowledge on drought and rainfall records was more obvious with seasonal precipitation than other rainfall indicators, and globally lower for heavy rainfall than for drought (Figure 3.4).

Figure 3.4. Conditional Pearson' residuals as function of rainfall ordered categories (drought and heavy rainfall). A. Frequency of rainy days - FREQ; B. Rainfall intensity - INT; C. Seasonal duration - DUR; D. Number of rainy days – NRD



3.4 Discussion

The aim of this paper was to show how the two approaches used to study traditional knowledge, culturally built-in and externally assessed, are complementary for understanding farmers' past climate knowledge. We described how climate knowledge of Meru farmers (Kenya) is culturally built-in, and how highly accurate it is in the light of rainfall records.

The peoples' everyday knowledge of the abiotic world, folk climatology if you will, is quite different from knowledge of the biological one (plants and animals) where many named categories allow comparison with western knowledge. A methodological difficulty also exists for studying farmer traditional knowledge of past rainfall variations. As stated by Diamond and Bishop (1999), there is an obvious risk to posing a leading question or one with a yes/no answer because it provides no internal check on the correctness of the answers. This is why in the present study farmer knowledge of past rainfall variation was not studied directly, but indirectly, without referring to climate or to rainfall variation in the questions asked. The survey referred to crop diversity loss over time, which itself can be related to rainfall. This methodological problem was also solved by considering farmers as a group.

Using the group of farmers as a reference, indeed, it was possible to measure the agreement between farmers' knowledge and rainfall records, what an individual approach does not allow. We have shown that Meru farmers' knowledge accuracy was more obvious with seasonal precipitation amount than the other four climatic indicators. It was also possible to identify how many implicit unnamed rainfall categories farmers referred to in their perception of past rainfall variations. The number of rainfall categories used by Meru farmers is an indication of the way they conceptualize rainfall variation and drought severity. Six categories were identified for seasonal rainfall, but this number varied depending on the climatic indicator considered.

Figure 3.4 showed that usually higher values of rainfall were not clearly distinguished by farmers when they apprehended past heavy rainfall events. For instance, heavy rainfall was under-mentioned for the fourth category of seasonal duration as compared to the third (figure 3.4c), which were over-mentioned. Grouping and summing residuals of the third and fourth categories increased the correlation. This inversion was also observed for drought with higher level values when considering number of rainy days (figure 4d; $r = -0.86$, $p = 0.01$ after grouping categories 7 and 8), and for rainfall intensity ($r = -0.94$, $p = 0.059$ after grouping categories 1 and 2). This factual inversion does not contradict the high accuracy of Meru farmers' knowledge in the light of rainfall records.

Conceived as a whole, Meru past climate knowledge imply many cultural aspects that this knowledge refers to within the society. Farmers had not expressed drought severity in terms of rainfall amount, but in terms of intra-specific crop diversity loss, which itself can be related to rainfall. That is a characteristic of the Meru climatic cultural built-in knowledge where *relations* are used in remembering, understanding and conceiving rainfall variations. This knowledge is not only climatic *per se*, it is also economical (crop failure), sociological (*cf.* "I am as you are") or political (Tanzania Army 9th Battalion, for instance).

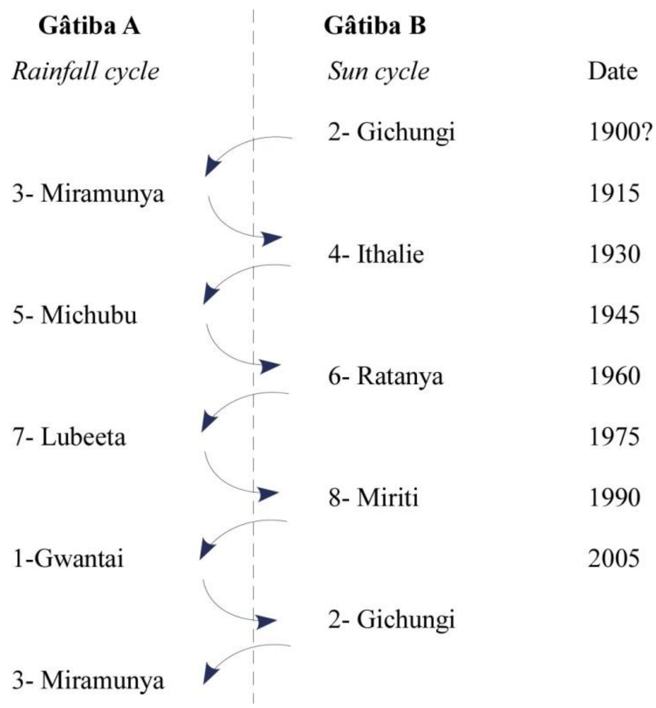
However, Meru climate knowledge does not only refer to external factual events. This knowledge is embedded into a social organization, where succession of age classes, and generation, acted as a sociological/climatic clock. This organization was precisely described among Meru society by A.M. Peatrick (1999a). Her descriptions help us to describe how innovative the Meru climate knowledge is, as cultural built-in object.

In Meru society, local knowledge is passed down from one generation to the next through casual conversations. But the internal social organization of the Meru farming communities probably also facilitated remembrance, as they were grouped into strong, well defined, age and generation classes. This organization allowed old farmers (majorly considered by our survey) to remember past events, including drought, by referring to successive age classes that were renewed and named every 15 years. Each age class was itself subdivided into echelons, dated and named. It thus facilitated farmers referencing and remembrance of past climate events.

As described by A.M. Peatrick (1999a) among Tigania-Igembe territorial group, Meru society was divided into two named sections (here A and B), and each alternatively got the political authority linked to age class successions. The Meru system was slightly different to the one in use among Karamajong circle (Turkana), but similar to one in use among Maasai or among Borana. Figure 3.5 was derived from descriptions by A.M. Peatrick (1999a) among the Tigania-Igembe Meru territorial group.

The Meru's generation classed had a cyclic naming system with eight terms, the first being reused after the eighth. Political authority was alternatively in the hand of *gâtiba* A or *gâtiba* B. Each section implied a succession of generation in such a way that A3, A5 and A7 correspond to father-father, father, and father-son generations. The same name was succeeded every five generations. Meru say that "the old generation is back", or yet that the cycle of generations is completed (PEATRIK, 1999a). The five generations cycle was associated to recurrent and antagonist rainfall patterns: among the two *gâtiba*, one was associated to the rain, and the other one to the sun. When the rainfall cycle (*gâtiba* A) is back and acquires political authority to govern human society, farmers believe that drought episodes are also back; on the contrary, sun cycles coincide with the return of heavy rainfall. The Meru climatic system, based on successive dry and wet periods, is associated to ideas of "differential prosperity" (1999a: 81).

Figure 3.5. Transmission of political power over generation classes, alternately between two sections, Gâtiba A and gâtiba B (after A.M. Peatrick, 1999). The two sections are respectively associated to rainfall cycle and sun cycle. The return of rainfall cycle corresponds to the return of droughts; on the contrary, the return of sun cycle corresponds to the return of heavy rainfall. Past climate knowledge is embedded within the Meru social organization



Because farmer memory of past rainfall variations is linked to cycles of transmission of political power within the society, this knowledge can be described as a cultural built-in object embedded within the farmers' social organization itself. As compared to Andean South America farmers that have historically linked stars in the Pleiades to inter-annual rainfall variability (ORLOVE et al., 2000), climate knowledge in Meru society is embedded into the social organization, which is based on climatic opposition between drought and heavy rainfall. Succession of farmers' generations over time, and their fine tuned drought nomenclature, acts as a sociological clock. Comparing rain and sun cycles, as it is conceived in Meru culture, and how these cycles can be linked to climate variability in western sciences (Rind, 2002) need to be more precisely investigated over a longer time interval. One promising issue would be to investigate phase relationship between decennial and inter-decennial climate signals, and the loss of crop genetic diversity.

3.5 Conclusion

The aim of this paper was to describe the Meru farmers' climatic knowledge as a cultural built-in object, and to assess it by referring to an external built object, i.e. past rainfall records. The two approaches shed light on each other. They are thus complementary and neither one nor the other can stand by itself to deal with traditional past climatic knowledge. This paper not only revealed the high accuracy of farmers knowledge concerning past rainfall variations and droughts, but also gave us illustration of how climate knowledge can be embedded into social organization.

Accuracy of farmers' climate knowledge gives us confidence to analyze the dynamic of crop genetic diversity itself, over time based on farmers' memory. In retrospect, indeed, more than 3000 farmer's varieties were declared lost by farmers. Were these varieties have been definitively abandoned or supplied after drought events using local seed exchange systems? Is the vulnerability to drought the same for all crop species that Meru farmers used in their multi-cropping systems? Is there also practical knowledge, culturally defined, that can mitigate the risk of seed loss due to rainfall variations and droughts? Climatologists, agronomists, or anthropologists could better integrate farmer cultural built-in and western knowledge, allowing an inter-cultural approach of knowledge.

3.6 References cited in Chapter 3

Agresti A. (2007) *An introduction to categorical data analysis*. Wiley, Gainesville, Florida, USA. pp. 373.

Ambler C. (1988) The great famine, 1897-1901, in: C. Ambler (Ed.), *Kenyan communities in the age of imperialism. The central region in the late nineteenth century*, Yale University Press, New Haven, London, UK. pp. 123-149.

Berlin B. (1973) Folk systematics in relation to biological classification and nomenclature. *Annual Review of Ecology and Systematics* 4,259-271.

Berlin B. (1999) How folkbotanical system can be both natural and comprehensive: one Maya indians's view of the plant world, in: L. M. Douglas and S. Atran (Ed.), *Folkbiology*, The MIT Press, Cambridge, USA; London, UK. pp. 71-90.

Berlin B., Breedlove D.E., Raven P.H. (1973) General principles of classification and nomenclature in folk biology. *American Anthropologist* 75,214-242.

Berlin B., Breedlove D.E., Raven P.H. (1974) *The principles of Tzeltal plant classification*. Academic Press, New-York, NY, USA, London, UK. pp. 660.

Camberlin P., Moron V., Okoola R., Philippon N., Gitau W. (2009) Components of rainy season' variability in Equatorial East Africa: onset, cessation, rainfall frequency and intensity. *Theoretical and Applied Climatology* 98 (3),237–249,.

Camberlin P., Boyard J.-M., Philippon N., Baron C., Leclerc C., Mwongera C. (2012) Climatic gradients along the windward slopes of Mount Kenya and their implication for crop risks. Part 1: climate variability. *International Journal of Climatology* [online] http://onlinelibrary.wiley.com/doi/10.1002/joc.3427,17.

Descola P., Pálsson G. (1996) (Ed.) *Nature and Society: Anthropological Perspectives*, Routledge, London, U.K., New-York, USA. pp. 320.

Diamond J., Bishop K.D. (1999) Ethno-ornitology of the Ketengban people, Indonesia New-Guinea, in: L. M. Douglas and S. Atran (Ed.), *Folkbiology*, The MIT Press, Cambridge, USA, London, UK. pp. 17--46.

Ellen R., Fukui K. (1996) (Ed.) *Redefining nature. Ecology, culture and domestication*, Berg, Oxford, Washington D.C, USA. pp. 664.

Joiris D.V. (1993) Baka Pygmy hunting rituals in Southern Cameroon: how to walk side by side with the elephant. *Civilisation* XLI (2),51-81.

Leclerc C. (1999) De l'usage social de la forêt tropicale. L'exemple des Pygmées baka du sud-est Cameroun. *Ethnies* 13 (24-25),87-99.

Leclerc C., Coppens d'Eeckenbrugge G. (2012) Social organization of crop genetic diversity The G x E x S interaction model *Diversity* 4,1-32.

Martin M.A. (1975) L'ethnobotanique, science *per se* ? A propos d'un livre de B. Berlin, D.E. Breedlove, P.H. Raven "The principles of Tzeltal plant classification". *Journal d'Agriculture Tropicale et de Botanique Appliquée* 22 (7-8-9),237-276.

Mbithi P., Wisner B. (1973) Drought and famine in Kenya: magnitude and attempted solutions. *Journal of East African Research and Development* 3,95-143.

Medin D.L., Atran S. (1999) (Ed.) *Folkbiology*, The MIT Press, Cambridge, Massachusetts; London, UK. pp. 470.

Meyer D., Zeileis A., Hornik K. (2005) *The strucplot framework: visualizing multi-way contingency tables with vcd*. Wirtschafts universität, Department of Statistics and Mathematics, Vienna, Austria. pp. 46.

Newman J.L. (1975) *Drought, famine, and population movements in Africa*. Syracuse University, Syracuse, N.Y, USA. pp. 149.

Nyamwange M. (1995) Famine Mitigation in Kenya: Some Practices, Impact and Lessons. *Middle States Geographer* 28,37-44.

Ogallo L.J., Otengi S.B., Ambenje P., Nyakwada W., Githui F. (2005) Monitoring agricultural drought : the case of Kenya., in: V. K. Boken, et al. (Ed.), *Monitoring and predicting* *agricultural drought: a Global Study*, Oxford University Press, New-York, USA. pp. 238-251.

Orlove B.S., Chiang J.C.H., Cane M.A. (2000) Forecasting Andean rainfall and crop yield from the influence of El Niño on Pleiades visibility. *Nature* 403,68-71.

Peatrik A.-M. (1999) *La vie à pas contés*. Société d'ethnologie, Nanterre, France. pp. 571.

Rind D. (2002) The sun's role in climate variations. *Science* 296 (5568),673-677.

4 Climate variability, droughts and farmers' crop variety losses by East African smallholders. A retrospective survey from 1961 to 2006

Abstract

Climate variability directly affects traditional low input and rain-fed farming systems, but few studies have paid attention retrospectively to crop diversity erosion. This study analyzes the impacts of rainfall variability on farmers' crop variety losses from 1961 to 2006, considering changes in smallholder farming systems. The cropping system dynamic, in favor of maize and at the expense of sorghum and millet, induced an increasing risk of loss of local farmers' varieties due to drought. Combining ecological anthropology and climatology, a retrospective survey was carried out at three altitudinal levels (750 m, 950 m and 1100 m asl) on the eastern slope of Mount Kenya from 1961 to 2006. Over that period, based on 3200 variety losses reported orally and independently by 195 farmers, the probability to lose a sorghum variety (0.056 to 0.065) was lower than the probability to lose a maize variety (0.071 to 0.087). All crop species were highly impacted by droughts and few by heavy rainfall. For the more impacted years along the slope of the mountain, the probability to lose a variety increased for seasons whose duration was less than 50 days, the number of rainy days less than 28, the frequency of rainy days less than 0.6, and the seasonal precipitation amount less than 400 mm. Logistic regression models confirmed that change in cropping systems, favoring maize and at the expense of sorghum and millet, induced an increasing risk of loss of farmer varieties due to drought over the period, with an accentuated impact at low altitude even during normal seasons.

4.1 Introduction

Mitigating the impacts of climate variability on smallholder rain-fed agriculture still today remains a challenge, notably in Africa where it is the source of livelihood to the majority of the rural population. Rainfall variability, including droughts, has historically been the major cause of famines (Glantz, 1987), affecting particularly smallholder rain-fed agriculture. According to FAO (2008), climate events such as extreme droughts have played an important role in crop diversity changes in the past. Comparing fifteen major farming systems around the world, Hyman et al. (2008) and Waddington et al. (2010) noted that high drought risk areas coincide with those of high levels of poverty.

Lobell et al. (2008) used crop models and climate projections for 2030, analyzing climate risks for crops in twelve food-insecure regions. Negative impacts of climate change on yield are expected to be more important for maize than sorghum in Southern Africa, and for cowpea than sorghum in East Africa. Similar analyses have been carried out on maize in Africa and Latin America (Jones and Thornton, 2003), and on maize and beans in East Africa (Thornton et al., 2009). However, these projections simulated often only one crop at a time whereas smallholder rain-fed agriculture usually favours multi-cropping systems.

Smallholder rain-fed agriculture systems are today increasingly dynamic notably under the impulsion of agricultural policies encouraging adoption of maize in place of sorghum and millet in arid and semi-arid areas. Maize known to be more susceptible to drought than traditional crops such as sorghum and millet, met an incontestable success with a wide acceptance by farmers (Ouma et al., 2002, showing increasing rates of adoption from 1965). Maize became a dominant food crop through the 1990s in Kenya, Zimbabwe, Zambia, and Malawi, where its adoption was encouraged by agricultural policies (Smale and Thom, 2003).

The partial conversion from sorghum and millet to maize has never itself been considered as a factor having the potential to increase the future impacts of climate variability on smallholder rain-fed multi-cropping systems. Models simulating the crop response to climate not only considered often only one crop at a time, but also assumed the same use of current varieties with unchanged cultural practices (Jones and Thornton, 2003; Thornton et al., 2009).

Combining ecological anthropology and climatology, our study analyzes impacts of past rainfall variability on rain-fed agriculture systems managed by East African smallholders, considering also their dynamic. While usual approaches consider present day characteristics of agricultural systems to assess their adaptability to hypothetical rainfall variability (projection into the future), our study was based on farmers' knowledge using a retrospective survey (looking into the past). In our case, past rainfall variability is already known, not hypothetical, and farmers' knowledge allowed recognition of their past agricultural systems. Indeed, considering the year they adopted (or abandoned) each crop, changes in the proportion of crops that were assembled by farmers in their farming systems can be monitored over time.

Assessing the vulnerability of rain-fed agriculture systems faced with extreme rainfall events, considering their dynamic, is particularly relevant in Kenya. The impact of rainfall variability on crop is usually assessed using yield while it is documented here through the losses of local farmers' varieties. Farmers' varieties are population varieties that are selected at harvest according to morphological criteria and agronomical performances, from season to season. The farmers' variety names refer to a classification that is based on morphological criteria. Farmers' varieties, thus, remain a key component of agriculture systems in semi arid areas. Crop varieties are in Kenya. A large proportion of seeds are self-reproduced by farmers in a traditional way, as in many other countries. Comparing results from nineteen studies describing farmers practices from different villages, a recent review stated that the rate of saved seeds from previous harvesting season to the next is about 58 % to 90 % for Maize in Mexico, from 70 % to 99 % for Sorghum in Burkina Faso, about 70 % for beans in Costa Rica and 70 % for rice in Sierra Leone (Leclerc and Coppens d'Eeckenbrugge, 2012). Such a farming system is based on a continuous link between harvesting and planting, which can be interrupted by extreme rainfall events and crop failure.

Farmers in Kenya manage two cropping seasons per year corresponding to the Long Rains from March to May and to the Short Rains from October to December. The analysis of variety losses due to rainfall variability is limited here to the Long Rains for agronomic and climatic reasons. Crop life cycles can be short (October to February or March to June) or long (October to July). Long cycle varieties are sown with short cycle varieties in October, so seed availability is crucial at this time. Seeds are selected from harvests at the end of the Long Rains (June - July). Crop failures during the Long Rains can thus interrupt the continuum in seed availability between both rainy seasons. Long Rains seem poorly predictable at interannual time scale. The interannual variations of seasonal rainfall amount during the Long Rains results from a combination of many features, partly independent from each other, which includes variations in onset, occurrence of wet days, rainfall intensity, and cessation date (Camberlin et al 2012; Camberlin et al., 2009). In chapter 5, we showed that the estimated odds of crop failure fifteen days after germination are 6.7 times more for the Long Rains than for the Short Rains and that the difficulty in predicting the onset, the irregularity of rainy days and the length of dry spells during crop emergence phase highly increased the risk of farmers' variety losses during the Long Rains. In sum, farmers are faced with a paradox during the Long Rains. This season is central to perpetuate their homeland varieties over time, but with a high risk of crop failure and variety losses. Understanding the part played by the different components of this rainy season in crop failure is a critical point for agro-climatologists

To assess impacts of the Long Rains seasonal variability on variety losses, considering the farming system dynamics, a retrospective survey was carried out at three altitudinal levels (750 m, 950 m and 1100 m above sea-level (asl) on the eastern slope of Mount Kenya, from 1961 to 2006. A typical agro-ecological zonation results from strong vertical gradients in both temperature and precipitation along the slope of the mountain (Jaetzold et al., 2007a). Recently, Camberlin et al. (2012) documented the vertical (altitudinal) and horizontal variability of precipitation, including the intra-seasonal distribution of the Long Rains along the eastern slopes of the mountain. Seasonal amount steadily increases uphill as well as the duration of the season that increases at a rate of 3.6 days per 100 m.

Some farmers adopted maize a few years ago, and are still cultivating traditional sorghum and millet varieties, while others abandoned these varieties earlier in favor of maize. Farming systems were thus intrinsically dynamic with different crop assemblage over time, implying that in retrospect its capacity to mitigate the risks of crop failure due to extreme rainfall events was never constant.

In such a context, ecological and social components cannot be analytically isolated, but have to be considered as part of a socio-ecological system. How did agricultural policies modify crop assemblage in a rain-fed farming system from 1961 to 2006? Is the probability to lose a variety the same for the different crop species when faced with extreme rainfall event? How do the different components of the rainy seasons contribute to variety losses? Has the farming system capacity to mitigate the risks of variety losses due to drought been reduced over the period with the increasing popularity of maize cultivated in place of sorghum and pearl millet, which are well known to be more resistant to drought?

4.2 Material and methods

4.2.1 Rainfall data

The Kenya Meteorological Department provided rainfall data from three stations in the neighbourhood of surveyed farmers. The three stations, namely Ishiara (S 0.45, E 37.78, alt. 872 m), Mitunguu (S 0.10, E 37.78, alt. 1189 m), and Embu (S 0.50, E 37.45, alt. 1433 m), are located at three different altitudinal levels (hereafter, low, mid and high levels, respectively). The stations had monthly and daily rainfall records encompassing the period 1961-2006 that have been analyzed in the recent study of Camberlin et al. (2012, for details). The onset date of the rainy season was defined as the first wet day of the first 2-day period recording at least 20 mm, not followed by a 10-day dry sequence, receiving less than 5 mm, in the next 20 days. To enable comparisons between the onset and the cessation of the rains, a symmetrical definition was adopted by Camberlin et al. (2012) for the cessation date of the rainy season. The onset and cessation dates of the Long Rains were determined by considering the February-June sub-periods. The duration of the seasons (Dur) was computed as the length in days between the onset and the cessation dates of the rainy season, as well as the number of rainy days over 1 mm (Nrd), and the seasonal amount (Ptot). The frequency of rain days during the rainy season (Frd) was computed as the number of rainy days divided by the duration of the rainy season. Finally, the daily mean intensity (Int) of the rains was computed as the seasonal rainfall amount divided by the number of rain days.

A statistical summary of rainfall variables from 1961 to 2006 is presented in table 4.1. The seasonal duration and the number of rainy days are significantly different between altitudes, with a marked increase from the lower to the higher altitudes. The same applies to the rainfall intensity, but it is not linearly related to altitude (Camberlin et al., 2012). The seasonal amount is not significantly different between the mid and high altitudes, and the frequency of rainy days only slowly increases with altitude. This is not surprising since the frequency of rainy days is a relative measurement, computed at a given altitude as the ratio between the number of rainy days and the seasonal duration. As both the number of rainy days and the seasonal duration strongly increase with altitude, the frequency of rainy days is likely to be only weakly related to altitudes. Furthermore, the interannual variations of seasonal rainfall are correlated among altitudes (r = 0.83 between low and mid, 0.89 between low and high, and 0.85 between mid and high), so that our sampling on three altitudes more emphasizes the role of interannual variability than spatial variability.

Table 4.1. Statistic summary of rainfall variables (duration of the season, number of rain days, seasonal amount, frequency of rainy days and daily mean intensity) for the 1961 to 2006 (46 years) period

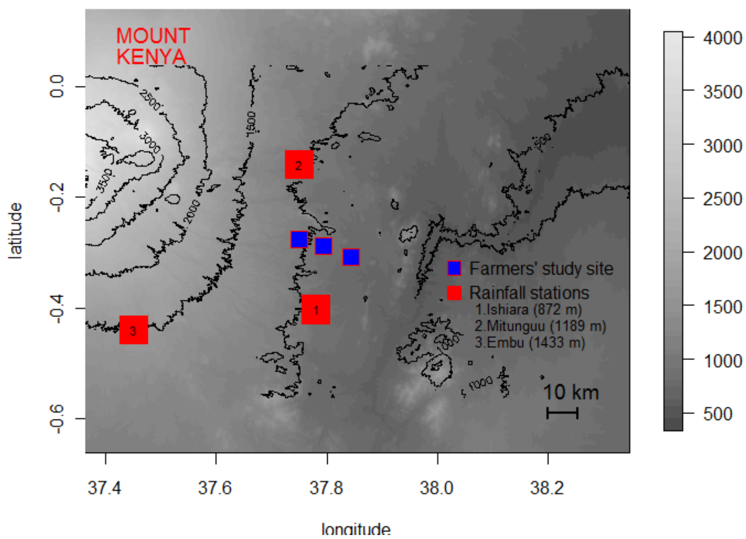
Variables	Low		Mid		High	
	mean (mm)	sd	mean (mm)	sd	mean (mm)	sd
Duration of the season (days)	51.8	23.1	64.4	20.6	91.2	26.9
Number of rainy days (days)	19.6	8.7	27.8	10.3	42.1	12.1
Seasonal amount (mm)	338.8	154.5	590.1	249.1	616.7	215.5
Frequency of rainy days	0.39	0.13	0.43	0.10	0.47	0.10
Daily mean intensity (mm/day)	17.2	4.9	21.5	5.4	14.6	3.3

4.2.2 Farmers' variety losses

Farmers surveyed were randomly sampled along a three-level altitudinal gradient (Figure 4.1) in order to broadly match to the altitude of rain gauges. The location of the three rainfall stations does not perfectly match that of the on-farm surveys, but they sample reasonably well the altitudinal gradients. The lowest rainfall station was associated to low altitude on-farm surveys, and so forth for the mid and high altitudinal levels. We concentrated our attention on relative (interannual) variations along the rainfall stations gradient, to analyze the yearly variations of variety losses along the on-farm surveys gradient. Frequency of rainy days was used to compare variety losses along the on-farm surveys gradient, as there are only small variations of this variable between altitudes.

Figure 4.1 Study site, Eastern slope of Mount Kenya showing the location of the three altitudes considered for the on-farm surveys and the rainfall stations

The retrospective survey assessing the number of varieties losses over time was carried out in



October 2009 by using the independent interview technique, whereby each farmer was interviewed individually and not in a group setting. The number of varieties lost was determined by referring to farmers' population variety names. The responses given by an individual farmer were not influenced by those given by a different farmer. A total of 195 farmers were surveyed at three altitudinal levels across three Meru communities: 45 at 750 m, 89 at 950 m, and 61 at 1100 m. The survey focused mainly on female farmers as Meru farming activities are mainly their domain (126 females against 82 males).

In retrospect, from 1961 to 2006, eight main crops, namely beans (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), finger millet (*Eleusine coracana*), green gram (*Vigna radiata*), maize (*Zea mays*), pearl millet (*Pennisetum glaucum*), pigeon pea (*Cajanus cajan*), and sorghum (*Sorghum bicolor*), have been identified as component of the rain-fed farming systems. For each crop variety, the year of its first acquisition, years of loss, and, for each loss, reasons given by farmers to explain the losses were recorded.

Data analysis

Data allowed analyzing of the dynamic of the cropping system on the yearly base. Crop species that were assembled into individual farming systems were never the same because of adoptions or abandons during the period. Crop responses to climate variability were analyzed by using logistic and smoothing models, the proportion of variety lost being the response variable. In both models, fitted values equal the logarithm of the odds. They can be transformed to probability using model parameters ($\alpha + \beta x$) and exponential function (Agresti, 2007).

Farmers have orally reported 3204 events of variety losses from 1961 to 2006, as compared to a total of 45025 farmers-crop-varieties cultivated all over the 46 years period. We first considered variety lost all over the period, before analyzing the proportion of variety lost yearly, controlling altitude and rainfall variable (Dur, Nrd, Ptot, Frd, or Int). To understand the part played by the different components of rainy season in crop failure, both individual species and the farming systems as a whole were analyzed.

4.3.1 Cropping system dynamics

The cropping system dynamic was assessed using the crop variety assemblage characterizing local farming systems from 1961 to 2006. For each crop species, the total number of farmer-varieties was divided by the number of farmers. Cropping system dynamic was thus shown as the year-to-year variations in the average number of varieties per farmer per crop. This intra-specific

$$P(x) = \exp^{\alpha+\beta x} / 1 + \exp^{\alpha+\beta x}$$

diversity was used as crop species popularity index. Considering the evolution in time of the numbers of varieties per farmer, Pearson's correlation test was implemented to know which crop species was substituted by which other. A positive correlation between two crops implied that both became synchronically more (or less) popular from 1961 to 2006, whereas a negative correlation implied increasing popularity for one and decreasing popularity for the other. This pattern was interpreted as a crop substitution, the crop losing popularity being over time replaced by the one that became more popular. Similarly, the number of varieties lost was also displayed per year as the average number of varieties lost per farmer.

4.3.2 Crop species and altitudinal effects

The proportion of varieties lost was analyzed at each altitudinal level all over the period 1961-2006, first without considering rainfall. The proportion of variety lost was thus considered globally and computed as the total number of variety lost divided by the total number of varieties cultivated by all farmers during the period. A preliminary analysis of data suggested a logistic regression model excluding interaction (Model 1) to assess the marginal effect of crop species, and of altitudes, on proportion of variety losses (response variable). Goodness-of-fit, $D^{2,}$ which is similar to R^2 in linear regression, corresponds to the percentage of explained deviance. It was estimated in each model by comparing null deviance to residual deviance of the minimal adequate model, $D^2 = 1 -$ *(model deviance/null deviance).* Model 1 was formalized as follows:

$$\log(p/q) = \alpha + \beta_1 crop_i + \beta_2 alt_j + \varepsilon_{ijk}$$

where p is the proportion of variety lost, q the proportion not lost, i = 1 to 8 species, j = 1 to 3 altitudes (low, mid and high, respectively). Weighted regression was carried out, using logit link function to ensure linearity, which was confirmed. Sample sizes were the total number of varieties cultivated by farmer grouped by crop and per altitude.

4.3.3 Impacts of rainfall variations on crop variety losses

4.3.3.1 Crop response to extreme rainfall events

Rainfall characteristics, notably the maximum and minimum seasonal amounts (Ptot), depend on altitude (Table 4.1, section 4.2.1). In order to control this interaction, the seasonal amount was transformed into ranked deciles. This transformation was done separately for each altitudinal level. Ranked into the same number of ordered categories, rainfall from different altitudes can be compared. The scientific advantage was that the most extreme droughts (i.e. the first deciles) or the heavy rainfall (the last deciles) were relative to each altitude, allowing testing of the crop response to drought by controlling interactions with altitudes.

Our attention focused on the conditional probability at the 1st decile, which was used to represent drought conditions. Chi squared statistic, with Monte Carlo simulation and 999 replicates, was computed separately for each crop species (conditional independence) in order to know if the number of variety lost was randomly distributed among rainfall classes. The proportion of varieties lost (and not lost) allows estimation of the probability to lose a variety. Under very dramatic water conditions (1st decile), the probability for a given crop to lose a variety was computed with 95 % confidence intervals.

4.3.3.2 Probability to lose a variety and rainfall threshold values

The number of varieties lost did not increase proportionally to decreasing rainfall values, as there was a threshold below which the number of varieties lost increased faster as rainfall value decreased. Linear models were thus not suitable to estimate such a threshold value. Smoothing model (Chambers and Hastie, 1992; Venables and Ripley, 2002), also called generalized additive model (GAM), which is usual in social sciences by allowing a non linear relationship between response and explanatory variables (Keele, 2008), was used to estimate the threshold value of rainfall from which the probability to lose a variety increased faster as the rainfall value decreased. This analysis was implemented for the nine years that were highly impacted by crop failures, sample size for other years being too small (with high variance) for robust estimations. Model 2 was formalized as follows:

$$\log(p/q) = \alpha + s(rain_i) + \varepsilon$$

where *s* is the smoothing function applied successively to different rainfall variables, *i* = Dur, Nrd, Ptot, Frd, or Int.

4.3.3.3 Probability to lose a variety and frequency of rainy days

A specific analysis was implemented with frequency of rainy days to compare crop response to climate variability. Model 3 was formalized as follows:

$$\log(p/q) = \alpha + \beta Frd + \varepsilon$$

Backward elimination procedure from the saturated to the minimal adequate model (Agresti, 2007; Crawley, 2007) was implemented to confirm that altitude is not a significant factor. Quasi-binomial error was used to consider over dispersion. This model was computed separately for each crop species to estimate the probability to lose a variety along the slope.

4.3.3.4 Increasing vulnerability of the farming systems from 1961 to 2006

The proportion of crop varieties that have been lost over time were analyzed in light of the interannual rainfall variability of the Long Rains. The proportion of varieties lost was thus considered yearly and computed as the total number of varieties lost divided by the total number of varieties cultivated by all farmers. Retrospective surveys implied that the number of farmers considered was yearly never constant in our sample, as old farmers started cultivating earlier than young farmers. Once a new crop species was adopted by an individual farmer, this crop was usually still cultivated the year after, but, depending on new adoptions or abandons, the crop species and the number of varieties cultivated were never the same over time. Binomial error and logistic analyzes allowed controlling of these variations by focusing on the proportion of varieties lost. Each year was thus individually considered to determine the total number of cultivated varieties, the total number of farmers, and the proportion of varieties lost.

The increasing vulnerability of the farming systems was tested by considering the relative popularity of each crop over time, using the methods proposed in sociology by Fox (1987; 2003), after Hastie (1992), for computing marginal effects. Preliminary analysis of data suggested a logistic regression model excluding interaction. A large part of variety losses was explained by rainfall and year. Crop was included as a variable of interest in Model 4, formalized as follows:

$$\log(p/q) = \alpha + \beta_1 crop_i + \beta_2 rain_j + \beta_3 year_k + \varepsilon_{ijk}$$

where i = 1 to 8 species, *j* = 1 to 5 rainfall variables (Dur, Nrd, Ptot, Frd, or Int), *k* = 1 to 46 years (1961-2006).

The year effect, controlling rainfall and crop, was considered in order to show how the probability to lose a variety increased during the period 1961-2006. If the farming system sensitivity to drought was constant over the period, year effects should have also been constant; if not, the increasing effect would imply that farming systems response to climate variability was not constant. Linear regression between fitted values of each year, and time from 1961 to 2006, was computed for all the five rainfall variables considered.

To consider the cropping system as a whole, marginal effects of each crop species, controlling rainfall and year, were weighted based on their yearly popularity, the sum of weight equaling 1. For instance if sorghum represented 70 % of crop diversity cultivated by farmers, and maize 30 % at a given year, the sorghum effect was weighted by multiplying it by 0.7, and the one of maize by 0.3, and so forth for each year. The cropping systems were thus considered as assembled crops, and its effect computed in each year as the mean of weighted crop effects, expressed in the scale of the fitted values. Analyses were done using R software (Team, 2010).

4.4 Results and discussion

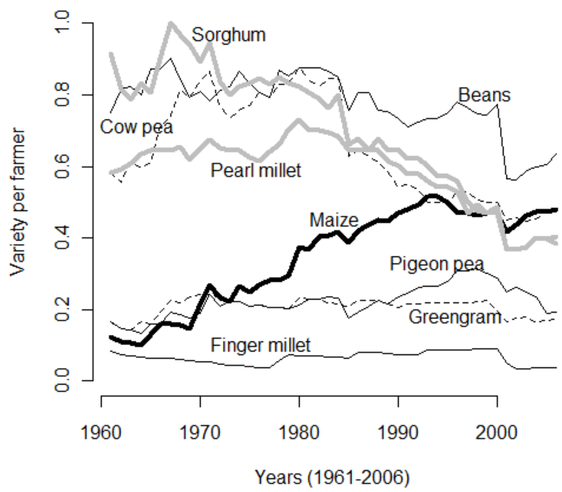
From 1961 to 2006, farmers cultivated a mean of 1.72 ($\sigma = 1.13$) varieties per species at the low level, 1.17 ($\sigma = 0.44$) at the mid level, and 1.15 ($\sigma = 0.39$) at the high level. However, intra specific diversity managed by farmers varied considerably during the period. The intra-specific diversity was used as an index of crop species popularity, revealing when maize became the dominant crop in place of sorghum and millet.

4.4.1 The cropping systems dynamics

At low level, maize popularity increased from 1960 to 1985, but sorghum and millet remained the dominant crops over the period (not shown). However, the decreasing popularity of sorghum (from 3.0 to 2.0 varieties per farmer during the period) was negatively correlated to the increasing popularity of maize (from 1 to 1.2 varieties per farmer; $r = -0.57$; $p = 0.001$). At mid level, the increase of maize popularity was significantly ($p = 0.001$) correlated to the decreasing popularity of sorghum ($r = -0.81$) and millet ($r = -0.55$). Maize popularity exceeded millet by 1980, and sorghum by 2000 (not shown).

At higher altitude (Figure 4.2), while the popularity of maize increased continually from 1970, that of sorghum and millet, well known to be resistant to drought, decreased from 1980. In 1970, pearl millet and sorghum were about three and four times more popular than maize, respectively. By 1990, maize adoption was stabilized and by 2000 maize became the dominant food crop in place of sorghum and millet.

Figure 4.2. Cropping system dynamic at high altitude (1961-2006). The popularity of sorghum and millet decreases during the period while that of maize increases



The dynamics of farming systems were generally not considered by models that simulate the future crop response to climate change, assuming continued use of current varieties and unchanged cultural practices. Figure 4.2 illustrates how farming systems were highly dynamic from 1961 to 2006. This dynamic is partly related to agricultural policies that positively valuated maize whereas sorghum and millet were devaluated, being perceived as "the crop of the poor people". Aside from being more resistant to pests and diseases, maize grew in popularity because it was easier to store and process than traditional food crops (Hassan and Karanja, 1997). Maize currently covers 25 M ha in Sub-Saharan Africa, largely in smallholder farming systems (SMALE et al., 2011). Figure 4.2 shows that the adoption of maize was stabilized from 1990. Climate variability, contraction of state subsidies and market support, progress in liberalizing of the maize seed industry, and erratic agricultural policies after structural adjustment explain maize stabilization from 1990 in East African countries (Byerlee and Heisey, 1997; Smale and Thom, 2003; Smale et al., 2011).

Favoring maize in place of sorghum remains a paradox as maize is more sensitive to drought than the latter. Impact of agricultural policies on cropping system dynamic has to be considered in addition to other factors, notably farmers' food preferences and market value of crop. Bernard, 1972 already noted by 1970 the remarkably rapid diffusion of maize in Meru as a consequence of new roads and markets, even in areas where the crop cannot be successfully grown. The increasing popularity of maize occurred even earlier, i.e. beginning of 1950, among Kikuyu communities located in the southern slope of Mount Kenya (Middleton and Kershaw, 1953). As maize was culturally favored with a positive valuation as compared to sorghum and millet, the current dynamic of agricultural systems thus implies many dimensions, which are not only economical or agronomical but also cultural.

4.4.2 Crop species and altitudinal effects

The mean number of variety losses during 1961-2006 period decreased with altitude with a mean of 4.6 varieties per farmer at low altitude ($\sigma = 3.6$), 3.05 at mid altitude ($\sigma = 1.9$), and 2.0 at high altitude ($\sigma = 1.4$). This altitudinal effect was observed for all species, but with different magnitude (Table 4.2, see section 4.3.2 for model details)

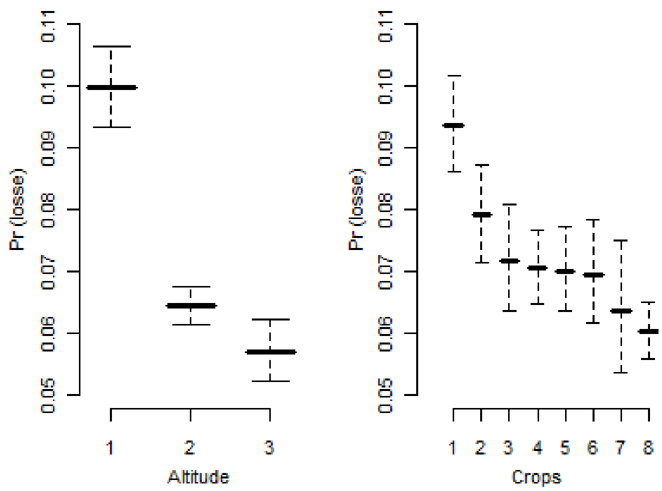
Table 4.2. Estimated parameters from Logistic regression model. Variety losses as function of altitude and crop species. 90.4 % of deviance explained.

	Estimate	Std. Error	z value	Pr(>|z|)	
Intercept	-2.51563	0.05909	-42.574	< 2e-16	***
Alt.low	0.60569	0.05937	10.202	< 2e-16	***
Alt.mid	0.12885	0.0527	2.445	0.014498	*
Cowpea	-0.31511	0.06943	-4.538	5.67E-06	***
Finger millet	-0.42155	0.10096	-4.176	2.97E-05	***
Green gram	-0.28982	0.07877	-3.679	0.000234	***
Maize	-0.18524	0.07024	-2.637	0.008359	**
Pearl millet	-0.30894	0.06634	-4.657	3.21E-06	***
Pigeonpea	-0.32489	0.07891	-4.117	3.84E-05	***
Sorghum	-0.47755	0.06318	-7.559	4.07E-14	***
Signif. codes: *** : 0.001; **: 0.01; *: 0.05					
Null deviance: 176.99 on 23 degrees of freedom					
Residual deviance: 16.9 on 14 degrees of freedom					
Min	1Q	Median	3Q	Max	
-1.998	-0.451	-0.079	0.317	1.806	

Probabilities to lose a variety from 1961 to 2006 given crop species and altitude are presented in Figure 4.3. The 95 % confidence intervals suggest that all of the effects were reasonably precisely estimated. The probability to lose a variety at low altitudinal level (0.1 ±0.007, at $\alpha = 0.05$) was about twice larger than the probability to lose at higher level (0.057 ± 0.005, at $\alpha =$

0.05). In terms of relative risk at low level, when one variety was lost ten were not lost, whereas at higher level for one variety lost about seventeen were saved. The probability of loss was also contrasted between crop species, being significantly higher for beans and maize as compared, respectively, to all other crops and sorghum.

Figure 4.3. Component and residuals from logistic regression computed without considering rainfall. LEFT PANEL: Altitude components (1. low, 2. mid, 3. high). RIGHT PANEL: Crop species components (1. beans; 2. maize; 3. green gram; 4. pearl millet; 5. cow pea; 6. pigeon pea; 7. finger millet; 8. sorghum). Y axis expressed in the scale of probability



Controlling altitude, the probability to lose a maize and bean variety (Figure 4.3, right panel, n° 2) was significantly higher than the probability to lose a sorghum variety (Figure 4.3, right panel, n° 8). At 95 % confidence interval, the probability to lose a variety was estimated from 0.086 to 0.101 for beans, and from 0.071 to 0.087 for maize, which were significantly higher than the probability to lose a sorghum variety (from 0.056 to 0.065). Such an analysis allows estimation of the effect of each factor, controlling the other, so that factor effects can be compared. The relative risk to lose a variety was about 30 % more for maize than sorghum. The probability of loss at low altitude is similar to the probability to lose a bean variety, whereas the probability to lose sorghum is close to the probability of loss at high altitude. We can deduce from the figure 4.3 that the risk to lose a variety highly increases for farmers cultivating beans and maize at low altitude.

4.4.3 Impacts of rainfall variation on crop variety losses

According to farmers, out of 3204 events of variety losses from 1961 to 2006, 81 % were due to rainfall variation. "Drought" was mentioned 73 % of times whereas 8 % of losses were associated with "heavy rainfall". In chapter 3, we compared farmers past climatic knowledge to rainfall records to show how highly accurate this knowledge is. Farmers' rainfall knowledge is both common and diverse, but largely under-considered in agro-climatic studies (see Orlove, 2005; Orlove et al., 2000; Phillipsa et al., 2002; Roncoli, 2006; Roncoli et al., 2001; Thomas et al., 2007a).

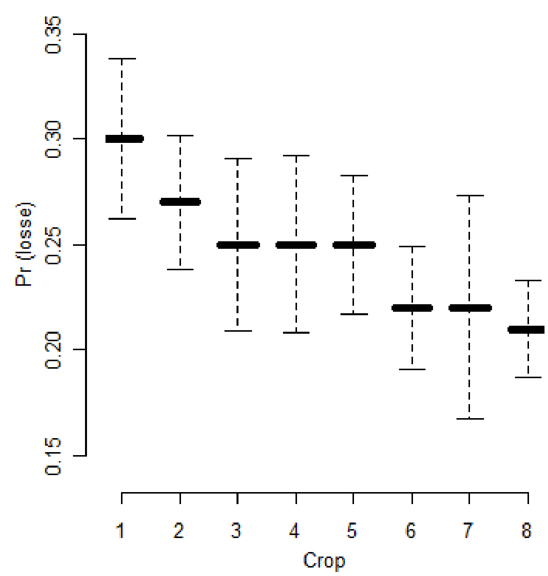
Table 4.3 Sample probabilities to lose a variety (Pr lost) as function of crop species (lines) and as a function of deciles of rainfall seasonal amount. Upper bounds (mm) of each decile was reported per altitude. More than 3200 events of variety losses were orally reported by farmers from 1961 to 2006, as compared to a total of 45025 farmers-crop-varieties cultivated all over the 46 years period.

Deciles	1	2	3	4	5	6	7	8	9	10
Alt. low (mm)	141	214	246	277	321	398	422	479	550	614
Alt. mid (mm)	341	384	457	490	529	610	703	842	880	1204
Alt. high (mm)	385	464	496	551	590	634	700	792	910	1118
Maize	0.3	0.03	0.08	0.01	0.02	0.03	0.1	0.05	0.08	0.01
Beans	0.27	0.03	0.07	0.02	0.04	0.04	0.2	0.03	0.09	0.01
Pigeon pea	0.25	0.03	0.08	0.04	0.03	0.03	0.07	0.03	0.08	0.01
Greengram	0.25	0.02	0.06	0.04	0.04	0.04	0.08	0.03	0.09	0.02
Cowpea	0.25	0.03	0.06	0.03	0.03	0.03	0.08	0.04	0.08	0.01
Pearl millet	0.22	0.02	0.08	0.07	0.06	0.07	0.07	0.05	0.06	0.01
Finger millet	0.22	0.01	0.11	0.03	0.04	0.04	0.05	0.02	0.08	0.01
Sorghum	0.21	0.02	0.05	0.07	0.07	0.06	0.05	0.05	0.05	0.01
Total size (n)	**5221**	**4543**	**4068**	**4602**	**4017**	**4998**	**3961**	**5149**	**3928**	**4538**
Losses	**1267**	**109**	**279**	**204**	**191**	**231**	**371**	**214**	**286**	**52**
Pr (losses)	**0.243**	**0.024**	**0.069**	**0.044**	**0.048**	**0.046**	**0.094**	**0.042**	**0.073**	**0.011**

The distribution of Pearson's residuals across rainfall classes and all altitudes reveals that variety losses were determined by low rainfall value (Figure not shown, p=0.001 from Monte Carlo simulations). For all crops, a highly significant (> 4) positive Pearson's residuals were observed for the first decile, whereas they were not significant or negative for higher deciles (2nd to 10th decile), except for beans that was significantly impacted by high rainfall in the 7th decile. The impact of heavy rainfall on crop variety losses is therefore quite small, being limited to one crop (beans), but all crop species were severely impacted by drought.

The proportion of varieties that have been lost (and not lost) allows estimation of the probability to lose a variety. Under very critical water conditions (first decile), figure 4.4 shows that the probability to lose a variety was significantly higher for maize (from 0.26 to 0.33), as compared to pearl millet (from 0.19 to 0.25) and to sorghum (from 0.18 to 0.23). Beans (from 0.24 to 0.30), which was the most popular crop over the period, was along with maize more sensitive to drought.

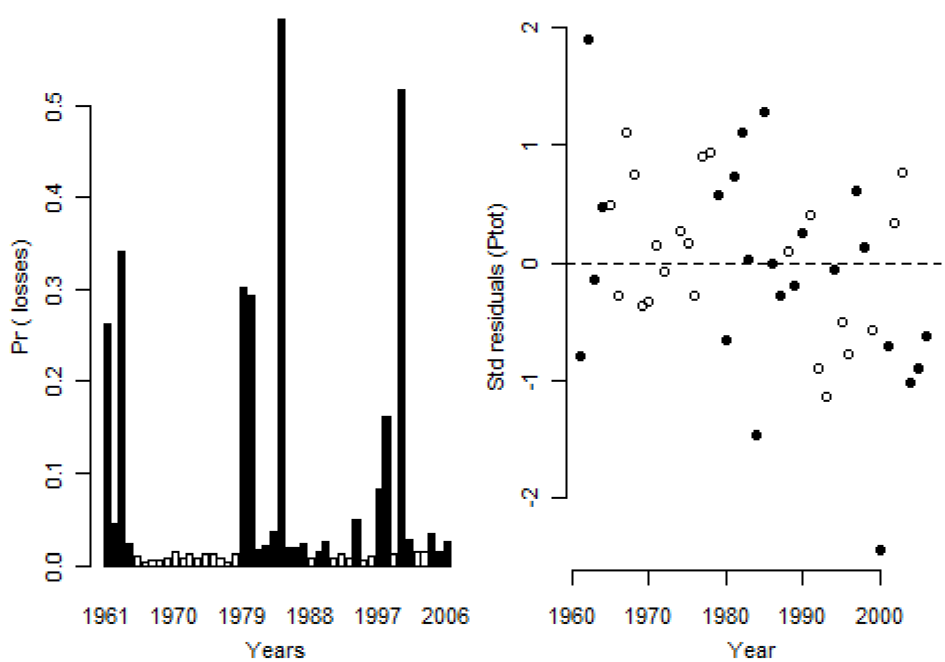
Figure 4.4. Crop probability to lose a variety under extreme drought condition (corresponding to the first decile of seasonal amount estimated at each altitude);1. maize; 2. beans; 3. pigeon pea; 4. green gram; 5. cowpea; 6. pearl millet; 7. finger millet; 8. sorghum. Bar errors display 95 % confidence interval



The seasonal rainfall values delimiting the deciles at each altitude (reported in Table 4.2 as upper bounds) allow consideration of the spatial variability of seasonal rainfall and crop adoption into the analysis. The values delimiting the deciles at the mid and high altitudes globally coincide, but the range of values delimiting the deciles at the low altitude is by far lower than higher altitudes. The 5th to 10th deciles at the low altitude range from 321 mm to 614 mm, which correspond to the 1st to the 6th deciles at the mid altitude. When varieties less tolerant to drought are faced with an extreme event of 400 mm in high altitude (1st or 2nd deciles), this situation corresponds to a "normal" year in low altitude, i.e. 400 mm falls at the 6th and 7th deciles. Adoption of a variety usually cultivated at high altitude by farmers living at low altitude implies an increasing risk of variety losses. During the "normal" years (at the 7th deciles of low altitude in table 2, probabilities to lose a variety ranged from 0.05 for sorghum to 0.1 for maize). So, moving crops from highlands to lowlands is likely to increase the vulnerability of the low latitude farming systems to climate.

The number of varieties lost per farmer was assessed yearly from 1961 to 2006. Variety losses independently reported by farmers mainly concerned nine years, all of them, except for 1962, being above the yearly mean of the period. The nine highly impacted years represent 83 % of variety losses over the period. The maximum was reached in 1984 with a mean of 3.5 varieties lost per farmer (Figure 4.5, left panel).

Figure 4.5. Left panel: Number of variety losses per farmer from1961 to 2006 (all altitudes). Nine years were more impacted than others (over the mean of the period). Bold bars represent year's probability that is over the median. Right panel. Standardized residuals based on the mean seasonal amount from 1961 to 2006. Bold points represent years over the median displayed in the left panel. Variety losses occurred during extreme years as well as during "normal" year, notably after 1980.



These years partly correspond to droughts (− 1 SD) inventoried by several authors for Kenya (Mbithi and Wisner, 1973;

Newman, 1975; Nyamwange, 1995; Ogallo et al., 2005), the 1984 drought being considered as the worst in the last century. Variety losses also occurred during heavy rainfall (+ 1 SD), but majority occurred during "normal" seasons (Figure 4.5, right panel).

Extreme events such as drought and heavy rainfall are relative not only to the altitude but also to the crop under consideration. If cultivating of highland crops at lowlands increases the risk of variety losses during the "normal" season, conversely, we cannot exclude that crops that are less tolerant to heavy rainfall at low altitude are more likely to be impacted during "normal" season in mid and high altitude (above the 6^{th} deciles in Table 4.2). Indeed, at this altitude, the seasonal amount bound of the 6^{th} decile (610 and 634 mm respectively) are comparable to the maximum seasonal amount experienced by crops at the low altitude (614 mm). In addition, crops adapted to low altitude are likely to be less impacted by drought at high altitude (see chapter 5).

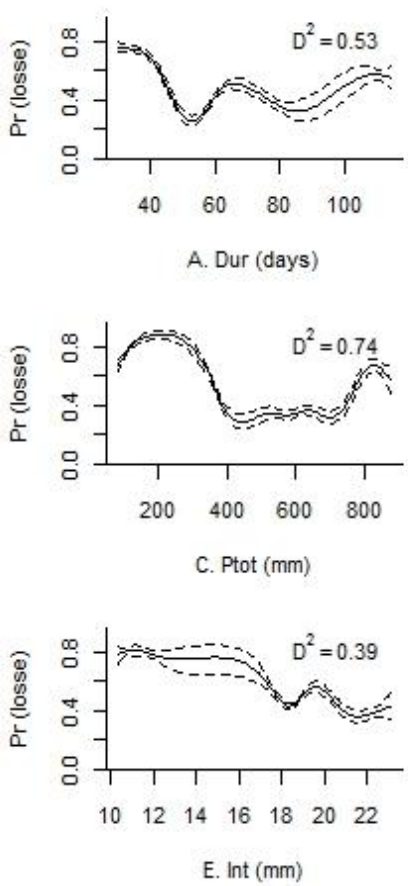
No relation was established between years of El Niño Southern Oscillation (ENSO) and the nine highly impacted years. According to Indeje et al. (2000), during the ENSO onset years, drier than normal conditions are expected in central Kenya during the dry season from June to September and that is outside the Long Rains. This corresponds to the cropping inter-season period on Mount Kenya, and it is probably why ENSO has no significant impact on variety losses.

The role played by extreme events and "normal" seasons in variety losses can be assessed if the probability to lose a variety varies as a function of the interannual rainfall variations. Probabilities should increase as both the rainfall values decrease (the case of drought) or increase (the case of heavy rainfall), but should be constant between these two extreme rainfall events.

The effect of rainfall variation on the probability to lose a variety is not linear. All rainfall variables had an increasing effect on variety losses as their values decreased, except seasonal duration. Goodness of fit D^2 ranged from 0.39 to 0.82 suggesting that model parameters were reasonably precisely estimated for all rainfall variables (see section 2.3.3.2, for model details). The threshold value must be considered as an average value computed along the slope of the mountain. Probability to lose a variety increased for seasons for which the duration (Dur) was less than 50 days, the number of rainy days (Nrd) was less than 28, the seasonal precipitation amount (Ptot) was less than 400 mm, and the frequency of rainy days (Frd) was less than 0.6. Among the five rainfall variables analyzed, frequencies of rainy days (Frd) better explains variety losses in retrospect from 1961 to 2006 (D^2 = 82 %). Figure 4.6 also shows that probability to lose a variety increased slightly when rainfall variables reached higher values.

Figure 4.6. Threshold effects computed with the nine highly impacted years using smoothing model. Y axis is expressed in the scale of probability to lose a variety. X axis is expressed in the scale of the rainfall variable considered: A. Season duration (DUR); B. Number of rainy days per season (Nrd); C. Seasonal precipitation amount (Ptot); Frequency of rainy days (Frd); E. Intensity of rain (Int). From 39 % to 82 % of deviance explained.

Indeed, there is a secondary increase of risk toward the right side of the plots (i.e., for higher



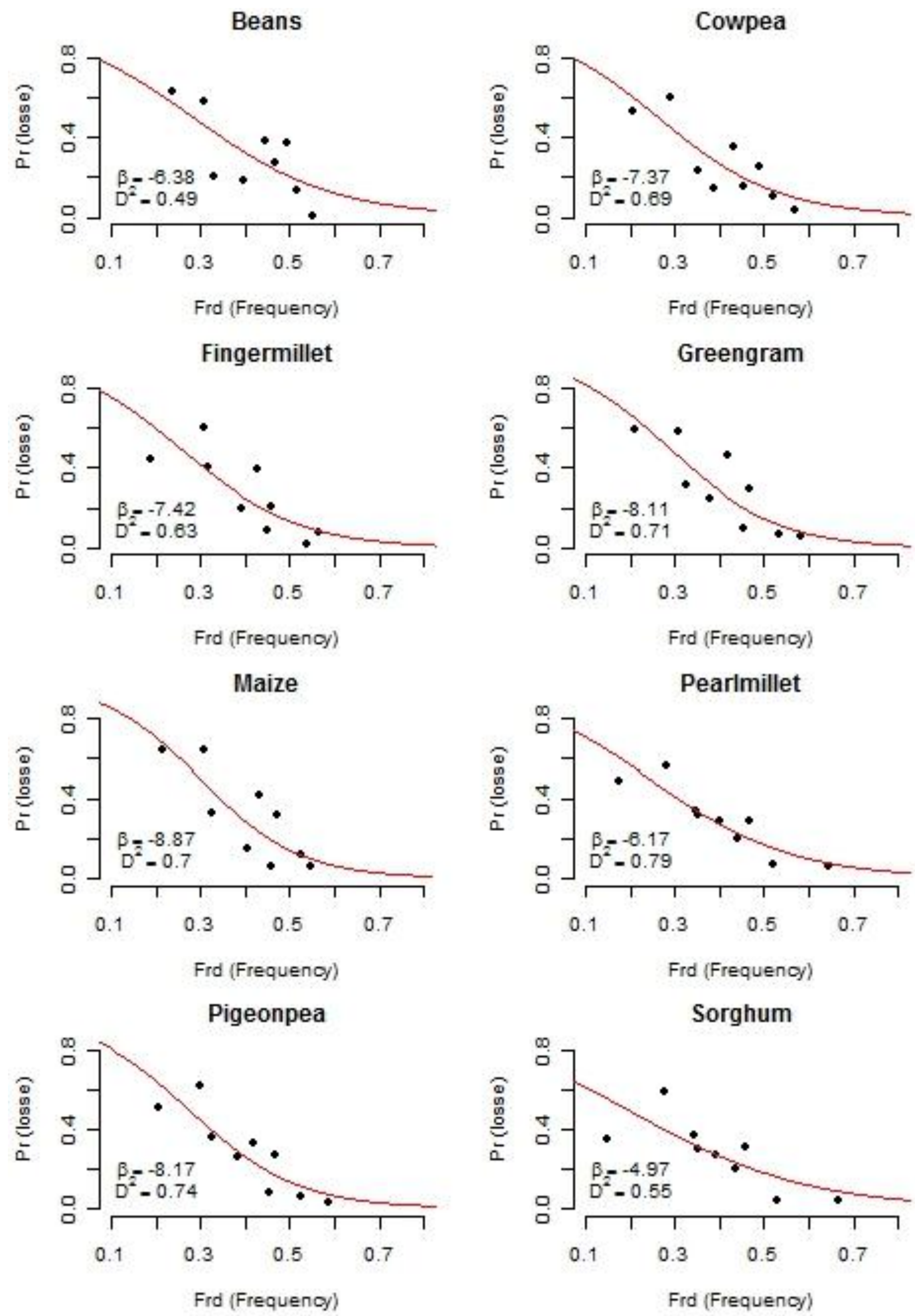
values of the climate variables), at least for Dur, Nrd and Ptot. That is well illustrated with seasonal amount (Ptot). The probability to lose a variety increases below 400 mm and above 700 mm, but remains constant between these values. The increasing probability of losses below 400 mm seasonal amount corresponds to drought condition at both mid and high altitude (1st and 2nd deciles, Table 4.2) and to the "normal" seasonal amounts at low altitude, which are usually below 400 mm (6th deciles and below, Table 4.2). The increasing rate of variety losses due to heavy rainfall mainly concerns the 9th decile (Table 4.2), which corresponds to the seasonal amounts range between 700 and 900 mm in figure 4.6c.

What is intriguing is that Frd is almost linearly related to losses. Intra seasonal variations, notably the length of the dry spells occurring after seed germination, can cause variety losses (Chapter 5). It is reasonable to think that the number of prolonged dry spells within the season increases as the frequency of rainy days decreases, so by increasing the risk of variety losses, whereas high frequency of rainy days limit this risk.

Figure 4.7 shows per crop species how the probability of variety losses increased as the frequency of rainy days decreased. Goodness of fit D^2 ranged from 0.49 to 0.79, depending on crop species considered, suggesting that model parameters were reasonably precisely estimated for all crop species (see section 4.3.3.3 for model details). Sample sizes were the total number of varieties cultivated per crop, considering the more impacted years for robust estimations. The magnitude of parameter β in the equation determines how fast, for different species, the proportion of variety lost increases as the rainfall value decreases. It allows estimation of the percentage of variety losses at a given rainfall value.

For all crop species, the probability to lose a variety was influenced by rainfall variation. If there was an average of one rainy day per week during the season, the model estimated that on average about 70 % of varieties should be lost. The β parameters were not significantly different from crop to crop as all crop species inevitably failed under very dramatic water conditions. However, the relationship between the frequency of rainy days and the probability to lose a variety was steeper for maize (β: 8.87) as compared to pearl millet (β: 6.17) and sorghum (β: 4.97).

Figure 4.7. Probability to lose a variety as a function of the frequency of rainy days (Frd). Each dot represent one of the nine highly impacted years during the period 1961-2006. From 49 % to 79 % of deviance is explained.



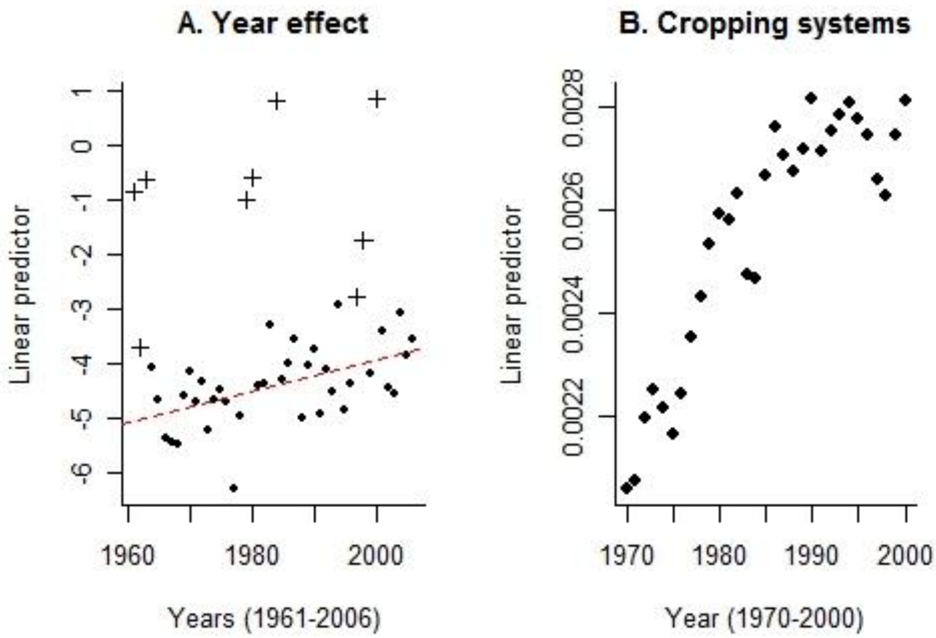
4.4.4 Increasing vulnerability of the farming systems from 1961 to 2006

In sum, our analysis shows that the popularity of crops less resistant to drought (maize and beans) increased or remained constant from 1961 to 2006, whereas the popularity of crops more resistant to drought (pearl millet and sorghum) decreased. The consequence is that the cropping system dynamic itself induced an increasing risk of variety losses over the period, even during the "normal" years.

The proportions of crop varieties that have been lost over time were analyzed in light of the interannual rainfall variability of the Long Rains. 93.7 % of deviance was explained with quasi binomial error. Analyzes concerned both year and crop effects over the period. Farming system sensitivity to drought was indeed not constant from 1961 to 2006 (Figure 4.8, left panel, see section 4.3.6 for model details). A linear regression was computed on "normal" years (dots with dashed line), and the effect of years, controlling effects of crop and rainfall, increased significantly from 1961 to 2006 ($p < 0.05$) for all the five rainfall variables considered. In the right panel (Figure 4.8), analysis focuses on the 1970-2000 period, which corresponds to the substitution of sorghum and pearl millet by maize (see section 4.4.1). In this case, cropping systems effects were estimated yearly by considering the relative popularity of crops species assembled in cropping systems (section 4.3.3.4 for model details). The probability to lose a variety increases exponentially from 1970 to 2000, with a stabilization from 1990.

Lyon and Dewitt (2012) have shown that a significant decrease of seasonal amount occurs in the Long Rains during the post-1999 period. We have computed the linear trends of the rainfall variables for the 3 stations from 1961 to 2006. All the stations display negative trends for seasonal rainfall, but they are not significant (both Pearson and Spearman trends). However, there are significant downward trends for the frequency of rain days at high (95 % c.i.) and low altitudes (90 % c.i.). Most other variables display no significant trends at any of the three altitudes. The dynamic of the farming systems remains a key factor in the increase of vulnerability of smallholder farmers faced with drought, although rainfall trends may marginally contribute as well.

Figure 4.8. Increasing risk of variety losses estimated by logistic regression model. LEFT PANEL: Year effect s on variety losses, given frequency of rainy days and crop from 1961 to 2006; crosses represent the nine more impacted year and dots the normal years; Regression line was computed on the normal year during which the risk of variety losses significantly increases. Y axis is expressed in the scale of fitted values. RIGHT PANEL: Cropping systems effect weighted on crop yearly popularity, given frequency of rainy days and year from 1970 to 2000, ; effect increased exponentially during the period



Models outputs (which can include crop, socio-economic and climate components) are used to assess the vulnerability of farmers and cropping systems to climate change. However, as stated by Berry et al (2006), the results from such approaches showed that the vulnerability of both farmers and species depends on the scenario under consideration, and on underlying hypotheses that allow projection into the future. Our study was based on a retrospective survey allowing reconstruction of past farming systems and diachronic analysis. Our results suggest that changes in farming systems (section 4.4.1) substituting crops resistant to drought by those less resistant to drought induced an increasing risk to lose varieties over the period, even during the "normal" seasons. As many farmers turned to maize cultivation in place of sorghum and pearl millet, notably under the impulsion of agricultural policies, the farming system capacity to mitigate the risks of variety losses due to drought was reduced during the period 1961-2006. The five rainfall variables analyzed did not equally explain variety losses (section 4.4.3, Figure 4.6). Frequency of rainy days, the seasonal precipitation amount, and the number of rainy days during the season better explained variety losses than seasonal duration and rainfall intensity.

Smallholder rain-fed agriculture is a key economic sector for many developing countries, representing a relatively important part of gross domestic products (Hansen, 2002; Hansen et al., 2007; Oram, 1989). The success of rain-fed agricultural systems largely depends on rainfall variability. Vulnerability is also a consequence of rainfall unpredictability (Hansen, 2002). If crop genetic diversity that is still today managed by smallholder farmers is a means to mitigate the negative impacts of rainfall variability, combining ecological anthropology, climatology, and agronomy could help to preserve these systems against genetic erosion and variety losses.

4.5 Conclusion

The purpose of this paper was to document the impact of rainfall variability on rain-fed agriculture systems managed by East African smallholders, considering their dynamic. The retrospective survey and the farmers' memory based approach allowed diachronic analyses to show how, faced with drought, the cropping system dynamic itself induced an increasing risk of crop failure over time, and, as a direct consequence, an increasing risk to lose seeds that farmers used to perpetuate their homeland varieties. From year to year, the increasing popularity of maize cultivated in place of sorghum and pearl millet, which are well known to be more resistant to drought, have modified crop assemblage characterizing farming systems, and reduced its capacity to mitigate the risk of crop failure when faced with drought.

The possibility for the cropping system to return, after a variety loss, to its previous level of variety diversity directly concerns its resilience (Holling, 1973; Holling, 1986; Holling, 2001). In a resilient social–ecological system as defined by Folke (Folke, 2006), disturbance has the potential to create opportunity for doing new things, for innovation and for development, by emphasizing non-linear dynamics rather than linear one. Indeed, the remarkable capacity for traditional cropping systems to get back varieties lost impose to underline the crucial role of the informal seed supply systems, which are based on social relations that also work outside of the agricultural domain.

Bellon et al. (2011) assessed the vulnerability of traditional maize seed systems to climate change in Mexico. The structure and spatial scope of seed systems of twenty communities in four transects across an altitudinal gradient from 10 to 2980 meters above sea level in five states of eastern Mexico were studied. Results indicate that 90 % of all the seed lots are obtained within 10 km of a community and 87 % within +/- 50 m altitudinal range. Other studies have shown how crucial the role of social relations is in seed supply (Badstue et al., 2006; Leclerc and Coppens d'Eeckenbrugge, 2012; McGuire, 2008), but all analysis were based on a synchronic perspective, not diachronic.

The functioning of such a system remains unknown when we consider it over time, and when it is linked to rainfall variability. Does the seed supply system work differently if droughts are severe? If variety losses mainly concerned farmers living at lower altitudinal levels, do farmers go to the upper level to recover the variety? Do they seek the variety from other farmers or go to the local market to acquire the lost variety?

4.6 References cited in chapter 4

Agresti A. (2007) *An introduction to categorical data analysis*. Wiley, Gainesville, Florida, USA. pp. 373.

Badstue L.B., Bellon M.R., Berthaud J., Juarez X., Rosas I.M., Solano A.M., Ramírez A. (2006) Examining the role of collective action in an informal seed system: A case study from the Central Valleys of Oaxaca, Mexico. *Human Ecology* 34 (2),249-273.

Bellon M.R., Hodson D., Hellinc J. (2011) Assessing the vulnerability of traditional maize seed systems in Mexico to climate change. *Proceeding of the National Academy of Sciences* 108 (33),13432–13437.

Bernard F.E. (1972) *East of mount Kenya : Meru agriculture in transition*. Weltforum Verlag, München. pp. 176.

Berry P.M., Rounsevell M.D.A., Harrison P.A., Audsley E. (2006) Assessing the vulnerability of agricultural land use and species to climate change and the role of policy in facilitating adaptation. *Environmental Science & Policy* 9,189-204.

Byerlee D., Heisey P. (1997) (Ed.) *Africa's Emerging Maize Revolution*, Lynne Rienner Publishers, Boulder, CO. pp. 301.

Camberlin P., Boyard J.-M., Philippon N., Baron C., Leclerc C., Mwongera C. (2012) Climatic gradients along the windward slopes of Mount Kenya and their implication for crop risks. Part 1: climate variability. *International Journal of Climatology* [online] http://onlinelibrary.wiley.com/doi/10.1002/joc.3427,17.

Chambers J.M., Hastie T.J. (1992) *Statistical models in S*. Wadsworth & brook / cole, Computer Science Series.pp.500.

Crawley M.J. (2007) *The R Book*. John Wiley & Sons, Chichester, West Sussex, England.pp. 950.

FAO. (2008) *Diversity of experiences. Understanding change in crop and seed diversity*. Food and Agriculture Organization of the United Nations, Rome, Italy. pp. 42.

Folke C. (2006) Resilience: The emergence of a perspective for ‚social–ecological systems analyses. *Global Environmental Change* 16,253–267.

Fox J. (1987) Effect displays for generalized linear models. *Sociological Methodology* 17,347–361.

Fox J. (2003) Effect displays in R for generalised linear models. *Journal of Statistical Software* 8 (15),1-9.

Glantz M.H. (1987) (Ed.) *Drought and hunger in Africa: denying famine a future*, Cambridge University Press, Cambridge. pp. 457.

Hansen J.W. (2002) Realizing the potential benefits to agriculture: issues, approaches and challenges. *Agricultural Systems* 74,309-330.

Hansen J.W., Challinor A., Ines A.V.M., Wheeler T., Moron V. (2007) Translating climate forecasts into agricultural termes: advances and challenges. *Climate Research* 33,27-41.

Hassan R.M., Karanja D.D. (1997) Increasing Maize Production in Kenya: Technology, Institutions and Policy. In Africa's Emerging Maize Revolution, eds. D. Byerlee and C.K. Eicher. Boulder: Lynne Rienner Publishers, in: D. Byerlee and C. K. Eicher (Ed.), *Africa's Emerging Maize Revolution*, Lynne Rienner Publishers, Boulder. pp. 81-94.

Hastie T.J. (1992) Generalized additive models. In Chambers, J. M., and Hastie, T. J. (eds.) Statistical Models in S, Wadsworth., in: J. M. Chambers and T. J. Hastie (Ed.), *Statistical Models in S*, Wadsworth & Brooks, Cole, Pacific Grove, California, USA. Pages 250-308.

Holling C.S. (1973) Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4,1-23.

Holling C.S. (1986) The resilience of terrestrial ecosystems: local surprise and global change, in: W. C. Clark and R. E. Munn (Ed.), *Sustainable Development of the Biosphere*, Cambridge University Press, London, England. pp. 292–317.

Holling C.S. (2001) Understanding the complexity of economic,ecological, and social systems. *Ecosystems*(4),390-405.

Hyman G., Fujisaka S., Peter J., Wood S., de Vicente M.C., Dixon J. (2008) Strategic approaches to targeting technology generation: Assessing the coincidence of poverty and drought-prone crop production. *Agricultural Systems* 98,50-61.

Indeje M., Semazzi F.H.M., Ogallo L.J. (2000) ENSO signals in East African rainfall seasons *International Journal of Climatology* 20,19-46.

Jaetzold R., Schmidt H., Hornetz B., Shisanya C. (2007) *Farm management handbook of Kenya (2nd edition), vol.II : natural conditions and farm management information, part C east Kenya*. Min of Agriculture, Kenya. pp. 573.

Jones P.G., Thornton P.K. (2003) The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change* 13,51-59.

Keele L.J. (2008) *Semiparametric regression for the social sciences*.. John Wiley & Sons Ltd, Chichester. pp. 230.

Leclerc C., Coppens d'Eeckenbrugge G. (2012) Social organization of crop genetic diversity The G x E x S interaction model *Diversity* 4,1-32.

Lobell D.B., Burke M.B., Tebaldi C., Mastrandrea M.D., Falcon W.P., Naylor R.L. (2008) Prioritizing climate change adaptation needs for food security in 2030. *Science* 19,607-610.

Mbithi P., Wisner B. (1973) Drought and famine in Kenya: magnitude and attempted solutions. *Journal of East African Research and Development* 3,95-143.

McGuire S.J. (2008) Securing access to seed: social relations and sorghum seed exchange in Eastern Ethiopia. *Human Ecology* 36,217-229.

Middleton J., Kershaw G. (1953) *Central Tribes of the North-Eastern Bantu: The Kikuyu Including Embu, Meru, Mere, Chuka, Mwimbi, Tharaka, and the Kamba of Kenya*. Hazell, Watson & Viney, London. pp. 105.

Newman J.L. (1975) *Drought, famine, and population movements in Africa*. Syracuse University, Syracuse, USA. pp. 149.

Nyamwange M. (1995) Famine Mitigation in Kenya: Some Practices, Impact and Lessons. *Middle States Geographer* 28,37-44.

Ogallo L.J., Otengi S.B., Ambenje P., Nyakwada W., Githui F. (2005) Monitoring agricultural drought : the case of Kenya., in: V. K. Boken, et al. (Ed.), *Monitoring and predicting agricultural drought: a Global Study*, Oxford University Press, New-York, USA. pp. 238-251.

Oram P.A. (1989) Sensivity of agricultural prediction to climatic change, an update,in: *International symposium on climate variability and food security in developing countries*,New Delhi, India,25-44.

Orlove B.S. (2005) Human adaptation to climate change: a review of three historical cases and some general perspectives. *Environmental Science & Policy* 8,589–600.

Orlove B.S., Chiang J.C.H., Cane M.A. (2000) Forecasting Andean rainfall and crop yield from the influence of El Niño on Pleiades visibility. *Nature* 403,68-71.

Ouma J.O., Murithi F.M., Mwangi W., Verkuijl H., Gethi M., Groote de H. (2002) *Adoption of maize seed and fertilizer technologies in Embu district, Kenya*. CIMMYT, Kenya, Mexico, D.F. pp. 34.

Phillipsa J.G., Deaneb D., Unganaic L., Chimelia A. (2002) Implications of farm-level response to seasonal climate forecasts for aggregate grain production in Zimbabwe. *Agricultural Systems* 74 (351–369).

Roncoli C. (2006) Ethnographic and participatory approaches to research on farmers' responses to climate predictions. *Climate Research* 33,81-99.

Roncoli C., Ingram K., Kirshen P. (2001) The costs and risks of coping with drought: livelihood impacts and farmers' responses in Burkina Faso. *Climate Research* 19,119–132.
Smale M., Thom J. (2003) Maize in Eastern and Southern Africa: seeds of success in retrospect. *EPTD Discussion Papers* 97,1-90.
Smale M., byerlee D., Layne T. (2011) Maize revolution in Sub-Saharan Africa. *Policy Research Working Paper* 5659,1-34.
Team R.D.C. (2010) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, http://www.R-project.org, Vienna, Austria.pp. 409.
Thomas D.S.G., Twyman C., Osbahr H., Hewitson B. (2007) Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change* 83,301-322.
Thornton P.K., Jones P.G., Alagarswamy G., Andresen J. (2009) Spatial variation of crop yield response to climate change in East Africa. *Global Environmental Change* 19,54–65.
Venables W.N., Ripley B.D. (2002) *Modern applied statistics with S*. Springer, New-York, USA.pp. 495.
Waddington S.R., Li X., Dixon J., Hyman G., de Vicente M.C. (2010) Getting the focus right: production constraints for six major food crops in Asian and African farming systems. *Food Security* 2,27-48.

5 Social process of adaptation to global environmental changes. How Eastern African societies interfere between crop and climate

Abstract

Climate change with longer dry spells during crop emergence can cause sowing failures. However, studies on climate change can only be conducted on a long-time scale, and observing how societies adapt their sowing practices to climate variability is challenging and costly to conduct. In this paper, as an alternative, we use a space-and-time substitution design among eastern African smallholders, where change in space correspond to that induced in time by environmental change. The Tharaka community originating from Mount Kenya eastern slopes semi-arid lowlands (750 m) moved up in midlands (950 m) with their lowlands adapted resources whereas the Mwimbi community originating from wetter upland (1100 m) moved down in midlands with their highlands adapted genetic resources. The aim of this paper is to show that societies interfere between crop and climate, and farmers' practices and knowledge, as well as the genetic resources that they manage, are an integral part of the social process of adaptation to climate change. A weather station was installed at 950 m and 1100 m, and GLM logistic model used to analyse the probability of sowing failure as a function the length of dry spells after sowing. 1691 plots among 40 surveyed farmers were used to compare Mwimbi and Tharaka in the same agro-climatic zone, as well as Mwimbi in midlands and highlands, during two year and four growing seasons, controlling crop species. In midlands, while the crop relative importance, the number of varieties, the sowing practices and the seed management are closely similar between Mwimbi and Tharaka, impact of dry spells on crop sowing failure is not uniform between the two communities in midlands. The relative risk of sowing failure was 3.3 times more for Mwimbi than for Tharaka during the Short Rains, and 1.5 times more during the Long Rains. GLM logistic regression confirmed that the seeds sown by Tharaka failed less than those sown by Mwimbi. Historical and social factors had more influence on mitigating risk of sowing failure due to dry spells than altitude, which was not a significant factor when comparing Mwimbi in midlands and highlands. Our results clearly show that crop genetic adaptability

depends on farmer community that historically manages it. This social factor must be reflected in crop genetic sampling strategies used in breeding programmes to foster genetic adaptation.

5.1 Introduction

Crop genetic diversity is a key factor for long-term viability, and adaptation to changing environmental conditions (Hammer and Teklu, 2008). It helps preventing crop failure (Altieri, 1994; Vandermeer, 1989), contributes to more resilient systems and limits susceptibility to pests and diseases (Tonhasca and Byrne, 1994). A wide gene pool is essential for world food security and as a source of materials for breeding new plant varieties to mitigate current and future production risks. In particular, the ability of agricultural systems to mitigate climate risk lies in genetic diversity (Kotschi, 2007; Lin, 2011; Sgrò et al., 2011). Genetic diversity is therefore crucial to ensure resilience of farming systems in the present context of environmental change. This is also true at the farm level, particularly where local landraces still exist. Selected and reproduced by farmers for many generations, landraces are likely to be locally adapted (Wood and Leene, 1997) and maintain a high adaptation potential.

In smallholder agriculture systems, rainfall distribution is a key input to the success of a crop growing cycle. Prolonged dry spells during the wet season are common and can cause crop failures and seed losses (Araya et al., 2010; Barron et al., 2003; Segele and Lamb, 2005). One main concern for farmers is that crops obtain adequate soil moisture for seedling emergence and throughout the vegetative and reproductive phases (Maracchi et al., 1993; Marteau et al., 2011). Marteau et al. (2011) showed that most of the sowing failures of pearl millet in Niger were related to long dry spells (> 7 days). Long dry spells that occur after sowing induce a water stress to the newly emerging seedlings, contributing to their mortality.

Many farmers around the world observe rainfall patterns at the beginning of the rainy season with one question in mind: is it the right time to sow? Predicting rainfall and synchronizing the sowing to ensure better water conditions for crop emergence remains a key challenge for farmers. The high variation in the onset, cessation and length of the growing season points out to the risk of sowing too early or too late and subsequently the risk of sowing failures. Many strategies are used by farmers to mitigate this risk. The ways of interpreting rainfall signals at the beginning of the season, and the decision of sowing, is not uniform among farmers. They do not sow all crop species at the same time. As such, length of dry spells after sowing cannot be considered as a factor that is independent of farmers' practices. Farmers directly interfere in the length of dry spells by choosing different sowing dates.

Farmers' sowing practices and the origins of genetic resources are potentially different from one farming community to another, but such a social factor is rarely considered. Yet, studying how societies today interfere between crop and climate to mitigate the negative impacts of rainfall variations should allow a better understanding of the social process of adaptation to climate changes in the future.

The eastern slope of Mount Kenya is a particularly relevant region to study how societies mitigate the risk of crop failure during seedling emergence. Over the mountain, agriculture is rain-fed, making rainfall a key factor in crop production. The region, at altitudes ranging from 750 to 1100 m asl, receives relatively low (600-900 mm mean annual rainfall) and highly variable rainfall (Camberlin et al., 2012) and farming communities are characterized by a high cultural diversity (Fadiman, 1982, 1993; Heine and Moehlig, 1980; Moehlig, 1974; Peatrik, 1999).

Combining ecological anthropology and climatology, in chapter 4, we have implemented a retrospective survey from 1961 to 2006, and concluded that the cropping system dynamics (a social factor) induced over time an increasing risk of local crop variety losses due to drought. The present study is complementary in identifying, at a smaller time scale, social and environmental factors that can mitigate this risk, considering farmers' cultural practices, and the origin of crop genetic resources they manage. Historical, sociological and ecological variables are controlled with a double comparative approach (Leclerc and Coppens d'Eeckenbrugge, 2012), and this allows describing what a social process of adaptation to climate change can be. As studies on environmental changes usually occur on a long-term scale and are costly to conduct, we propose an alternative space-and-time substitution design. We compared two communities that moved along the slope of Mount Kenya into a new climatic environment, representing for both a rapid environmental change. Change in space, involving ecological contrasts, is similar to that induced in time by global environmental change. This context does allow analyzing factors at work in the social process of adaptation to climate change.

Around 1960, Mwimbi farmers began to move from 1100 m (highland climatic zone) to 950 m (midland climatic zone), whereas, about ten years later, Tharaka farmers began to move up from 750 m (lowland climatic zone). The two communities, originating from different climatic environments, are today geographically close to each other in the midlands. They live in the same climatic environment, but their experience of drought events and their genetic resources differ. Indeed, Mwimbi came down from higher altitude, with knowledge and practices associated with their crop genetic resources adapted to the highland climatic zone, whereas Tharaka farmers came up, with their crop genetic resources adapted to the lowland climatic zone. The historical and social contrast between the two communities is amplified by their respective social networks, which still remain differentiated today. Midlands Tharaka farmers have contacts and relations (notably with intermarriages) with Tharaka farmers living in lowlands. The same happens for midlands Mwimbi with highlands Mwimbi farmers. But intermarriage between the two cultural communities is unlikely in midlands, even if they are geographically close to each other. Their respective social identity is usually reaffirmed by farmers. Each community talks about the other maintaining a dichotomy between "us" and "them". Such a social opposition is usual (Barth, 1969), but its consequence on crop management and genetic resources have been the object of few studies (for instance, see Brush and Perales, 2007; Longley, 2000; Perales et al., 2005; Pressoir and Berthaud, 2004a, 2004b).

Leclerc and Coppens d'Eeckenbrugge (2012) have suggested that social factors organizing crop genetic diversity *in situ* operate less at farmer individual level than at community level. They proposed in place of the usual two-way genotype by environment interaction (G × E), a three-way interaction model, G × E × S, in order to consider explicitly the social component (S). Under similar environmental conditions (E), crop genetic diversity (G) should be portioned between cultural communities (S). Following such a model, the hypothesis to be tested in the present context was that the coexistence of two historically differentiated communities of farmers, Mwimbi and Tharaka, should be reflected in differential crop genetic adaptability to long dry spells during the seedling emergence phase. Six main crops, namely beans (*Phaseolus* sp), cowpea (*Vigna unguiculata*, (L.) Walp), green gram (*Vigna radiate*, (L.) R. Wilcz), maize (*Zea mays*, L), pearl millet (*Pennisetum glaucum*, (L.) R. Br), and sorghum (*Sorghum bicolor*, (L.) Moench) were considered in our analysis. If Tharaka farmers use local varieties that are more adapted to drought conditions than those of Mwimbi, the probability of sowing failure should thus be lower for Tharaka than for Mwimbi in midlands, within their common climatic zone. Testing this hypothesis is possible if Tharaka and Mwimbi farmer practices are similar while their crop response to dry spells after occurring after sowing differs significantly.

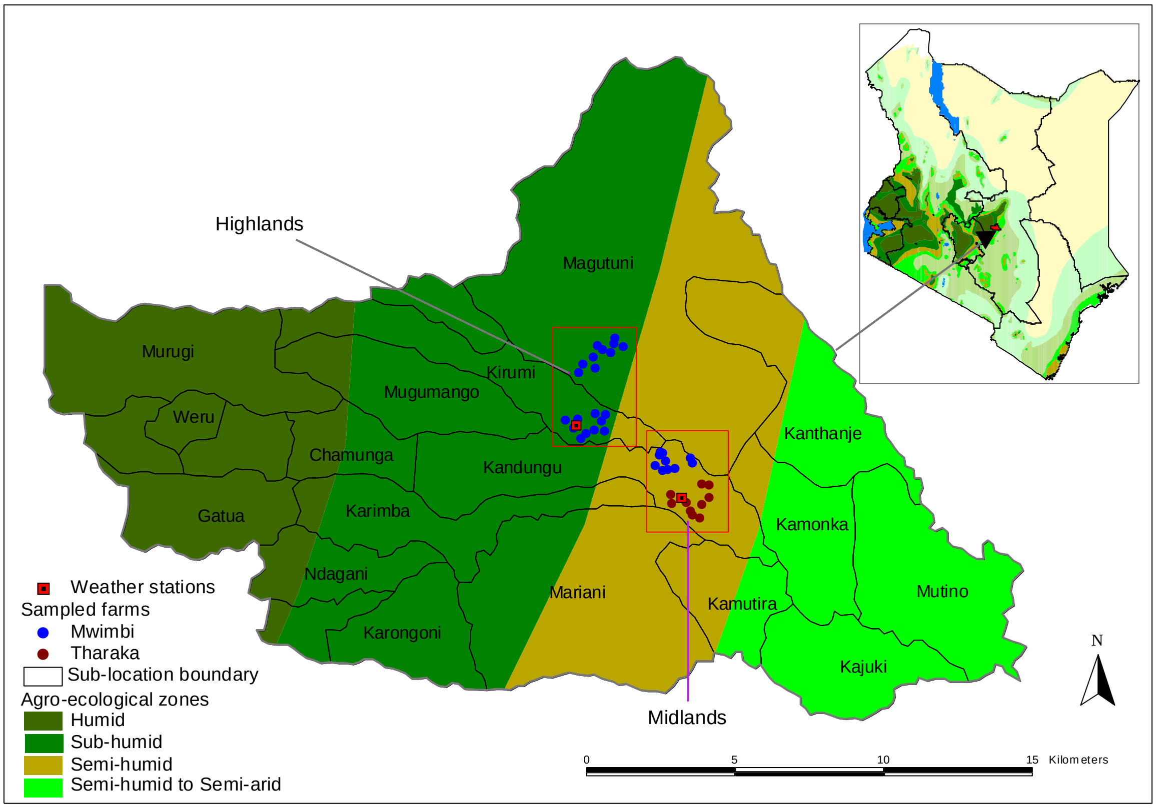
Our strategy and methods, described in the next section, allowed comparing practices of individual farmers from Tharaka and Mwimbi communities, and testing the differences in probability of sowing failure. Thence, comparing these two communities while they are geographically close to each other within the same climatic zone, with similar soil conditions, should allow identifying social factors involved in adaptation to climate changes, and how societies interfere between crops and climate.

5.2 Material and Methods

On the eastern slope of Mount Kenya, farmers manage two cropping seasons per year corresponding to the Long Rains and to the Short Rains from March to May and from October to December, respectively (see chapter 4 for additional information). Surveys were carried out over two years (2009-2011), including two Short Rains seasons (SR) and two Long Rains (LR) seasons (SR 2009, LR 2010, SR 2010 and LR 2011).

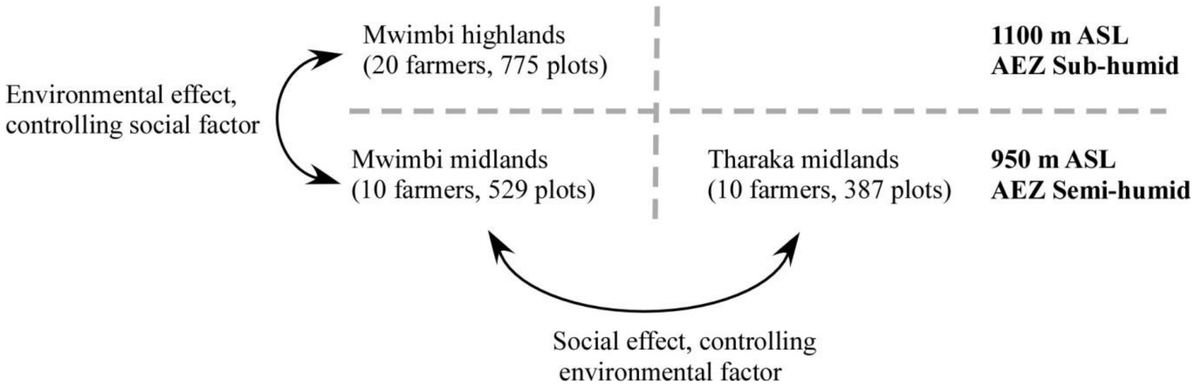
A double comparative approach was used to isolate climatic and social factors in the analysis. A total of 40 farming households were surveyed, twenty at each of the two selected climatic environments (950 m, hereafter midland climatic zone, and 1100 m, hereafter highland climatic zone) (Figure 5.1). On one hand, our sampling strategy aimed at having within the same midland climatic and agro-ecological zone (AEZ, after Jaetzold et al., 2007) a favourable representation of two distinct farmer communities, Mwimbi and Tharaka (one environment, two communities). On the other hand, we could compare Mwimbi farmers living in midlands and highlands, i.e. distributed between two distinct climatic zones, with a semi-humid climate in midlands and a sub-humid one in highlands (one community, two environments). Figure 5.2 summarizes this double comparative approach.

Figure 5.1. Map showing location of the study site with households surveyed. Farmers were surveyed at two different agro-ecological zones corresponding to semi-humid (midlands) and sub-humid (highlands). At midlands farmers were selected to represent the two cultural communities, Mwimbi and Tharaka. An automatic weather station was installed at each of the two agro-ecological zones.



Schematically, figure 5.2 shows the on-field comparative setting that allows double comparative approach. Mwimbi and Tharaka farmers living at midlands can be compared by controlling the environmental effect, whereas Mwimbi farmers living at midlands or highlands can also be compared, in this case by controlling farmers' cultural identity to assess the environmental effect. The two effects, environmental and social, thus can be isolated and studied to show how they are involved in adaption to climate changes, and how societies interfere between crop and climate.

Figure 5.2. Double comparative setting of the study site. At 950 m elevation, Mwimbi and Tharaka live in the same agro-ecological zone. Environmental conditions being controlled; this zone was used to test effects of social communities on seed management and on response of their crop to climate variability. Mwimbi farmers at midlands and highlands live in different agro-ecological zones. In this case, the social identity of farmers is controlled, and the two zones was used to test how different environments influence crop response to climate variability. A total of 1691 plots were surveyed.



5.2.1 Farmer seed management and practices

Crop varieties cultivated by farmers were inventoried, including their seed sources over the four seasons. The proportion of seeds that were locally produced by farmers was also recorded in order to assess how similar farmer practices and seed management was within and between communities.

Farmers were observed throughout the cropping season to characterize their sowing practices, by noting the dates of each sowing event, and their choice of crop species and varieties. Observations were carried out at each of the farmers' fields for the four seasons. Each farmer field was subdivided into plots representing an individual sowing event that is of a given crop variety. A mean of 42 plots were surveyed by farmer with on average 12 replicate per crop, for a total of 1691 plots. Fifteen days after germination, each plot was assessed and sowing failure recorded. Each plot was evaluated for the proportion of emerged seedlings out of the total area sown (empty hills corresponding to sowing failure). We confirmed the reliability of this method by comparing independent observations by different field assistants. In the analysis, plots with sowing failure were recorded as 1, and those without sowing failure as 0. The sowing failure proportion was analysed with a logistic regression model (detailed in section 5.3).

5.2.2 Climatic data collection

A Davis Vantage Pro 2TM weather station was installed at each of the two environments, midlands and highlands, at 950 m and 1100 m, respectively. The weather station has temperature and humidity sensors, a rain collector and an anemometer. The automatic station use frequency hopping spread spectrum radio technology to transmit data to a console in which a data logger was installed for data storage. In midlands, the mean distance between the households surveyed and the weather station was 910 m for Tharaka and 1340 m for Mwimbi. Given this short distance, we assume that the rainfall variation between the two communities is negligible.

Rainfall variability was assessed on a daily basis to define the length of dry spell during crop emergence for the four growing seasons. The onset and the cessation date and the duration of the rainy season was defined following Camberlin et al. (2012, for details). A threshold of 2 mm was used to define a rainy day.

The germination date was defined as the first rainy day after the sowing date. The length of dry spell was defined as the number of consecutive dry days, using germination date as the starting point and the next rainy day (> 2 mm) as the ending point. The length of the dry spells was computed separately for each sowing event. Doing so, climatic conditions were specifically defined for each crop-sowing date. Soil water holding capacity was not used in the analysis as it is likely to be similar within the same AEZ, after Jaetzold (2007).

5.3 Statistical analysis

Multivariate analyses were carried out considering cultural communities (Mwimbi and Tharaka), agro-ecological and climatic zones (semi-humid in midlands and sub-humid in highlands), climatic season (SR 2009, LR 2010, SR 2010 and LR 2011), crop species (maize, bean, pearl millet, cowpea, green gram and sorghum), and the length of dry spells after germination. The response variable, i.e. the proportion of sowing failures was modelled by a logistic regression with quasi-binomial error in place of binomial error to consider over dispersion of our data. The regression was weighted by plot sizes, and the logit link function was used to ensure linearity. Factors considered in the specific models were selected using a backward elimination procedure (Agresti, 2007). This procedure begins with a saturated model and the non-significant factors are sequentially removed to get the minimal adequate model. This model of analysis was run over the four seasons to compare the probability of sowing failure as a function of

(i) crop species, given the length of dry spell (lds, in equations), and formalized as follow:

$$\log(p/q) = \alpha + \beta_1 crop_i + \beta_2\, lds_j + \varepsilon_{ijk}$$

(ii) agro-climatic zones, considering only Mwimbi, given the crop and the length of dry spell, and formalized as follow:

$$\log(p/q) = \alpha + \beta_1 crop_i + \beta_2 lds_j + \beta_3 AEZ_k + \varepsilon_{ijkl}$$

and (iii) farmer community, considering only midlands, given the length of dry spell, and formalized as follow:

$$\log(p/q) = \alpha + \beta_1 communities_l + \beta_2\, lds_j + \varepsilon_{ljk}$$

where *p* is the proportion of sowing failure, *q* the proportion sowing success, *i* = 1 to 6 crops, *j* the length of dry spell (expressed in days), *k*=1 to 2 AEZ (midlands and highlands, respectively), *l*= 1 to 2 farmer communities (Mwimbi or Tharaka).

Goodness-of-fit, D^2, similar to R^2 in linear regression, corresponds to the percentage of explained deviance. It was estimated by comparing null deviance to residual deviance of the minimal adequate model, D^2= 1− (model deviance/null deviance). Statistical analyses were performed with R (R Development Core Team, 2011).

5.4 Results

5.4.1 Length of dry spells after germination and crop sensibility

The mean length of dry spells was significantly longer during the Long Rains (10.3 ± 0.12 days, n=658) than during the Short Rains (7.6 ± 0.09 days, n=1033), and in midlands (9.0 ± 0.136 days, n=916) than in highlands (8.2 ± 0.127 days, n=775). However, in midlands, the mean length of dry spells after seed germination was not different between Mwimbi and Tharaka, except for the Long Rains 2010 during which they were significantly longer for Tharaka than for Mwimbi (Table 5.1).

Table 5.1. Mean length of dry spells after germination comparing Mwimbi and Tharaka in midlands. A. Short Rains in 2009 and in 2010; B. Long Rains in 2010 and in 2011. The mean number of consecutive dry day after seed germination was significantly greater for Tharaka than for Mwimbi during the Long Rains 2010

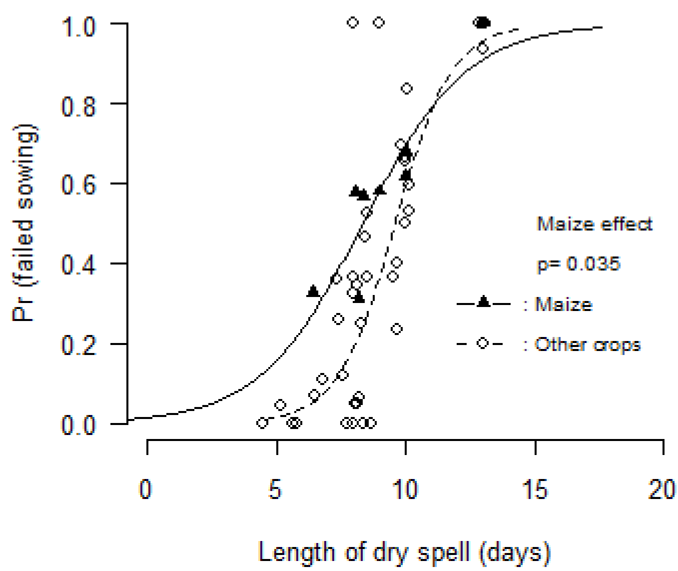
	Social groups	Mean (days)	SE	No of plots	T-value	Pr(>T)	
A. Short Rains							
2009	Mwimbi	8.04	0.018	191	1.75	0.082	NS
	Tharaka	8.11	0.038	144			
2010	Mwimbi	7.81	0.141	162	1.83	0.069	NS
	Tharaka	7.32	0.133	83			
B. Long Rains							
2010	Mwimbi	9.55	0.094	104	3.91	0.0012	**
	Tharaka	10.1	0.100	96			
2011	Mwimbi	13.01	0.085	72	0.34	0.73	NS
	Tharaka	12.98	0.015	64			

Significance codes: ***: <0.001 ; **: 0.01; *: 0.05 ; NS: no significant

We implemented a logistic regression to analyze the probability of sowing failure as a function of the length of dry spells. Out of the six crop species considered, only maize was significantly more impacted (Figure 5.3).

Figure 5.3. Proportion of sowing failure as a function of the mean length of dry spells after seed germination, comparing maize to other crop species. Model explained 56.7 % of the null deviance. Each crop was assessed during the four climatic seasons at two elevations (8 dots per crop). Maize is significantly more impacted than other crops

The model explained 56.7% of the null deviance (D^2). Its parameters suggest that while short dry



spells (less than five days) impact maize during emergence, other crops are not impacted at all.

The number of consecutive dry days needed to reach 50% loss is 8.3 days for maize, whereas it is 9.6 days for sorghum and pearl millet. When dry spell is more than ten days, all crop species are equally impacted.

5.4.2 How societies interfere between crop and climate

The highest proportion of sowing failure was recorded for the Long Rains with 65.8 ± 3.62 % (0.95 c.i.) as compared to 22.2 ± 2.53 % (0.95 c.i.) for the Short Rains. Even though the Long Rains were associated with higher amounts of rainfall, the high level of sowing failure can be attributed to rainfall irregularities and the prolonged dry spells observed after seed germinations during this season. The proportion of plots where crop failed was significantly higher (0.95 c.i.) in midlands (42.9 ± 3.2 %) than in highlands (34.7 ± 3.35 %).

5.4.2.1 One community, two environments. Controlling farmers' social identity to assess the altitudinal effect

Comparing midlands and highlands, thus controlling the farmer social identity by considering only Mwimbi farmers, Figure 5.4 shows that agro-ecological and climatic zone was not a significant factor differentiating crop response when faced with prolonged dry spells. However, the analysis showed that maize crop failure was significantly lower in highlands than in midlands. The fact that maize is a highland climatic crop and less well suited to the semi-arid and sub-humid conditions could explain maize response as compared to other crops. To confirm the null effect of agro-ecological zones and altitude on how crops respond to increasing length of dry spells, maize was removed from the model, and the logistic regression recomputed. Effect of agro-ecological zones and altitude on crop response remained insignificant.

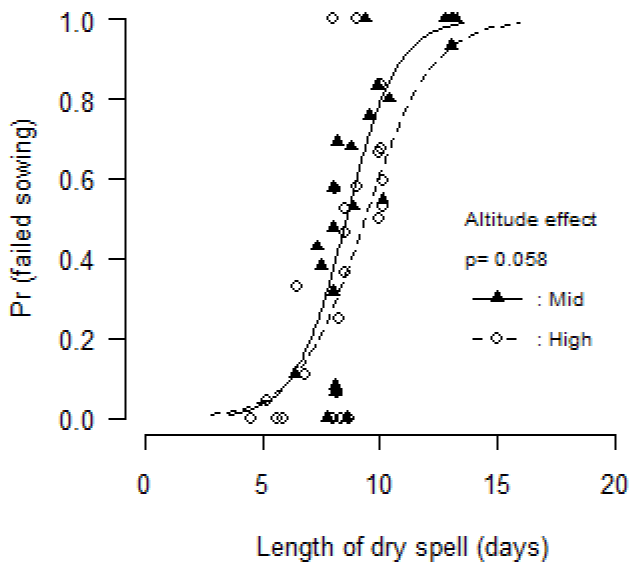


Figure 5.4. Probability of sowing failure as a function of dry spell length, comparing Mwimbi plots in midlands and highlands. The model explains 61.2 % of null deviance. Effect of agro-ecological zones and altitude on crop response was not significant.

5.4.2.2 One environment, two communities. Controlling altitude to assess the social effect

Controlling altitude, sowing failure was observed in almost all farmer plots during the Long Rains in 2011. For all other seasons, percentages of lost seeds were significantly higher for Mwimbi than for Tharaka (Table 5.2).

Table 5.2. Proportion of plots where crop failed, comparing Mwimbi and Tharaka at 950 m asl during the Long Rains and the Short Rains. Proportions were significantly greater for Mwimbi than for Tharaka.

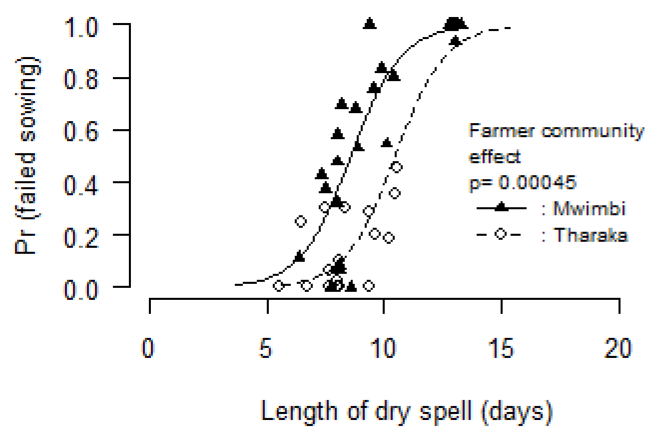
	Social groups	% field	Std. Error	No of plots	Chi2	Df	Pr(>Chi2)	
A. Short Rains								
2009	Mwimbi	31.9	0.03	191	23.3	1	<0.001	***
	Tharaka	9.7	0.03	144				
2010	Mwimbi	40.7	0.04	162	19.24	1	<0.001	***
	Tharaka	13.3	0.04	83				
B. Long Rains								
2010	Mwimbi	74.0	0.04	104	38.5	1	<0.001	***
.	Tharaka	30.2	0.05	96				
2011	Mwimbi	98.6	0.01	72	0.89	1	0.34	NS
	Tharaka	100.0	0	64				

Significance codes: ***: <0.001 ; **: 0.01; *: 0.05 ; NS: no significant

Comparing percentages of sowing failure from different seasons (by grouping the two years), the difference (0.95 c.i.) between Mwimbi and Tharaka in midlands was as high as 25.9 ± 9.4 %, during the Long Rains and 24.97 ± 6.45 % during the Short Rains. The relative risk of sowing failure was 3.3 times more for Mwimbi than for Tharaka during the Short Rains, and 1.5 times more during the Long Rains.

Figure 5.5 provide a global comparison (across all seasons), showing that the probability of sowing failure differs significantly between Tharaka and Mwimbi in midlands. To confirm this effect of farmer community on crop response to increasing length of dry spells, maize and bean were successively removed from the model, and the logistic regression recomputed. Effect of farmer community on crop response remained highly significant. The seeds sown by Tharaka failed less than those sown by Mwimbi.

Figure 5.5. Proportion of sowing failure as a function of dry spell length, comparing Mwimbi and Tharaka in midlands. The model explains 69.9 % of the null deviance. Probability of sowing failure is higher for Mwimbi than Tharaka



5.4.3 Farming system and sowing practices

The total number of varieties per crop species was not significantly different between Mwimbi and Tharaka in midlands, except for bean. Respectively, the two communities cultivated during the four seasons a mean of 5.35 and 1.15 bean varieties, 3.35 and 2.75 cowpea varieties, 1.60 and 2.45 green gram varieties, 7.75 and 5.65 maize varieties, 2.9 and 2.6 pearl millet varieties and 5.5

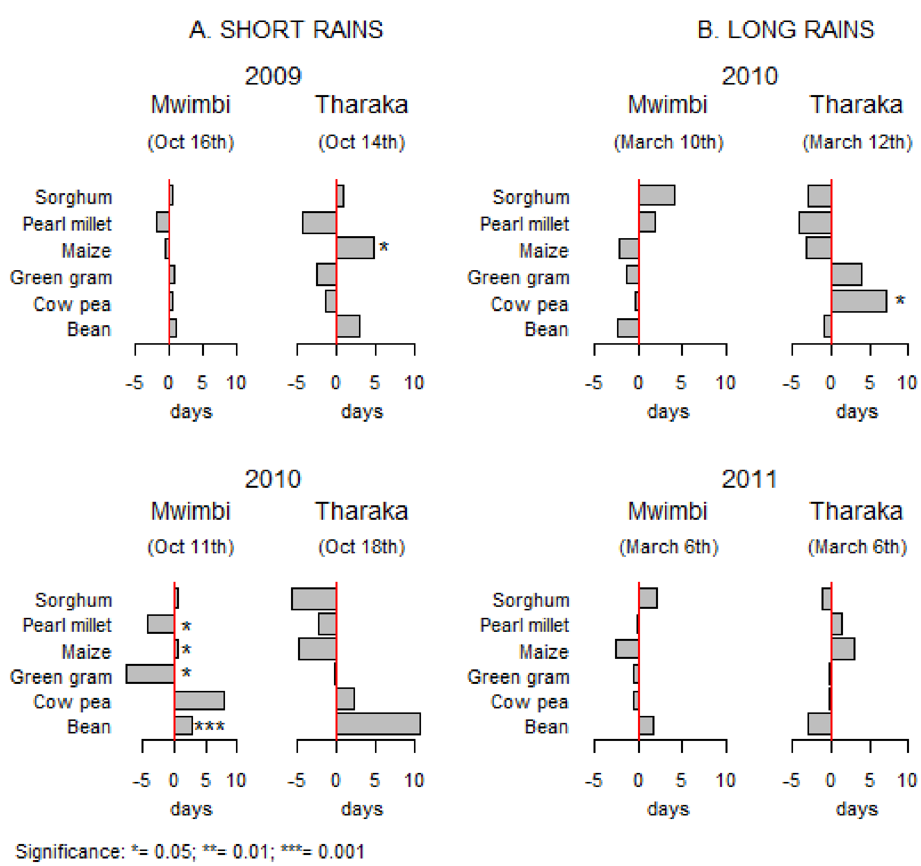
and 4.0 sorghum varieties. As shown in Table 5.3, the mean number of crops per farmer and the percentage of local/improved varieties were not significantly different between Mwimbi and Tharaka in midlands. The proportion of crop cultivated in midlands by Mwimbi and Tharaka differ for bean and green gram, while for both maize is the dominant crop species (about 29 %). There was only small variation in the relative importance of crop species among seasons. The proportion of seeds saved by farmers from their own harvest or obtained from relatives or friends were similar between Mwimbi and Tharaka (66.2 vs. 69.5). The proportion of seed obtained from the local seed markets differ slightly. There is a local seed market at lowlands, midlands, and highland. Both Mwimbi and Tharaka mostly used the lowland market to supply seeds, as, respectively, 70% and 80% of their local market seeds originated from lowland market. Almost all seed sold in the local markets are produced by individual farmers living in the area.

Table 5.3. General characteristics of the surveyed population. Statistics were compiled for the four climatic seasons by combining midlands and highlands (left part of the table). For midlands, statistics were compiled to compare four-season averages of Mwimbi and Tharaka (right part of the table).

	Seasons				At 950 m midlands	
	SR 2009	SR 2010	LR 2010	LR 2011	Mwimbi	Tharaka
Mean crops per farmer	5.65	5.52	4.14	4.11	4.2 to 5.6	4.6 to 6.0
Local varieties cultivated (%)	68	63	58	60	33 to 49	38 to 51
Improved varieties cultivated (%)	32	38	42	40	51 to 67	49 to 62
Mixed varieties in a single hill (%)	14	23	6	4	22.2	3.6
Mixed crops in a single field (%)	96	99	93	99	99.8	99.5
Maximum number of re-planting	2	2	2	4	3	4
Same crop species re-planted (%)	27	57	37	14	74.5	42.2
Average crop area (hectares)	0.89	0.94	0.77	0.74	1.23	0.99
No of fields cultivated per farmer	2.7	2.6	2.4	2.1	3.0	2
Crop relative importance (%)						
Bean	24.7	20.4	19.9	22.3	20.2	5.9
Cow pea	12.3	11.6	14.2	16.5	12.7	14.2
Green gram	7.4	5.2	6.9	5.8	6	12.7
Maize	24.8	30.4	34.4	32.7	29.3	29.2
Pearl millet	7.6	5.4	8.2	6.7	11	13.4
Sorghum	23.1	27	16.3	15.9	20.8	24.5
Seed sources (%)						
Own, relative or friends	66.5	57.2	65.5	70.7	66.2	69.5
Community chief	21.8	19.9	17.9	12.7	23.1	14.2
Market	5.4	22.3	14.9	8.6	7.8	15.2
Other	6.3	0.6	1.7	7.9	3	1.1

The average sowing dates for Mwimbi and Tharaka living in the midlands were similar, except during the Short Rains in 2010 where it was one week earlier for Mwimbi (mean date Oct 11th) than for Tharaka (mean date Oct 18th). Out of the 24 crop sowing dates tested (Figure 5.6) only 6 were significantly different between the two communities. Tharaka sown cowpea and maize later than Mwimbi during the Long Rains 2010 and the Short Rains 2009, respectively. Mean sowing dates were the same during the Long Rains 2011. During the Long Rains 2010, Mwimbi sown first bean, maize and green gram while Tharaka sown first sorghum, pearl millet and maize. The sowing dates were on average 3.75 days later in highlands than in midlands.

Figure 5.6. Crop sowing order per season comparing Mwimbi and Tharaka. LEFT PANEL: A. Short Rains 2009 and 2010. RIGHT PANEL: B. Long Rains 2010 and 2011. The date between brackets is the seasonal mean sowing date computed for all crop. The horizontal axis represents the sowing dates per crop as compared to the seasonal mean. Crop sown first have a negative values and those sown last a positive values. The stars indicate when the difference of sowing dates between Mwimbi and Tharaka are significantly different.



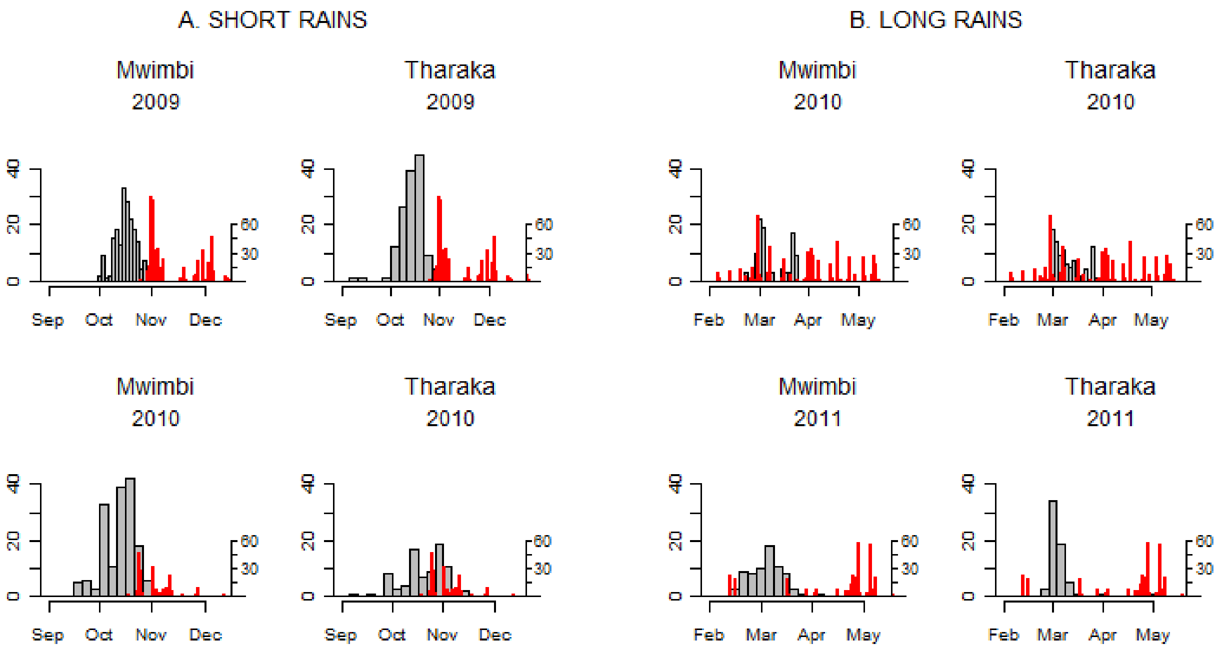
The statistical summary of rainfall variables (Table 5.4) shows how unpredictable these variables can be among seasons and years. In 2011, the Long Rains duration was 30% shorter than in 2010. In midland, the frequency of rainy days is likely to be higher during the Short Rains than the Long Rains. The number of rainy days was also highly variable among season and year (e.g. 6 vs. 16 days in highlands during the Short in 2009 and 2010). The spatial and the seasonal and interannual variability of rainfall increase the difficulty for farmers to know the best sowing time.

Table 5.4. Statistical summary of rainfall variables for the Short Rains (SR) and the Long Rains (LR) from 2009 to 2011. A. Highland climatic zone. B. Lowland climatic zone.

	Climatic seasons			
	SR 2009	SR 2010	LR 2010	LR 2011
A. Highland climatic zone				
Onset date	Nov 24	Oct 17	Feb 13	Mar 18
Cessation date	Dec 04	Nov 10	Apr 26	May 08
Duration (days)	11	25	73	52
Number of rainy days (days)	6	16	29	26
Frequency of rainy days	0.55	0.64	0.4	0.5
Seasonal amount (mm)	96.8	319.8	518.8	473.8
B. Midland climatic zone				
Onset date	Nov 24	Oct 22	Feb 28	Mar 18
Cessation date	Dec 04	Nov 10	May 12	May 08
Duration (days)	11	20	74	52
Number of rainy days (days)	6	15	27	17
Frequency of rainy days	0.55	0.75	0.36	0.33
Seasonal amount (mm)	139.6	202	499	284.6

We have observed no contrast in sowing strategies between Mwimbi and Tharaka in midlands. Both communities may start sowing before the beginning of the rainy season (dry sowing well illustrated during the Short Rains 2009 and 2010; Figure 5.7 A) or after the beginning of the rainy season (wet sowing well illustrated during the Long Rains 2010 and 2010; Figure 5.7 B). Figure 5.7 B shows how risky was their common positive interpretation of an isolated first rainy event at the beginning of Long Rains 2011. This contrasts with Long Rains 2010, when both communities avoided sowing immediately after early first rains. They preferred a prudent strategy, with highly scattered sowing dates.

Figure 5.7. Plots of the observed sowing dates (histogram) and rainfall distribution (red bars) comparing Mwimbi and Tharaka in midlands. A. LEFT PANEL: sowing date and daily rainfall during the Short Rains in 209 and 2010. RIGHT PANEL: sowing date and daily rainfall during the Long Rains in 2010 and 2011. Horizontal axis: first day of each month from January to May (Long Rains) or from September to December (Short Rains); Left vertical axis: frequency of sowing events; Right vertical axis: daily rainfall amount.



5.5 Discussion

Our study confirmed the close relationship between rain distribution and farmers' success in establishing cultivation plots. Thus, the rainfall irregularities and the prolonged dry spells during the Long Rains explain the higher proportion of sowing failure as compared to the Short Rains. Out of the six crop species considered, maize, the dominant food crop for both Mwimbi and Tharaka in midlands, was significantly more impacted by dry spells. Considering globally all six crops, the odd ratio of sowing failure was 6.7 times more for the Long Rains than for the Short Rains. These results clearly confirm those obtained over a 46-year period (chapter 4) where farmers oral report of variety losses was associated to the climate variability of the Long Rains, with a stronger impact on maize variety losses. All together, our results underline the impact of rainfall variability and thence the crucial role of germplasm adaptation and sowing practices in crop success. Understanding the processes at work is essential in the present context of relatively rapid global climatic change, imposing a significant effort of adaptation to the farmers. This was precisely the aim of the present study, which exploited the favourable context provided by the migrations along the slope of Mount Kenya, with Mwimbi farmers moving from wet highlands to dryer midlands, and Tharaka farmers moving from dry lowlands to wetter midlands.

Our results provide surprisingly strong elements on the importance of social factors in this adaptation. Indeed, the double comparative approach revealed that social factors have more influence on reducing risk of sowing failures due to rainfall variation than AEZs and altitude. The logistic models have demonstrated that the variability of crop response to dry spells was lower among farmers within each community than between the two communities. Thus, there were less differences among Mwimbi farmers located in two distinct AEZs than between Mwimbi and Tharaka living in the same AEZ. Explanations to this social differentiation in sowing success can be sought in better adapted farming practices and/or in better adapted crop genetic resources. Indeed, the two communities differ in their experience with drought and in the origin of their genetic resources. Thus, Tharaka, migrating from a drier environment, might have a better experience in managing rainfall variability and/or they may have developed more drought-resistant landraces, as compared to Mwimbi, who come from a more humid environment. Alternatively, the Tharaka may have adapted by basing their farming system on a higher proportion of crops that are less susceptible to dry spells.

Farming system and the relative importance of crops are comparable among individual farmers and between Mwimbi and Tharaka communities, even if the former favour beans while the latter favour green gram (Table 5.3). Maize occupies the same dominant position (29%) among food crops for both communities in midlands, so this drought sensitive crop does not induce a difference between them when they face with long dry spells. No appreciable difference was observed at the varietal level either. The total number of varieties per crop species was similar for both communities, as well as seed sources, with a dominance of seeds saved from previous harvest or supplied within the community, and similar proportions of local vs. improved varieties. Proportion of seeds obtained from market was slightly different between Mwimbi and Tharaka (7.8% vs. 15.2%), but both preferred the lowland market to supply seeds.

Individual practices did not appear to play a role either, in the process of adaptation to climate change. Sowing strategies showed no differences between communities, except for the Short Rains season 2010, when Mwimbi started sowing one week earlier. No community-related sowing strategy were detected, neither when analysing the relative timing of sowing different crops (Figure 5.6), nor when comparing the distribution of sowings and that of rains, with wet and dry sowings in both communities (Figure 5.7). Thus the way of Tharaka and Mwimbi interpret rainfall signals at the beginning of the rainy seasons and their choices of the sowing date were very similar. As a result, the mean length of dry spells after seed germination was not different between Mwimbi and Tharaka, except for the Long Rains 2010 during which they were significantly longer for Tharaka than for Mwimbi (Table 5.1).

Despite the high similarity in crop management, at both specific and varietal levels, and in sowing strategy, we have observed a high contrast in sowing failure between Mwimbi and Tharaka, with a relative risk of sowing failure that is 3.3 times more for Mwimbi than for Tharaka during the Short Rains, and 1.5 times more during the Long Rains. Even in the Long Rains 2010, when dry spells were significantly longer for Tharaka farmers, the latter were considerably less impacted than Mwimbi farmers (30% vs. 74% sowing failure). The only possible explanation to such a difference is that Tharaka genetic resources are much better adapted to long dry spells than those of Mwimbi. This conclusion is not related to the importance of maize, as a dominant and drought sensitive crop, as this social effect remained significant after removing maize from the logistic regression analysis.

The fact that the crops cultivated by the two communities in midlands were differently impacted by dry spells can be related to the different origins of the crop genetic resources managed by the two communities. Indeed, the differential genetic adaptability to droughts of Mwimbi and Tharaka' seed is likely to correspond to their historical differentiation as communities of farmers. In a way the history of the two communities gets reflected in the "genetic history" of their seeds. Tharaka seeds better endure drought conditions than those of Mwimbi probably because they originate from semi-arid lowlands where droughts are usual.

The orientation of seed exchange system must also be considered. As well as elsewhere, Kenyan farmers have to trust the supplier when exchanging information and seeds that are so important for their subsistence (Badstue et al., 2007). The fact that exchanged seeds are mainly obtained through trusted persons, members of the same family, the same village or the same community has been documented for maize in Mesoamerica (Badstue et al., 2006; Perales et al., 2005; Perales et al., 2003; Van Etten, 2006), Andean tubers in Peru (Zimmerer, 2003), sorghum in Ethiopia (Mcguire, 2007); and rice in Gambia (Nuijten and Almekinders, 2008) and Sierra Leone (Longley, 2000). Where several ethnic groups live in the same village, the seed exchanges are preferentially (up to 90%) concluded with members of the same ethnic group (Almekinders et al., 1994; Delaunay et al., 2008). Reversely, seeds are rarely supplied by outsiders. In the cases studied by Badstue (2006) only 1% of the seeds come from such sources. Considering these studies from different countries all together, most seeds (52-99%) are produced on farm and those obtained from outside mostly come from within the community of the farmer.

Seed genetic differentiation is thus favoured both by the low level of seed exchanges between communities and the high level of exchanges within the community (Leclerc and Coppens d'Eeckenbrugge, 2012). Such a factor was not well considered in crop genetic studies with a sampling strategy that allow considering both environmental and social variations. When social factor have been taken into account, significant progress have brought in our understanding of social and biological processes, as in the study of Deu *et al.* (2008) or those of Brush and Perales (2007) and Benz *et al* (2007).

5.6 Conclusion

Our double comparative approach fully supported our working hypothesis, even showing that not only the process of adaptation to climate change involves a social component, but that this component may be more important in explaining differential success of farmer social groups than the environmental variation itself.

The migration of Mwimbi farmers along the slope of Mount Kenya from wet highlands to dryer midlands, and that of Tharaka from dry lowlands to wetter midlands, provided a favourable context, with a useful contrast allowing the isolation of this social component in the adaptation to rapid environmental changes. Both communities are today geographically close to the other in midlands, but their experience with drought and the origin of their genetic resources differs.

The impact of rainfall variations and droughts on sowing failure is not uniform. Societies interfere between crop and climate, and the social process of adaptation to climate variability implies considering farmers' practices and knowledge, and the genetic resources that they historically manage. Crop adaptation to drought and more generally to climate changes, should thus be not only a biological, but also a social process.

The results obtained from this study highlight some needs for future breeding programmes. Most critically such programmes should consider crop genetic adaptability together with the history and the sociology of farmers' community. This must be reflected more accurately in the crop genetic sampling strategies used to collect new material, and to improve crop adaptation to climate variability.

5.7 References cited in chapter 5

Agresti, A. (2007) An introduction to categorical data analysis. Wiley, Gainesville, Florida, USA.

Almekinders, C.J.M., Louwaars, N.P., Bruijn, G.H. (1994) Local seed systems and their importance for an improved seed supply in developing contries. Euphytica 78, 207-216.

Altieri, M.A. (1994) Biodiversity and pest management in agroecosystems. Hayworth Press, New York.

Araya, A., Keesstra, S.D., Stroosnijder, L. (2010) A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. Agr. Forest Meteorol. 150, 1047–1064.

Badstue, L.B., Bellon, M.R., Berthaud, J., Juarez, X., Rosas, I.M., Solano, A.M., Ramírez, A. (2006) Examining the role of collective action in an informal seed system: A case study from the Central Valleys of Oaxaca, Mexico. Hum. Ecol. 34, 249-273.

Badstue, L.B., Bellón, M.R., Berthaud, J., Ramírez, A., Flores, D., Juárez, X. (2007) The Dynamics of farmers' maize seed supply practices in the Central Valleys of Oaxaca, Mexico. World Dev. 35, 1579–1593.

Barron, J., Rockstrom, J., Gichuki, F., Hatibu, N. (2003) Dry spell analysis and maize yields for two semi-arid locations in east Africa. Agr. Forest Meteorol. 117, 23-37.

Barth, F., (1969) Ethnic groups and boundaries. Little, Brown & Co, Boston, MA, USA.

Benz, B.F., Perales, H.R., Brush, S.B. (2007) Tzeltal and Tzotzil farmer knowledge and maize diversity in Chiapas, Mexico. Curr. Anthropol. 48, 289-300.

Brush, S.B., Perales, H.R. (2007) A maize landscape: ethnicity and agro-biodiversity in Chiapas Mexico. Agr. Ecosyst. Environ. 121, 211-221.

Camberlin, P., Boyard-Michaud, J., Philippon, N., Baron, C., Leclerc, C., Mwongera, C. (2012) Climatic gradients along the windward slopes of Mount Kenya and their implication for crop risks. Part 1: climate variability. Int. J. Climatol. [online] http://onlinelibrary.wiley.com/doi/10.1002/joc.3427, 17.

Delaunay, S., Tescar, R.-P., Oualbego, A., Vom Brocke, K., Lancon, J. (2008) La culture du coton ne bouleverse pas les échanges traditionnels de semences de sorghos. Cah. Agric. 17, 189-194.

Deu, M., Sagnard, F., Chantereau, J., Calatayud, C., Hérault, D., Mariac, C., Pham, J.-L., Vigouroux, Y., Kapran, I., Traore, P.S., Mamadou, A., Gerard, B., Ndjeunga, J., Bezançon, G. (2008) Niger-wide assessment of in situ sorghum genetic diversity with microsatellite markers. Theor. Appl. Genet. 103, 903-913.

Fadiman, J.A. (1982) An oral history of tribal warefare. The Meru of Mont Kenya. Ohio University Press, Athens, Ohio.

Fadiman, J.A. (1993) When we began, There were witchmen. An oral history of Mont Kenya. University of California Press, London, England.

Hammer, K., Teklu, Y. (2008) Plant genetic resources: selected issues from genetic erosion to genetic engineering. Journal of Agriculture and Rural Development in the Tropics and Subtropics 109, 15-50.

Heine, B., Moehlig, W.J.G. (1980) Language and dialect atlas of Kenya. Volume I. Geographical and historical introduction : language and society. Dietrich Reimer Verlag, Berlin.

Jaetzold, R., Schmidt, H., Hornetz, B., Shisanya, C. (2007) Farm Management Handbook of Kenya (2nd edition), vol.II : Natural Conditions and Farm Management Information, part C East Kenya. Min of Agriculture, Kenya.

Kotschi, J. (2007) Agricultural biodiversity is essential for adapting to climate change. Ecological perspectives for science and society 16, 98-101.

Leclerc, C., Coppens D'eeckenbrugge, G. (2012) Social organization of crop genetic diversity The G x E x S interaction model Diversity 4, 1-32.

Lin, B.B. (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. BioScience 61, 183-193.

Longley, C., (2000) A social life of seeds: local management of crop variability in North-Western Sierra Leone, Department of Anthropology. University of London, London, p. 309.

Maracchi, G., Bacci, L., Cantini, C., Haimanot, M.T. (1993) Effect of water deficit in vegetative and post-flowering phases on pearl millet grown in controller environment. Agr. Med., 123, 65-71. Agricoltura Mediterranea 123, 65-71.

Marteau, R., Sultan, B., Moron, V., Alhassane, A., Baron, C., Traoré, S.B. (2011) The onset of the rainy season and farmers’ sowing strategy for pearl millet cultivation in Southwest Niger. Agr. Forest Meteorol. 151, 1356-1369.

Mcguire, S.J. (2007) Vulnerability in farmer seed systems: farmer practices for coping with seed insecurity for sorghum in Eastern Ethiopia. Econ. Bot. 616, 211-222.

Moehlig, W.J.G. (1974) Die Stellung der Bergdialekte im Osten des Mt. Kenya: ein Betrag zur Sprachgliederung im Bantu. Dietrich Reimer Verlag, Berlin.

Nuijten, E., Almekinders, C.J.M. (2008) Mechanisms explaining variety naming by farmers and name consistency of rice varieties in the Gambia. Econ. Bot. 62, 148-160.

Peatrik, A.-M. (1999) La vie à pas contés. Société d'ethnologie, Nanterre, France.

Perales, H.R., Benz, B.F., Brush, S.B. (2005) Maize diversity and ethnolinguistic diversity in Chiapas, Mexico. Proc. Nat. Acad. Sci. U.S.A 102, 949-954.

Perales, H.R., Brush, S.B., Qualset, C.O. (2003) Dynamic management of maize landraces in Central Mexico. Econ. Bot. 57, 21-34.

Pressoir, G., Berthaud, J. (2004a) Patterns of population structure in maize landraces from the Central Valley of Oaxaca in Mexico. Heredity 92, 88-94.

Pressoir, G., Berthaud, J. (2004b) Population structure and strong divergent selection shape phenotypic diversification in maize landraces. Heredity, 95-101.

R Development Core Team (2011) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Segele, Z.T., Lamb, P.J. (2005) Characterization and variability of Kiremt rainy season over Ethiopia. Meteorology and Atmospheric Physics 89, 153-180.

Sgrò, C.M., Lowe, A.J., Hoffmann, A.A. (2011) Building evolutionary resilience for conserving biodiversity under climate change. Evolutionary Applications 4, 326-337.

Tonhasca, A., Byrne, D.N. (1994) The effects of crop diversification on herbivorous insects: a metaanalysis approach. Ecological Entomology 19, 239-244.

Van Etten, J., (2006) Seeds, hands and lands. Maize genetic resources in highland Guatemala in space and time. Wageningen University, Wageningen, Netherlands, p. 132.

Vandermeer, J.H. (1989) The ecology of intercropping. Cambridge University Press, Cambridge.

Wood, D., Leene, J.M. (1997) The conservation of agrobiodiversity on-farm: questioning the emerging paradigm. Biodivers. Conserv. 6, 109-129.

Zimmerer, K.S. (2003) Geographies of seed networks for food plants (potatoes, ulluco) and approaches to agrobiodiversity conservation in the Andean countries. Society and Natural Resources 16, 583-601.

Annex 5.1. Backward elimination procedure to select minimal adequate logistic regression Models

Table 5.5a. Backward elimination procedure to select the model testing the effect of crop species

	Model	Term deleted	Df	Deviance	P(>|Chi|)
Saturated model	y ~ c * d * s * a	-	71	873.56	-
Step 1	y ~ c * d * s * a	-c:d:s:a	-5	-19.764	0.562
Step 2	y ~ c + d + s + a + c:d + c:s + d:s + c:a + d:a + s:a + c:d:s + c:d:a + c:s:a + d:s:a	-c:d:s	-5	-51.400	0.062
		-c:d:a	-5	-8.646	0.880
		- c:s:a	-5	-17.620	0.608
		- d:s:a	-1	-0.3677	0.784
Step 3	y ~ c + d + s + a + c:d + c:s + d:s + c:a + d:a + s:a	-c:d	-5	-11.135	0.8123
		-c:s	-5	-46.379	0.094
		-d:s	-1	-6.082	0.267
		-c:a	-5	-36.096	0.198
		-d:a	-1	-4.0499	0.365
		-s:a	-1	-17.196	0.062
Step 4	y ~ c + d + s + a	-s	-1	-15.611	0.085
		-a	-1	-1.88	0.550
Minimal model	y ~ c + d		65	378.04	-
Where Y: proportion of plots with crops failure; a : altitude; d: number of dry days after germination; c: crop species; s :climatic season					
Deviance explained ; D^2 : 56.7 %					

Table 5.5b. Backward elimination procedure to select the model testing effect of altitude, comparing Mwimbi at midlands and highlands

	Model	Term deleted	Df	Deviance	P(>|Chi|)
Saturated model	y~c*d*a	-	47	607	-
Step 1		-c:d:a	-5	-27.594	0.399
Step 2	y ~ c + d + a + c:d + c:a + d:a	- c:d	-5	-30.522	0.437
		- c:a	-5	-22.871	0.605
		- d:a	-1	-0.026279	0.949
Step 3	y ~ c + d + a	-c	-5	-53.605	0.049 *
Minimal model	y ~ c + d + a	-	40	235.5	-
Where Y: proportion of plots with crops failure; c: crop species; d: number of dry days after germination; a: altitude					
Deviance explained ; D^2 : 61.2 %					

Table 5.5c. Backward elimination procedure to select the model testing the effect of social communities. The comparison was implemented within the same agro-ecological zone at midlands comparing Mwimbi and Tharaka

	Model	Term deleted	Df	Deviance	P(>|Chi|)
Saturated model	y~c*d*sc	-	47	546.85	-
Step 1		-c:d: sc	-5	-14.625	0.482
Step 2	y ~ c + d + sc + c:d + c: sc + d: sc	- c:d	-5	-37.449	0.042 *
		- c: sc	-5	-28.477	0.118
		- d: sc	-1	-0.43152	0.715
Step 3	y ~ c + d + sc + c:d	-c:d	-5	-14.068	0.5325
		-c	-5	-17.492	0.4013
Minimal model	y ~ d + sc	-	45	166.43	-
Where Y: proportion of plots with crops failure; c: crop species; d: number of dry days after germination; sc: social community. Deviance explained ; D^2 : 69.6 %					

Annex 5.2. Output table of logistic regression analysis

Table 5.6. Seed loss observed among farmers belonging to the Mwimbi cultural group at two different altitudinal levels

Factors	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-7.276	1.1395	-6.385	1.36E-07	***
Dry spell	0.755	0.1269	5.949	5.58E-07	***
Altitude Mid	0.5822	0.3016	1.931	0.0606	
Cowpea	-0.1563	0.4969	-0.315	0.7547	
Green gram	0.3126	0.7	0.447	0.6576	
Maize	0.9006	0.3764	2.392	0.0215	*
Pearl millet	-0.4061	0.7193	-0.565	0.5755	
Sorghum	-0.1388	0.4279	-0.324	0.7474	
Significance. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05					
Null deviance: 607.00 on 47 degrees of freedom					
Residual deviance: 235.53 on 40 degrees of freedom					
Deviance explained, d: 61.2 %					

Table 5.7. Seed loss observed among two different cultural groups, Tharaka and Mwimbi, living at midlands

Factors	Estimate	Std. Error	t value	Pr(>|t|)	
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-8.001	1.1387	-7.027	9.31E-09	***
Dry spell	0.9344	0.1339	6.976	1.11E-08	***
Dialect Tharaka	-1.7768	0.3798	-4.678	2.66E-05	***

Significance codes: ***: p<0.001 ; **: p< 0.01; *: p< 0.05					
Null deviance: 546.85 on 47 degrees of freedom					
Residual deviance: 166.43 on 45 degrees of freedom					
Deviance explained, D: 69.6 %					

ANNEX 5.3. ADDITIONAL STATISTICS

Table 5.8. Average number of seeds sown per hill for different crop species

Crop	Mean	SD
Bean	2.1	1.2
Cowpea	2.2	0.8
Green gram	2.3	0.5
Maize	2.1	0.4
Pearl millet	5.7	2.1
Sorghum	6.7	2.7

Table 5.9. Percentage of plots with crop failure per season, year, and crop, comparing Mwimbi and Tharaka at midlands.

			Mwimbi		Tharaka		Total	
Season	Year	Crop	% failed	n	% failed	n	% failed	n
Long Rains	2010	Bean	83.3 %	18	20.0 %	5	69.6 %	23
		Cowpea	54.5 %	11	28.6 %	14	40.0 %	25
		Green gram	80.0 %	5	0.0 %	12	23.5 %	17
		Maize	75.6 %	41	45.7 %	35	61.8 %	76
		Pearl millet	100.0 %	12	35.7 %	14	65.4 %	26
		Sorghum	52.9 %	17	18.8 %	16	36.4 %	33
		Mean2010	74.0 %	104	30.2 %	96	53.0 %	200
	2011	Bean	93.3 %	15	100.0 %	1	93.8 %	16
		Cowpea	100.0 %	12	100.0 %	10	100.0 %	22
		Green gram	100.0 %	5	100.0 %	10	100.0 %	15

		Maize	100.0 %	20	100.0 %	22	100.0 %	42
		Pearl millet	100.0 %	8	100.0 %	11	100.0 %	19
		Sorghum	100.0 %	12	100.0 %	10	100.0 %	22
		Mean2011	98.6 %	72	100.0 %	64	99.3 %	136
	Mean Long Rains		84.1 %	176	58.1 %	160	71.7 %	336
Short Rains	2009	Bean	47.5 %	40	6.7 %	15	36.4 %	55
		Cowpea	57.7 %	26	0.0 %	20	32.6 %	46
		Green gram	69.2 %	13	10.5 %	19	34.4 %	32
		Maize	31.7 %	41	30.3 %	33	31.1 %	74
		Pearl millet	8.0 %	25	0.0 %	18	4.7 %	43
		Sorghum	6.5 %	46	2.6 %	39	4.7 %	85
		Mean2009	31.9 %	191	9.7 %	144	22.4 %	335
	2010	Bean	38.2 %	34	0.0 %	2	36.1 %	36
		Cowpea	11.1 %	18	0.0 %	11	6.9 %	29
		Green gram	0.0 %	9	25.0 %	8	11.8 %	17
		Maize	67.9 %	53	30.4 %	23	56.6 %	76
		Pearl millet	0.0 %	13	0.0 %	9	0.0 %	22
		Sorghum	42.9 %	35	6.7 %	30	26.2 %	65
		Mean2010	40.7 %	162	13.3 %	83	31.4 %	245
	Mean Short Rains		36.0 %	353	11.0 %	227	26.2 %	580
	GRANDMEAN		52.0 %	529	30.5 %	387	42.9 %	916

Table 5.10. Percentage of plots with crop failure per season, year, and crop, comparing Mwimbi Midlands and highlands.

			Mid		High		Total	
Season	Year	Crop	% failed	n	% failed	n	% failed	n
Long Rains	2010	Bean	83.3%	18	46.5%	43	57.4%	61
		Cowpea	54.5%	11	36.4%	22	42.4%	33
		Green gram	80.0%	5	100.0%	6	90.9%	11
		Maize	75.6%	41	57.9%	38	67.1%	79
		Pearl millet	100.0%	12	100.0%	1	100.0%	13
		Sorghum	52.9%	17	52.4%	21	52.6%	38
		Mean 2010	74.0%	104	51.9%	131	61.7%	235
	2011	Bean	93.3%	15	59.6%	57	66.7%	72
		Cowpea	100.0%	12	53.1%	32	65.9%	44
		Green gram	100.0%	5	50.0%	4	77.8%	9
		Maize	100.0%	20	67.7%	65	75.3%	85
		Pearl millet	100.0%	8	66.7%	3	90.9%	11
		Sorghum	100.0%	12	83.3%	30	88.1%	42
		Mean 2011	98.6%	72	64.9%	191	74.1%	263
	Mean Long Rains		84.1%	176	59.6%	322	68.3%	498
Short Rains	2009	Bean	47.5%	40	6.6%	91	19.1%	131
		Cowpea	57.7%	26	0.0%	27	28.3%	53
		Green gram	69.2%	13	25.0%	12	48.0%	25
		Maize	31.7%	41	57.5%	73	48.2%	114
		Pearl millet	8.0%	25	0.0%	2	7.4%	27
		Sorghum	6.5%	46	0.0%	52	3.1%	98
		Mean 2009	31.9%	191	19.8%	257	25.0%	448

2010	Bean	38.2%	34	0.0%	54	14.8%	88
	Cowpea	11.1%	18	4.5%	22	7.5%	40
	Green gram	0.0%	9	0.0%	6	0.0%	15
	Maize	67.9%	53	32.8%	58	49.5%	111
	Pearl millet	0.0%	13	0.0%	2	0.0%	15
	Sorghum	42.9%	35	11.1%	54	23.6%	89
	Mean 2010	40.7%	162	13.3%	196	25.7%	358
	Mean Short Rains	36.0%	353	17.0%	453	25.3%	806
	GRAND MEAN	52.0%	529	34.7%	775	41.7%	1304

General conclusion

The aim of this thesis was to describe how smallholder farming systems cope with climate variability. Smallholder farming systems have remained under considered whereas they can be fundamental to food security, as the account for over 75% of all the farms worldwide. The Mount Kenya was relevant and suited for describing how smallholders cope with climate variability. Crop production is primarily rain-fed, and farmers favour multi-cropping systems with a high level of intra-specific diversity. The Mont Kenya had several additional advantages for implementing a multidisciplinary and comparative approach. On one hand, the slope allows considering strong environmental contrasts in a short geographical distance. On the other hand, within the same agro-ecological zone, farmer communities are socially and linguistically differentiated. Our comparative approach was thus directly based on environmental and social field (empirical) conditions, using these conditions to control factors that can be at work in our analysis (avoiding any confusion in the inferential procedure). Describing how smallholder farming systems cope with climate variability imply considering multidimensional processes, which include interactions. Thus, the historical, social, environmental and biological components cannot be study separately, but jointly. It is what we tried to developed.

In the chapter one, we focus on seed losses rather than yield, this for many complementary reasons. Considering impact of climate variability on yield is more usual than on diversity erosion. Yet, the latter is a key component of the cropping system resilience. Indeed, smallholders in rain-fed farming systems depend on the diversity of species for their well being and for coping with climate risk, that is, the identity, abundance, and range of species traits. A key challenge therefore is that to preserve biodiversity and the multiple services that it provides, we should focus on preserving or restoring their biological integrity in terms of species composition, diversity, relative abundance, functional organization, and species numbers rather than on simply maximizing the number of species present, or maximizing yield.

In the chapter two, we have characterized crop diversity that is on-farm traditionally managed by farmers, and tried to identify factors that determine its distribution. A total of 13 cultivated crop species, and 53 varieties, were recorded; with on average 6 crop species per farm. On the contrary of specialized agro-system, the risk of crop failure is distributed among many species and varieties (this strategy was observed for all communities). Such diversity is also favored by contrasted environments (significant along an altitudinal gradient).

In order to describe how smallholder farming systems cope with climate variability, we considered historical, social, environmental and biological components jointly, using both diachronic and synchronic approaches.

6.1 Diachronic approach

Diachronic approach was used to assess how accurate is the farmer past climate knowledge, and to assess how does climate variability induce variety loss over time. Using a retrospective survey, chapter three assessed the accuracy of past climate farmer knowledge by comparing it to western climatology (precipitation amount recorded by Kenyan Meteorological stations). We showed how climate knowledge of Meru farmers (Kenya) is culturally built-in, and how it is highly accurate in the light of rainfall records, during 1961-2006 period. Reasons given by farmers to explain crop variety loss events were mainly related to droughts or heavy rainfall. Chi square test showed that farmers' past climate knowledge was significantly associated to rainfall records.

The high accuracy of past climate farmer knowledge was extended to the crop variety losses, as declared by farmers. In chapter four, we analyzed the impacts of rainfall variability on farmers' crop variety losses from 1961 to 2006, considering changes in smallholder farming systems. We showed that the cropping system dynamic, in favor of maize and at the expense of sorghum and millet, induced an increasing risk of loss of local farmers' varieties due to drought. The probability to lose a sorghum variety (0.056 to 0.065) was significantly lower than the probability to lose a maize variety (0.071 to 0.087). All crop species were highly impacted by droughts and few by heavy rainfall. Logistic regression models confirmed that change in cropping systems, favoring maize and at the expense of sorghum and millet, induced an increasing risk of loss of farmer varieties due to drought over the period. This dynamic is partly related to agricultural policies that positively valuated maize whereas sorghum and millet were devaluated, being perceived as "the crop of the poor people". Our results thus allow linking political (agricultural policies) and cultural components in our analysis of how smallholder farming systems cope with climate variability.

6.2 Synchronic approach

While the diachronic approach was based on farmer memory, the synchronic was based on empirical assessment of crop failure during the crop emergence phase. In the crop production cycle, it is essential that at the germination phase, farmers' ensure a good crop stand to favor desirable crop yields at the end of the season.

Observing how societies adapt their sowing practices to climate variability is challenging and costly to conduct. As an alternative, we used a space-and-time substitution design among Eastern African smallholders, where change in space corresponds to that induced in time by environmental change. Our comparative approach has used in chapter five the on-field historical context, which is another component that has to be considered in this study.

The Tharaka community originating from Mount Kenya Eastern slopes semi-arid lowlands (750 m) moved up in midlands (950 m) with their lowlands adapted resources whereas the Mwimbi community originating from wetter upland (1100 m) moved down in midlands with their highlands adapted genetic resources. Contacts and relations favoured by intermarriage directly foster seed exchanges between Tharaka in midlands with those in lowlands. The seed system in this case is oriented to lowlands and drought tolerance. On the contrary, the social relations and intermarriage of Mwimbi favour moving seed from highlands to midlands, and the seed system is in this case oriented towards highlands and drought susceptibility. The effect of this within-community gene flow may be negligible when farmers essentially use their own seeds for the next season, maintaining them in the same environment, but it can be much stronger in case of seed loss. Then, renewing seeds with genetic resources originating from highlands implies decreasing adaptability to droughts at the lower altitude for Mwimbi, whereas renewing seeds with genetic resources originating from lowlands implies increasing adaptability to droughts at the higher altitude for Tharaka (notably with seeds obtained from lowlands markets). The differential adaptability to drought of crop managed by the two communities is thus maximized in midlands.

Indeed, in midlands, while the crop relative importance, the number of varieties, the sowing practices and the seed management are closely similar between Mwimbi and Tharaka, the impact of dry spells on crop sowing failure is not uniform between the two communities. The relative risk of sowing failure was 3.3 times more for Mwimbi than for Tharaka during the Short Rains, and 1.5 times more during the Long Rains. GLM logistic regression confirmed that the seeds sown by Tharaka failed less than those sown by Mwimbi. Historical and social factors had more influence on mitigating risk of sowing failure due to dry spells than altitude, which was not a significant factor when comparing Mwimbi in midlands and highlands. Our results clearly show that crop genetic adaptability depends on farmer community that historically manages it.

Complementary, thus, our PhD shows that to describe how smallholder farming systems cope with climate variability, we must consider multidimensional processes, and their interactions. How smallholder farming systems cope with climate variability is determined by agricultural policies, as well as historical, social, environmental and biological components, which cannot be considered separately

The overall farm diversity is correlated to seed source, and seed exchange networks should receive more attention in biodiversity conservation efforts in the local farming systems. Indeed, smallholder systems such as on the eastern slope with high reliance on the local seed supply channels, there is need to avoid seed losses as seed of landraces dominant in these farming systems is not available for replacement through the formal seed system. But the informal seed supply systems is based on social relations that are also operant outside of the agricultural domain. A multidisciplinary approach has to be developped.

Informal seed systems play a role in the transmission of genetic resources notably for most local landraces. This calls for strategies in strengthening the local seed system. Fostering the integration of the formal and informal seed systems is also crucial, such as by increasing the number of crops and varieties (with a clearer definition of varieties) supplied by the formal system to include important drought tolerant local landraces. Crop genetic adaptability must be considered together with the farmer community that historically manages it, and must be reflected in crop genetic sampling strategies used in breeding programs to foster genetic adaptation.

Other studies have shown the crucial role of social relations in seed supply, but all analysis was based on a synchronic perspective, not diachronically. Indeed, the functioning of such a system remains unknown when we consider it over time, and when it is linked to rainfall variability. Further work is required to understand social and cultural rules in the seed supply system and how seed recovery works if droughts are severe (or with one, two, three or more successive droughts).

This research focused on analyzing the current status of biodiversity in smallholder production systems and there still remains a need to identify further the incentives and disincentives that affect use; and the opportunities for agro-ecological intensification through incorporating biodiversity within a certain crop and in crop mixtures at the plot and landscape scales. The benefits for human well-being and ecological resilience of managing risk through diversified production are not completely understood. It is necessary to understand the impacts of a loss or gain of agricultural biodiversity, in terms of socioeconomics, policies and biological processes. In addition crop diversity was estimated empirically and further work should focus on the use of genetic markers to characterize the genetic diversity which was initially planned.

Detailed examination on the influence of institutions and policies on farmers' abilities and decisions to use biodiversity is also required. This will identify and ground-test policy reforms. Results can be synthesized across diverse agricultural ecosystems and under different socio-economic conditions to derive overarching approaches, methods and principles.

Our PhD raises awareness among policy makers on the impact on identifying crop varieties that are endangered or threatened and need to be given high priority in conservation efforts, as well as to acknowledge that food policies need to take into account many dimensions (cultural, economic and environmental) influencing biodiversity outcomes and resilience of the agricultural system to climate risk.

The list of potential research areas touched upon is not exhaustive. But it is hoped that this thesis contributed to increasing the knowledge needed for enhancing agricultural productivity and sustainability.