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Chapter 3

CONSERVATION, NATURAL RESOURCE MANAGEMENT AND DEVELOPMENT CHALLENGES IN RURAL AFRICA: EVIDENCE FROM EAST AFRICA

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ABSTRACT

There is consensus in the international community that development and poverty alleviation in rural Africa are among the most urgent global agendas for the 21st century. Many rural Africans have traditionally depended on natural resources. Land use patterns are highly heterogeneous across diverse agro-ecological/farming systems and even within the systems, some being more extensive, while others being more intensive. These days a range of factors, including increasing population pressure and global climate change, has made it impossible for development through conventional extensive technologies or degradational pathways to be sustainable as a viable strategy. To achieve both development and environmental goals, sound agricultural intensification technologies through more intensive and efficient use of inputs internal to systems, or conservation pathways, must be identified and tailored to specific local needs and conditions to be adopted by rural households, while enabling policy and infrastructure should be availed by government and development agencies.

This chapter investigates the challenges that Africa has faced in rural development and natural resource management and seeks guidance for policies and research. Firstly, the chapter gives an overview of the current state of heterogeneous agro-ecological and farming systems and the development challenges posed by population growth and climate change in rural Africa. We propose a conceptual framework to guide empirical research in effectively examining the multi-dimensional aspects of the evolution of farming systems/resource management and review how the framework is applied at meso-level in the recent literature. Secondly, a case study from a Rift Valley community in western Kenya is presented to show micro-level evidence of diverse portfolios of technology options in a semi-arid environment.

It turns out that some conservation pathways may exist to promote more sustainable development in rural Africa, possibly through the better integration of system components, i.e., crop and livestock, and the inclusion of agroforestry into the farming systems. Concurrently, there are also degradational pathways entailing substantial trade-offs between promoting economic development vs. conserving natural resources. To promote conservation development pathways, policies not only need to identify optimal technology portfolios best suited to local conditions and exploit the complementarities among system components but also to provide education with farmers to augment their human capital assets and to promote stable non-farm/off-farm income opportunities to enable investment in resource management. The chapter concludes by synthesising the findings for policy implications and by presenting another emerging challenge of rising food/fuel prices and a subsequent future research agenda.

1. INTRODUCTION

While globally the percentage of people who live in absolute poverty declined from 40% to 18% between 1981 and 2004, in Africa it has stayed almost constant at 42% to 41% with the number of extremely poor almost doubling from 168 million to 298 million (Chen & Ravallion 2007; Collier 2007; Kates and Dasgupta 2007). An African exceptionalism dominates the development needs of today and contributing to its reduction through identifying different strategies from those used elsewhere is one of the grand challenges of sustainable science (Kates and Dasgupta 2007).

Within sub-Saharan Africa (SSA), we focus on rural areas where more than 70% of the population live, a majority of whom are poor. As most rural Africans are critically dependent on natural resources for their livelihoods (Barrett et al. 2002; Williams et al. 2004; Ellis & Freeman 2005; Dar and Twomlow 2007; Frost et al. 2007), agriculture, including crops, livestock and agroforestry, does play a major role in poverty alleviation and sustainable development as an economic activity and as a provider of environmental services. In achieving economic development and poverty alleviation through agricultural development, rural African populations need sustainable technologies that increase the productivity and resilience of production systems even under fragile biophysical conditions (Dar and Twomlow 2007).

One estimate suggests that a 4% annual sustained growth rate of agricultural production in SSA is an absolute requirement (Sanchez and Leakey 1997). Yet, the region has long failed to achieve increased agricultural productivity (Bullock 1997), missing out on the Green Revolution (Sanchez and Leakey 1997; Dorward et al. 2004). Indeed, SSA lags behind the rest of the world, with an overall net decline in agricultural productivity (Dar and Twomlow 2007). Between 1980 and 2000, food production per capita declined by 0.01% per year in Africa, while in Asia and Latin America it grew by 2.3% and 0.9% respectively (Kates and

Dasgupta 2007). In what aspects are rural sectors in SSA exceptional from those of other developing regions in not benefiting from advanced agricultural technologies?

SSA countries consist of diverse agro-ecosystems and farming systems accordingly, ranging from commercial agriculture in high potential zones, subsistence crop–livestock mixed farming in semi-arid zones, and pastoral activities in arid-zones (Thornton et al. 2002; Kristjanson et al. 2005; Okwi et al. 2007). Indeed, the heterogeneous and risky rainfed farming systems of SSA—the broader mix of crops grown in the region; the agro-ecological complexities and heterogeneity of the region; and the lack of infrastructure, markets and supporting institutions—have so far all contributed to limiting the scope of the Green Revolution in the region (World Bank 2007). Furthermore, two-thirds of the rural population in SSA live in less-favoured areas defined as arid and semi-arid or with poor market access (World Bank 2007). Given this pervasive heterogeneity in agriculture and rural society in SSA, it is critical to pursue and formulate strategies tailored to local needs/contexts and to integrate agricultural intensification with sustainable management of local resources within small/medium-scale farming sectors (Dar and Twomlow 2007; Frost et al. 2007).

While heterogeneity in agro-ecological and farming systems in SSA has already made agricultural productivity growth difficult, there are emerging factors, both internal social dynamics of population growth and exogenous shocks of global climate change, which have made African sustainable development even more challenging (Sanchez 2000; Beg et al. 2002). SSA has recently been experiencing faster population growth than other developing regions (Thornton et al. 2002). Increasing population pressure has been held primarily responsible for the increasing conversion of indigenous forests into agricultural land and for the expansion of agricultural/pastoral activities on marginal lands, thus leading to depletion and degradation of the inherently fragile soil and resource bases (Zhang et al. 2000; Amissah-Arthur and Miller 2002). Concurrently, global climate change, e.g. changes in annual rainfall, has also negatively affected agricultural output. Persistent rural poverty has accelerated rapid urbanisation without productivity and employment growth, as falls in agricultural output and the resulting poverty have forced rural residents to migrate to urban areas (Ndiaye and Sofranko 1994; Barrios et al. 2006; Dar and Twomlow 2007).

While rural poverty alleviation needs growth in agriculture, increasing population pressure and subsequent decreasing resource bases have made it impossible for development through conventional extensive agricultural technologies to be sustainable as a viable growth strategy. Furthermore, global climate change could expose rural populations to ever more uncertain climatic risks. To achieve both poverty alleviation and environmental goals, sound agricultural intensification technologies and better resource management practices must be adopted by rural households, while enabling policy and infrastructural environments need to be provided by government and development agencies. Otherwise, there would be a vicious cycle of stagnant agricultural growth, persistent poverty, soil depletion, resource degradation, deforestation, loss of biodiversity, and more vulnerability to climate change.

Agricultural intensification through better utilisation of locally available resources through integration of system components, i.e. crop, livestock and agroforestry, without depending much on expensive external inputs, is especially desirable considering the poverty of rural populations. Therefore, the major research agenda for researchers and scientists would be to identify various agricultural development and resource management pathways across different agro-ecological zones/farming systems and to examine factors affecting respective pathways so as to better formulate policies to promote sustainable development pathways with optimal resource utilisation practices.

Yet, analyses can be quite complicated since agro-ecological and farming systems consist of diverse system components (crop, livestock, agroforestry, nutrients, natural resources) that interact dynamically in response to changing environment, such as increasing population pressure and climate change, aside from the extensive heterogeneity of agro-ecological and farming systems in SSA. Furthermore, interactions of diverse system components can take diverse pathways, in a complementary way or with trade-offs, not only across different agro-ecological and farming systems but also between heterogeneous plots/farms within particular systems. In other words, in research, we have to deal with (a) multi-dimensional aspects of agro-ecological and farming systems, i.e. interactions, complementarities or trade-offs, of multiple system components (among crop, livestock, agroforestry, nutrients, natural resources, etc.), at (b) certain layers of analytical scales (at farm-level, meso-level). A substantial number of empirical studies and surveys have been conducted for separate models on particular crop/animal types or technologies in rural Africa and there have been more frameworks to analyse multi-dimensional aspects of poverty such as livelihoods approach. On the other hand, unfortunately, there have been few established conceptual frameworks for guiding research and analysis of multi-dimensional aspects of agricultural intensification, making it rather difficult to convert distinctive case studies into comparable interpretations and synthesise them into policy formulations for integrated natural resource management.

The major objective of this chapter is to investigate the challenges that Africa has faced in rural development and natural resource management. In order to facilitate such investigation, we attempt to provide the conceptual framework for guiding research to allow the examination of multi-dimensional aspects of diverse system components and their interactions, especially complementarities/trade-offs, at various analytical scales. Then we present how to apply the guidance to the analysis to identify critical factors promoting optimal development and resource management pathways for policy formulation. Accordingly, Section 2 gives an overview of the development challenges in rural Africa, proposes key criteria and parameters included in conceptual frameworks for guiding research and analysis, and reviews the recent literature on empirical studies. In Section 3, some of the criteria are applied to guiding research and analysis of the micro-level data on rural development and natural resource management in the mixed crop–livestock-agroforestry system of a Rift Valley community in western Kenya. The case study attempted to identify and interpret diverse agricultural development and resource management pathways in the study area, to examine socio-economic, physical and institutional factors determining the households’ choices of technology portfolios with incentives for sustainable natural resource management, and to discuss policy options. Section 4 concludes by synthesising the findings for policy implications and future research agendas that advocate for a holistic system analysis approach to assess and evaluate viable technology options in rural Africa.

2. FARMING SYSTEMS, NATURAL RESOURCES, AND DEVELOPMENT NEEDS

2.1. Status and Challenges

As mentioned in the Introduction, there are two dimensions in Africa's stagnant agricultural growth: the inherent heterogeneity in agro-ecological/farming systems which has prevented agricultural technological breakthroughs, and emerging factors such as population growth and climate change which have further burdened an inherently fragile soil and resource base. This sub-section outlines the status of the systems in SSA and emerging challenges.

Heterogeneous Agro-ecological and Farming Systems

Understanding heterogeneity in agro-ecological and farming systems and the local potential is critical in the search for alternative strategies to increase agricultural productivity and sustainable resource management in SSA. In economic perspective, productivity increases in agriculture have come from specialization/intensification. Yet, African severe biophysical and climate conditions often limit the scope of specialization and risk-averse farmers often opt for diversification (Ellis 2000; Ellis and Francis 2005). Indeed, from ecological perspective diversification may be better than highly specialized, even mono-cropping, systems which may destabilize the fragile balance of local biodiversity and ecosystems. Since soils and climatic conditions of a region largely determine the suitability of different crops and their yield potential along with the potential of integration with livestock and agroforestry, mapping agro-ecological regions may facilitate the identification of optimal farming patterns, i.e. cropping, livestock keeping and agroforestry, for increasing agricultural production sustainably (Bullock 1997). While we do not discuss the significance of mapping in development policy making here, we review the methodology of mapping to deal with the inter-regional heterogeneity and the intra-system diversification in agro-ecological and farming systems in Africa.

For example, FAO has worked on refining the agro-ecological zone approach for crop systems. A set of information assembled for the agro-ecological zone delimitation included choice of crops (wheat, paddy rice, maize, pearl millet, sorghum, soybean, cotton, phaseolus bean, white potato, sweet potato and cassava) and identification of their climatic and soil requirements, assemblies of agro-climatic data (with emphasis on temperature and water availability whose combination is expressed in the length of the growing period) and of soil data. The information was then combined to produce a land inventory map. Such a map enables calculation of the maximum potential yield of each crop in each zone, taking into consideration how ideal the soil conditions were and problems of soil management where climatic conditions were less than ideal, and to produce a land suitability assessment for each particular crop (Bullock 1997). In summary, the FAO agro-ecological zone definition was mainly concerned with crops. Of course, crop types in SSA are far more diverse, and for a reasonably generic agricultural system classification to be applied to the region, refinements would be required to handle diverse cropping (and probably agroforestry) systems more adequately (Kruska et al. 2003). However, a certain focus will be inevitable to simplify the classification.

The small-scale farming sector in SSA rarely lacks a livestock component (Mortimore 1991; Thorne 1998). In mixed farming systems, livestock can contribute either to sustainable development by providing organic inputs into crop/agroforestry through better integration of system components or to resource degradation if managed extensively without integration under high population pressure (Iiyama et al. 2007a; 2007b). Agro-climatic and demography are both important factors in the definition of the farming systems including livestock components, as population density determines the available area of land for livestock farming (McIntire et al. 2002). To develop future scenarios of possible system changes in response to climate change and population growth in the future as discussed later, it may be convenient to develop the classification defined not only by climate but also by land cover and human population density for crop–livestock systems rather than for crops only to assess the development challenges and the status of natural resource management in SSA. What follows deals with (crop–) livestock production systems.

Thornton et al. (2002) and Kruska et al. (2003) proposed the development of a global livestock production system classification put forward by Seré and Steinfeld (1996) who disaggregated the systems by agro-ecological conditions and population density. The livestock systems are divided into: livestock only; rangeland based systems (areas with minimum cropping); mixed rainfed systems (mostly rainfed cropping combined with livestock); mixed irrigated systems (where a significant portion of cropping uses irrigation and is interspersed with livestock); and others (areas with the population density over 450 square km). Each sub-system is further disaggregated by agro-ecological potential as defined by the length of growing period (LGP); i.e. arid/semiarid zone (with LGP <180), humid/semi-humid zone (with LGP >180 and <270), and temperate /tropical highland zone (average temperature in growing season >5°C and <20°C or a month or more with an average >5°C) (Thornton et al. 2002; Kruska et al. 2003).

Diversity in crop–livestock systems in SSA is illustrated in Table 1. In 2000, 70% of the total population of SSA depended on mixed rainfed crop–livestock systems which account for 27% of the total land area, while 10% depended on livestock only systems and 1% on irrigated systems. Mixed rainfed systems are geographically widely distributed across SSA, depending on agro-ecological conditions and population density. For example, in West Africa, mixed rainfed systems are observed between zones neither too arid for crop cultivation nor too humid to allow diseases for livestock (Manyong et al. 2006). In East Africa, mixed farming systems are common in the highlands, and also in some semi-arid/sub-humid zones (Thornton et al. 2002).

Challenges

While principally defined by population density and agro-climatic conditions, agricultural settings in the farming systems in SSA are continuously evolving in response to changing conditions such as population growth and climate change (Pell 1999).

Table 1. Geographical and Demographic Distribution of Livelihood Production System

	% of land area	% of human population 2000	population density 2000	population density 2050	times population in 2000
livestock production system					
Livestock only	**37**	**10**	**7**	**17**	**2.41**
rangeland arid/ semi-arid	26.18	6.70	7	17	2.49
rangeland humid/ semi-humid	10.20	2.66	7	18	2.68
rangeland temperate & highlands	0.87	0.52	15	0	0
Mixed Rainfed	**27**	**70**	**67**	**158**	**2.35**
mixed rainfed arid/ semi-arid	14.17	25.06	46	105	2.28
mixed rainfed humid/ semi-humid	9.67	30.16	81	199	2.45
mixed rainfed temperate & highlands	3.30	14.59	115	263	2.29
Irrigated	**1**	**1**	**53**	**96**	**1.80**
mixed irrigated arid/ semi-arid	0.46	0.66	38	64	1.71
mixed irrigated humid/ semi-humid	0.00	0.02	155	422	2.72
mixed irrigated temperate & highlands	0.04	0.35	219	420	1.91
Others (landless city & others)	**35**	**19**	**14**	**35**	**2.47**
Total	**100**	**100**	**26**	**61**	**2.36**
Total (square km, population)	(24,066,355 square km)	(626,972,000 persons)			

Note: calculated from the data from Thornton et al. (2002) and Kruska et al. (2003).

Population Growth

Both livestock rangeland systems and mixed rainfed systems in SSA (from arid/semi-arid, sub-humid/humid, to temperate/highland zones) will see population density more than double by the year 2050 (Table 1). This expected population growth will require an expansion in food production and increase competition between crops and livestock. McIntire et al. (1992) claim that in the short term, conflicts would occur over the use of high quality land, while in the long term, population growth will intensify competition of crop and livestock enterprises for both land and labour. Rising population would also necessitate the expansion of cultivated areas, replacing pastures and thereby reducing the grazing area for animals. This indicates that unless farmers introduce intensive technologies such as high-yielding crop varieties or improved livestock breeds, it would be difficult to meet expected rising demand for animal products by the growing population (Delgado et al. 1999; Pell 1999; Steinfeld et al 2006).

Climate Change

In addition, recent climate change further affects agricultural outputs negatively (Barrios et al. 2006). The African continent is particularly vulnerable to the impacts of climate change because of factors such as widespread poverty and overdependence on rain-fed agriculture (IPCC 1998). Changes in climate will further add stresses to a deteriorating situation. A sustained increase in mean ambient temperatures beyond 1°C would cause significant changes in forest and rangeland cover; species distribution, composition, and migration patterns; and biome distribution. Many countries on the continent are prone to recurrent droughts, which could seriously impact the availability of food. African populations may also face challenges that will emanate from extreme climate events such as floods (and resulting landslides in some areas), strong winds, droughts, and tidal waves. High population growth rates, and lack of significant investment - coupled with a highly variable climate - have made it difficult for several countries to develop adaptation capabilities and patterns of livelihood that would reduce pressure on the natural resource base.

Nutrient Depletion and Soil Degradation

Sanchez and Leakey (1997) claim that static or decreasing crop yields in Africa are already occurring in the inherently less fertile, sandy soils of the savannahs and the Sahel, because of population increases in these more marginal areas and due to nutrient depletion. They have been indicative of a vicious cycle of population pressure, expansion of extensive agriculture on marginal soils, soil depletion, resource degradation, deforestation of indigenous forests, loss of biodiversity and watersheds, stagnant agricultural growth, persistent rural poverty and accelerated urban migration.

“In addition to marked reductions in crop productivity, nutrient depletion triggers several negative side effects on farm such as less fodder for cattle, less fuelwood for cooking, smaller amounts of crop residues, and less manure from the cattle. These in turn further increase runoff and erosion losses because there is less plant cover to protect the soils from wind and water erosion.… deforestation in search of the few remaining pockets of fertile land in densely populated areas often results in an almost total removal of trees from the landscape. Lack of tree protection at the upper parts of watersheds severely affects their functioning. Increasing soil erosion from unproductive cropland, communal grazing lands and denuded watersheds leads to silting of reservoirs, lakes and coastal areas and can lead to the eutrophication of fresh waters. Food shortages and famines become more acute during drought years. Lack of opportunities for cash income pushes people off the land and into urban areas where many cannot find productive jobs, further taxing the limited urban infrastructure” (Sanchez and Leakey 1997).

Urbanisation

Individuals living in marginal areas may be forced to migrate to urban areas if the marginal lands become less productive under increased population pressures new climate conditions (IPCC 1998). The growth of urban areas may boost the demand for non-traditional food products, such as rice, fruits and vegetables, thus creating new reliable domestic markets for rural farmers, if they have capitals to undertake new technologies and ventures. In turn, as infrastructure is already approaching its limits in urban areas, rapid urbanisation prompted by persistent rural poverty and agricultural stagnation should substantially increase the demand for modern energy (Wolde-Rufael 2006). As electricity provision is very limited in SSA (Karekezi & Kithyma 2002), most countries are predominantly dependent on traditional biomass fuels for their energy; 70–90% of primary energy supply and up to 95% of the total consumption (Karekezi 2002). Charcoal is especially popular for household use but its production process is very inefficient, thus the increased demand in urban areas has led to accelerated deforestation in rural areas (Morgan and Moss 1985; Cline-Cole 1990; Mwampamba 2007). The rural poor without capital assets to undertake productive farming increasingly find charcoal making by exploiting natural resources an easy means to earn ready cash (Iiyama et al. 2008). Accelerated deforestation has led to land degradation by exhausting soil organic contents (Ndiaye and Sofranko 1994; Chidumayo and Kwibisa 2003), further escalating the vicious cycle through aggravating the adverse impact of global climatic change on farm productivity.

Degradational vs Conservation Pathways

To feed a growing population, rural smallholders in African will need to accelerate the expansion of their production activities from subsistence to commercial farming and diversification into off-farm income generating activities. Much of the past expansion in commercial crop and livestock production has been managed by increased use of land at low inputs of capital and labour. As unoccupied land diminishes, increasing areas of natural vegetation have been transferred to arable areas with shorter fallow cycles. Concurrently, competition between grazing and cultivating systems for available land has more than intensified. Hence, soil fertility is expected to decline unless some measures are taken to improve soil management (Iiyama et al. 2007a; 2007b).

Yet, the long-term relationship between land resource degradation and demographic pressure should not be necessarily negative and linear. A cycle of poverty and environmental degradation can be reversed with land intensification through better crop–livestock integration and incorporation of trees within farms as well as through re-investment of capitals/income from off-farm/non-farm activities into external input use. This has indeed happened in the semi-arid Machakos District of Kenya, where despite increasing population pressure since the 1930s farmers were able to reverse land degradation through an indigenous soil conservation technology and agroforestry adoption that improved both crop and livestock productivity (Tiffen et al. 1994; Sanchez and Leakey 1997).

Therefore as Mortimore (1991) suggested, the farming systems in SSA are confronted with a choice between: (1) a degradational pathway—increasing the frequency of use without additional inputs, failing to replenish soil chemical properties or to conserve physical properties; and (2) a conservation pathway—increasing inputs, especially of labour, to maintain or raise productivity per hectare. Since most African smallholders are poor, it is unlikely that a conservation pathway can be achieved solely through an increased use of expensive external inputs, such as inorganic fertilisers. Therefore a conservation pathway should rather make efficient use of inputs internal to the systems and complementarities through interactions/integration of system components, i.e. crop, livestock, trees, as much as possible.

For example, in mixed crop–livestock systems, under demographic pressure, there is increased demand for integration in order not only to ease competition over resource use between components but also to exploit their complementarities (McIntire et al. 1992; Christiaensen et al. 1995). Crop–livestock integration, defined as a process by which farmers intensify their activities by integrating components of crop and livestock activities, is expected to be an economically feasible and environmentally sound conservation pathway for poor agropastoralists (Mortimore 1998; McIntire et al. 1992; Christiaensen et al. 1995; Iiyama et al. 2007b). The benefits of crop–livestock interactions are several. Animal traction could improve the quality and timeliness of farming operations now done by hand, thus raising crop yields and farm household incomes. Farm animals provide manure to improve soils. Livestock sales would generate cash to buy inputs. Keeping animals on the farm could also provide a use for other resources such as crop residue, which might be wasted in the absence of animals (Mortimore 1998; McIntire et al. 1992; Christiaensen et al. 1995; Thorne et al. 2002; Bationo et al. 2004; Manyong et al. 2006).

Agroforestry practices also have considerable potential for helping solve some of Africa’s development and resource management challenges, as agroforestry is defined as a dynamic, ecologically-based, natural resource management system that, through the integration of trees in farms and rangeland, diversifies and sustains smallholder production for increased social, economic and environmental benefits (Sanchez and Leakey 1997; Ong et al. 2007). Agroforestry trees can supply farm households with a wide range of products for domestic use or sale, including food, medicine, livestock feed and timber, and environmental and social services such as soil fertility, moisture conservation and boundary markers. For example, high-value trees can fit in specific niches on farms while leaving more open land to staple food crops or other profitable crops such as vegetables. Trees for timber and fuelwood trees can also be grown on farm boundaries with leguminous fodder trees under them or as contour hedges on sloping land. In such farms, income is increased and diversified, providing resilience against weather or price disruptions. Soil erosion is minimized, nutrient cycling maximized and above- and below-ground biodiversity enhanced (Erskine 1991; Sanchez and Leakey 1997; Franzel et al.2001; Thangata and Alavalapati 2003).

The potential for integrated crop, animal and tree production is perceived to be high while further population growth is expected in the next few decades (Mortimore 1991; Kristjanson and Thornton 2004). Of course, the realities are not always ideal and the optimal pathways are rarely evolving themselves spontaneously. Yet, if productivity is to increase because of increasing demand and increasing land pressure, then there are real research needs to enhance the complementarities between the existing system components (Thornton and Herrero 2001).

2.2. Concepts and Models

This sub-section proposes a conceptual framework for integrated system analyses and key parameters examined in the analysis of development and natural resource management.

General Conceptual Framework

Researchers and policy makers are urgently required to identify development and resource management pathways within particular local/institutional contexts, to examine the limiting factors/enabling environment for development and resource management practices, and to provide technological/institutional support for poor African smallholders to adopt optimal pathways that contribute to poverty alleviation, food security and sustainable resource use.

Yet, what makes research challenging is that agro-ecological and farming systems in SSA consist of distinctive but tightly interdependent components or sub-systems which are highly heterogeneous across regions depending on agro-climatic and demographic conditions. Furthermore, these systems have been dynamically evolving in response to changing circumstances, such as population growth and climate change as well as market conditions, while farmers may pursue multiple objectives (e.g. food security and income maximisation) with multiple system components (e.g. crops, animals, trees and natural resources) and through livelihood diversification (into various farm and off-farm activities).

While a wide variety of models exist for separate crop and livestock to assess the adoption potential of independent technologies, few models are available on the interaction of various crop and animal types, and integration with agroforestry or other ‘natural resource management’ and ‘sustainable agriculture’ practices (Franzel et al. 2001; Ong et al. 2007). A new integrated model is required to analyse interactions of diverse system components with a larger agro-ecosystem composed of non-agricultural systems, market systems and other biophysical conditions, to incorporate quantitative relations between system components, and to model optimal pathways of system component integration in terms of efficient nutrient cycling, in order to estimate the long-term impact of existing strategies on the sustainability of the system (Thornton and Herrero 2001; Herrero et al. 2007).

In other words, analytical methodologies for empirical research to identify the limiting factors/enabling environment for sustainable development and resource management are, at a minimum, required simultaneously to deal with multi-dimensional aspects of the systems, i.e. interactions (either complementarities or trade-offs) among crops, animals, trees and natural resources and the circumstances/factors affecting the evolution of agro-ecological/farming systems at particular analytical scale (meso-, farm-, or sector-level). A set of logical methodological steps is required to adequately represent the components of and transactions within and between the systems to be modelled. These steps include characterizing production systems, i.e. biophysical scales, management and interaction intensity, farm household objectives, temporal scales, and modelling the key components and processes.

In guiding empirical studies, we propose a conceptual framework that will reduce the complexity, consisting of three analytical steps (Box 1). The first step starts by identifying (a) distinctive development/resource management pathways observed at (b) a particular scale, either at (b-1) meso-level (regional or across different development/land use domains across regions) or at (b-2) farm-level (farms/household types with different land use/resource management patterns even within a region). Interactions of system components (crops, animals, trees and natural resources) of each development/resource management pathway are then examined to determine whether their interactions are more of trade-offs or of complementarities. These pathways are then evaluated as degradational or conservation pathways. The second step examines potential circumstances or factors affecting the adoption of (a) respective degradational/conservation pathways at a particular analytical scale, i.e. agro-ecological, demographic and market conditions at (b-1) meso-level, and capital asset endowments and livelihood strategies at (b-2) farm-level. The following paragraphs explain the assumptions/methodologies concerning (a) complex interactions of system components for the development/resource management pathways and (b) the factors affecting the evolution of pathways at diverse analytical scales.

Box 1. A Conceptual Framework/Analytical Steps

(1) identification of (a) development/resource management pathways at (b) a particular scale
  (a) identification of diverse development/resource management pathways
  - look at multi-dimensional system components (crop, animals, trees and natural resources)
  - examine the interactions (complementarities/trade-offs) between system components
  - interpret as degradational (trade-off) or as conservation (complementary) pathways

  (b) determination of the analytical scale
  - (b-1) meso-level: development domains reflecting heterogeneity in the pathways
  - (b-2) farm -level: farm types reflecting heterogeneity in the pathways

(2) examination of factors affecting each of (a) the pathways at (b) a particular analytical scale
    (b-1) meso-level…agro-ecological, demographic, market access and conditions
    (b-2) farm -level…capital assets, livelihood strategies (especially off-farm income)

(3) policy recommendation

System Components of Development/Resource Management Pathways

The initial stage of the research requires the identification of (a) development/resource management pathways at (b) a particular analytical scale by examining the interactions (complementarities/trade-offs) between system components (crop, animals, trees, natural resource) and interpreting them as degradational (trade-off) or as conservation (complementary) pathways.

Using an integrated model or the concept of system analysis approach is often advocated when dealing with multiple dimensions of particular farming systems. The systems analysis approach attempts to analyse interactions of system components with a larger agro-ecosystem composed of non-agricultural systems, market systems and other biophysical conditions, to incorporate quantitative relations between crop and animal production, and to model optimal pathways of system component integration in terms of efficient nutrient cycling, in order to estimate the long-term impact of existing strategies on the sustainability of the system (Thornton and Herrero 2001; Herrero et al. 2007). As the farming systems in SSA are facing tremendous challenges due to population growth and climate change, modelling systems can help identify and quantify significant interactions that occur between the various components of smallholder systems through simulation exercises of existing land use patterns or interventions.

Thornton and Herrero (2001) propose that a conceptual framework for modelling crop–livestock systems should meet several requirements if the resulting models are to be used reliably in a variety of systems analysis and impact assessment studies. Among the requirements they list are: to describe and quantify the interactions between the system's components; to represent the farmer's management practices; to determine the impact of management strategies on use of land and other resources; and to allow the possibility of studying both the medium- and the long-term effects of the strategies investigated. Still, empirical application of a modelling framework is quite challenging if dealing with all the interactions occurring in the system.

One way to tackle the complexity in modelling is to develop relatively simple models based on either experimental or empirical farm types with site-specific parameters, by integrating information in a rational way to address specific research priorities. On-station research with the simulation of whole farm systems allows maximum biological and economic responses to the farm models under optimal conditions to be closely monitored.

However, the simulation model approach often does not replicate treatments in space, while environmental factors, including agro-ecological, demographic and market conditions, significantly vary across regions and these local modifiers substantially affect localised system evolution which does not necessarily follow optimal pathways. Furthermore, though incorporating the basic elements of local farming systems as system components, i.e. crops, animals, trees and natural resources, the on-station model farm approach fails to simulate the behaviour and management of farms which face highly risky environments and thus manage them through livelihood diversification.

In the analyses of the interactions of diverse system components, relative effects of the local modifiers at meso-level and of engagement in off-farm income activities on development/resource management pathways at farm-level should be explicitly treated and empirically investigated. It is thus important to determine at which analytical scale the analysis is conducted to identify development/resource management pathways at the initial analytical step.

Analytical Layers/Scales

African farming systems are characterised by heterogeneity and diversity both at meso- and farm-level whose understanding is critical in formulating effective intervention (World Bank 2007). Most empirical studies using econometric models attempt to examine diverse factors promoting the evolution of the development/resource management pathways and especially in identifying the factors affecting the adoption of optimal pathways (conservation pathways) with incentives of better resource management, against degradational pathways.

These models are roughly divided into two groups; one group which emphasizes meso-level parameters, assuming whether a farm adopts a particular technology or not is a function of location specific factors, and the other which focuses on farm-level parameters or household-specific factors on the development/resource management pathways. Even in the discussion on targeting of interventions for sustainable agricultural development and resource management in SSA, there is an ongoing debate on the usefulness of geographic targeting (i.e. meso-level) versus targeting of specific household types (i.e. farm-level) (Kruseman et al. 2006). We review the assumptions on key factors either at meso-level or farm-level that are likely to affect the diverse evolutional pathways/heterogeneous land use patterns in rural SSA.

Mixed farming systems in SSA at a given place and time are largely defined by agro-ecological potential and population density, therefore land use/resource management pathways show certain spatial patterns with some areas observing more farms adopting intensification technologies than others (Iiyama et al. 2007b). Furthermore, access to markets/infrastructure is also among the important factors that drive land use change. For example, in general, the levels of agricultural intensification and crop–livestock interactions are low in arid, sparsely populated zones, but relatively higher in cooler more densely populated zones. Opportunities for development of high-value perishable commodities, such as horticultural crops or dairy, are likely to be greatest in areas with relatively high market access and agricultural potential (Staal et al. 2002; Pender et al. 2004a; Kristjanson et al. 2005; Place et al. 2006; Kruseman et al. 2006; Manyong et al. 2006; Okwi et al.2007).

The underlying theme of the meso-level analysis is that agricultural/soil and demographic conditions and market/infrastructural access are key factors that determine land use/livelihood options available to households (Pender et al. 2004a; Kruseman et al. 2006). Agricultural potential largely influences the absolute advantage (productivity) of a location in production of particular agricultural commodities, while access to markets and infrastructure, and population pressure help to determine the comparative advantage (profitability) of particular livelihoods, given the absolute advantages. Yet, improved access to markets and infrastructure has more ambiguous theoretical impacts on land use, land management practices and resource conditions, because of the ambiguous effects of output prices on incentives to conserve land (Pender et al. 2004a). It is suggested that if diversity between villages is more important than heterogeneity amongst households, geographical targeting can be considered as an effective strategy for selectively enhancing a process of agricultural intensification (Pender et al. 2004a; Kruseman et al. 2006). In efficiently capturing the dimension of locational factors, more recent studies incorporate GIS (geographical information system)-derived measures into their econometric models (Kristjanson et al. 2002; Staal et al. 2002; Manyong et al. 2006; Okwi et al. 2007).

However, there also exist heterogeneities in land use/resource management patterns among households sharing similar biophysical, demographic and market conditions (Evans and Ngau 1991; Tittonell et al. 2005; Iiyama et al. 2008).Farm-level analytical models then tend to assume that levels of capital asset endowments of particular livelihood diversification patterns adopted by households along with physical and institutional characteristics of plots affect the adoption of agricultural intensification and resource management technologies, in empirically examining the factors affecting heterogeneous land use patterns at community-level.

Agricultural intensification is a dynamic process involving the decision making process of individual farms to adopt new technologies in response to challenges posed to their systems by population growth, climatic changes and market opportunities (McIntire et al. 1992; Pender et al. 2004a). Yet, incentives to pursue environmentally sustainable practices are commonly lower than incentives to simply extract natural resources in an arid/semi-arid environment where the majority of Africa’s poorest and most food-insecure households live (Dar and Twomlow 2007). To survive in a harsh and variable environment, rural households often pursue a range of livelihood strategies to diversify their income sources into various farm and off-farm activities as a means to reduce risk from specialisation and, if possible, respond to rapidly changing market conditions (Ellis 2000; Barrett et al. 2001; Dar and Twomlow 2007). As households are different in capital asset endowments and capability to pursue different development paths or livelihood diversification portfolios with different incentives for resource management (Ellis 2000; Barrett et al. 2002; Williams et al. 2004), the rate at which technologies are adopted can be heterogeneous among households even within a small community (Tittonell et al. 2005; Iiyama et al. 2008).

In deriving meso-/sector-/macro-level policy implications, meso-level analyses may provide more straightforward recommendations than farm-level analyses. Nevertheless, detailed community-level case studies are also needed in order to more adequately address policy concerns for understanding what the effects of a household's capital asset endowments are with respect to the adoption of relatively high-return, sustainable agricultural activities. A few micro-level studies on rural livelihoods have revealed that households pursuing highly diverse income diversification strategies, usually including off-farm options, are more likely to adopt new farming technologies. These households are relatively well endowed with respect to education and skills (Evans and Ngau 1991; Iiyama et al. 2008). This implies that for poverty alleviation, meso-/macro-level development policies need to be multi-sectoral, encompassing education, and both farm and off-farm activities.

2.3. Methodologies and Application

Analytical methodologies for empirical studies on agricultural development and natural resource management in SSA are, at a minimum, required to identify dominant development/natural resource management pathways in particular locations, by simultaneously dealing with multi-dimensional aspects of the systems, i.e. interactions between multiple system components of crops, animals, trees, and natural resources. Then the analysis should include an examination of the factors affecting the evolution of the development/resource management pathways at a particular analytical scale, i.e. locational factors such as agro-ecological, demographic and market conditions at meso-level, and household-specific factors such as capital asset endowments and livelihood diversification strategies.

In empirical application, it is often difficult to capture multi-dimensional aspects of development/resource management pathways, the interactions and dynamics of system components, in the analysis. For example, the multi-dimensionality of crop–livestock integration includes the use of manure, animal traction, crop residue, and agricultural by-products as feed within the same farm enterprise (Manyong et al. 2006). However, most literature on crop–livestock integration deals with selected technologies as proxies to some dimensions of agricultural intensification rather than holistically treating all the technologies. For example, Staal et al. (2002) focus on the three technologies—keeping of dairy cattle, planting of specialised fodder, and use of concentrate feed—as proxies of crop–livestock integration in mixed smallholder farming systems in central and western Kenya, and investigate the effects of locational factors on technology adoption. Kristjanson et al. (2002) select the adoption of genetically improved double-purpose cowpea varieties as a proxy of crop–livestock integration in West Africa, and examine the ability of village-level factors to potentially influence spatial patterns in crop–livestock evolution pathways.

The typology of crop–livestock integration pathways or development/natural resource management pathways has long been challenging. Earlier attempts tried to disaggregate multi-dimensional features of farming and integrated natural resource management and to classify farming systems into domains/zones with particular features (Mortimore 1991). There are also new attempts to derive integrated, location/farm-specific indices of agricultural intensification by summarizing and reducing the multiple dimensionality of the interaction of system components. There are still only a few empirical studies at meso-level that have attempted to invent integrated indices to capture multi-dimensional aspects of farming system evolution (Pender et al. 2004a; Kruseman et al. 2006; Manyong et al. 2006), while there are even fewer case studies at micro-level (Iiyama et al. 2007b). The methodology used and implications of the work of Pender et al. (2004) are reviewed below.

Pender et al. (2004a) propose the concept of development domains and development pathways to investigate spatial patterns and factors affecting evolution in land use/income strategies across different locations in Uganda, and to test the hypothesis that the opportunities and constraints for sustainable development depend upon the comparative advantages that exist in a particular location. They define a “development domain” as a geographical region having similar comparative advantages, based upon similar agro-climatic conditions, access to markets and population density. In turn, a “development pathway” is defined as a common pattern of change in income strategy. This concept is more general than farming systems since it incorporates non-farm as well as on-farm activities, and is dynamic since it refers to changes and not merely income strategies pursued at a particular point in time. Their key research questions include: (i) what are the dominant development pathways occurring in different development domains in Uganda since 1990, and their relationship to land use and land management; (ii) what factors determine the development of particular development pathways and changes in land use and land management; and (iii) what are the implications of different development pathways, policies, programmes and other causes of change for natural resource and human welfare conditions.

While the high quality time-series and cross-sectional data on changes in land use and income strategies have virtually not been available in Uganda, Pender et al. (2004) collected some of the information on income strategies, perceptions of change in human welfare and natural resource conditions, land use, and land management using the following survey method. A community-level survey was conducted in 107 communities across different development domains in Uganda between 1999 and 2000 by interviewing with a group of 10–20 individuals representing the community to collect information. Where information about changes was sought, the focus was on changes during 1990–99. They used a common method of ranking perceptions of change in all cases: +2.major increase (or improvement), +1.minor increase, 0.no change, -1.minor decrease, -2.major decrease. As they acknowledged, given the qualitative and subjective nature of the data used, the findings of the study should be regarded as suggestive rather than definitive and should be confirmed by further study using more objective and quantitative (though more costly) methods. Even so, this approach is useful to estimate the overall evolution of land use and income strategies in Uganda, where it is extremely expensive to collect high-quality data at national scale.

Several steps were used to analyse the data. Firstly, different development domains in Uganda were classified based upon available secondary information related to agricultural potential (based on six agro-climatic zones), market access and population density (at the second lowest administrative unit). There are 24 possible domains, though only 18 are represented to any significant extent in the study region. Secondly, the factor analysis used data on the primary activities of men in 1999 and changes in the three main activities since 1990 to identify the development pathways. The first six factors have a clear interpretation as development pathways. Thirdly, the econometric analysis focused on determinants of the development pathways (as measured by the factor scores from the factor analysis) and changes in land use, land management practices, purchased input use, and various indicators of change in natural resource conditions and human welfare. The fixed explanatory variables included in the regression models include dummy variables for the agro-climatic zones, market access class, population density class, and whether there is irrigation in the village.

As a result of the factor analysis, six dominant development pathways were identified. These were: [1] expansion of cereals production; [2] expansion of banana and coffee production; [3] non-farm development; [4] expansion of horticulture; [5] expansion of cotton; and [6] stable coffee production. It is interpreted that the general pattern of agricultural development occurring in Uganda during the 1990s involved increasing specialization and commercialization of economic activities in different locations, based upon differences in comparative advantage.

In general, the econometric analysis found that the factors hypothesized to determine the comparative advantage of different development pathways—including agricultural potential, access to markets and infrastructure, and population density—are significantly associated with the development pathways, though different factors are important for different pathways. Agro-climatic conditions are particularly important for distinguishing areas of [1] cereal expansion from [2]/[4] perennials areas. Higher population density favours [1] intensified production of cereals, [4] horticulture and [3] non-farm activities, while closer access to rural markets favours [3] non-farm development and, moderately, [2] expansion of banana and coffee production. Access to irrigation is critical for [4] horticultural development, and improved access to roads is important for [3] non-farm development. Non-governmental organisations (NGOs) appear to foster [3] non-farm development, while CBOs are associated with [1] expanded cereal production.

The econometric analyses also revealed the association between respective development pathways, and the adoption of natural resource management as well as the changes in natural resource and human welfare conditions, controlling the impact of agro-ecological conditions, population growth and market access. Among the six development pathways, [2] expansion of banana and coffee was most strongly associated with adoption of soil and water conservation practices, including mulch, compost, manure and recycling of plant residues, and improvements in resource conditions, such as quality of forests, natural water, and human welfare. In contrast, while associated with improved nutrition in children, [1] expansion of cereals production was associated with decreased availability of grazing land and forests and decreased quality of forests, without use of external inputs and investment in improved land management. [3] Non-farm development was associated with the adoption of some resource conservation measures, such as mulching and recycling of crop residues, and some improvement in woodlots and natural water.

Based on the results, the dominant development pathways in Uganda are interpreted. Promotion of [2] expansion of banana and coffee production pathway may be a potential ‘‘win-win-win’’ development strategy, or ‘conservation pathway’, benefiting the environment while contributing to economic growth and poverty reduction, where this pathway is suited. [1] Expansion of cereals production without use of external inputs and investment in improved land management, as is common in Uganda, may not be sustainable because most cereals have a poor ground cover, exposing the soil to erosion and because a significant proportion of cereals is usually marketed, exporting soil nutrients from the farm. Increased efforts to protect remaining forest and woodland areas, and promotion of improved technology adoption through agricultural technical assistance programmes and development of markets, will be key to agricultural modernization and assuring sustainable land use where cereals expansion is occurring. Promotion of [3] non-farm development offers both environmental and economic benefits. By reducing dependence on crop production and promoting tree planting, non-farm activities appear to reduce soil erosion and improve water availability and quality.

In summary, Pender et al. (2004a) show that the development pattern in Uganda has been associated with changes in land use and agricultural practices, including expansion of cultivated areas, settlements and woodlots at the expense of fallow, forest and wetlands; increased adoption of purchased inputs; and resource conservation practices. They also reveal that the extent to which economic development is consistent with sustainable use of natural resource bases depends upon, among other things, the development pathways being pursued in different locations. These results imply that some ‘‘win-win-win’’ opportunities, or conservation pathway, may exist to promote more sustainable development in Uganda, for example, by promoting [3] the banana–coffee development pathway. Concurrently, there are also trade-offs between conserving forests and wetlands vs. promoting economic development through pursuing [1] expansion of cereal production which apparently lacks the incentives for sustainable resource management. Such trade-offs should be adequately considered as development strategies in Uganda and elsewhere.

There are few integrated models in existence to analyse development/natural resource management pathways at farm-level analysis, while a few case studies attempt to deal with the association between heterogeneous farm-livelihood strategy clusters and the adoption of natural resource management (Tittonell et al. 2005; Iiyama et al. 2008). In Section 3, we present a farm-level case study to apply the conceptual framework and to employ an integrated index to identify heterogeneous development/resource management pathways observed in a Rift Valley community in western Kenya. The aim is to examine the interaction between system components of each pathway, i.e. crop, livestock, trees and natural resources, and to investigate key factors affecting the adoption of these pathways by households.

3. CASE STUDY FROM A RIFT VALLEY COMMUNITY

3.1. Introduction to a Case Study

Most rural populations in SSA are dependent on mixed systems for survival (Thornton et al. 2002; Kristjanson and Thornton 2004). Within mixed rainfed farming systems, semi-arid zones are considered marginal for farming and are characterised by low population density. However, as higher potential zones become overpopulated, agropastoralists have gradually migrated to more arid zones in search of unoccupied land. Once settled, they have expanded cultivated and grazing areas with shorter fallow cycles, exhausting nutrients in inherently organic-deficient soils (Pell 1999; Place et al. 2003). As the population increases, semi-arid zones must accommodate more people on fragile soils. As Mortimore (1991) suggested, mixed farming systems in semi-arid zones in Africa are confronted with a choice between a degradational pathway—increasing the frequency of use without additional inputs, failing to replenish soil chemical properties or to conserve physical properties—and a conservation pathway (increasing inputs, especially labour, to maintain or raise productivity per hectare).

To sustain soils, conservation crop–livestock intensification pathways must be urgently identified and promoted and the role of livestock needs to be investigated. This is because, while animals are often blamed for degradation, they may be an essential component of intensification, which in turn creates the economic conditions for conservation land management (Mortimore 1991; McIntire et al.1992). While a number of studies have already been implemented in high potential zones (Shepherd and Soule 1998; Clay et al. 2002; Tittonell et al. 2005; Place et al. 2006), fewer studies have been conducted in semi-arid zones on the impact of diverse crop–livestock pathways on land degradation such as some monographs, for example, by Tiffen et al. (1994). In-depth case studies are urgently needed.

This Section presents empirical evidence of diverse crop–livestock (and horticulture/agroforestry) evolution pathways in a semi-arid community. The Kerio River Basin is located at the foot of the Great Rift Valley escarpment in western Kenya. The valley floor is hotter and drier than the escarpment and highlands and used to be considered neither habitable nor arable. When people first settled there in the 1970s, the lower parts of the valley became severely degraded with the formation of gullies and loss of natural vegetation due to expansion of grain production and grazing of indigenous animals. For the past two decades, however, some households have introduced horticulture and semi-zero grazing of exotic animal breeds on homestead plots in the upper parts of the valley. Residents claim that soils in the upper valley have been healing due to manure application, terracing and mulching in contrast to the degraded soils in the lower valley.

Our research question is to investigate factors affecting a household’s decisions to adopt either conservation or degradational pathways. Perceived heterogeneity in land use patterns and associated soil quality in the study area indicate the significant correlation at plot level between types of crops planted and degree of crop–animal integration. This suggests that land use pattern is determined by plot characteristics (i.e. location and tenure forms). At the same time, it is households that ultimately decide to adopt particular portfolios of crop and animal types (defined as crop–livestock diversification [CLD] patterns) and allocate their resources accordingly. Therefore, our hypothesis is whether a degradational pathway (CLD with low levels of soil management) or a conservation pathway (CLD with high levels of soil management) is adopted dependent on plot characteristics or on household characteristics.

The next sub-section describes the hypothesis, the study area and analytical methods used in this study. In the analytical process, land use patterns of the 177 households in the study area are first examined for 386 plots at plot level. Secondly, a new set of variables to represent the CLD patterns of the households is derived using principal component analysis. Thirdly, the effects of household and plot characteristics on the choices of the CLD patterns are tested using regression analysis. Sections 3.3 and 3.4 present and discuss the results. Brief policy implications are provided in Section 3.5.

3.2. Methods

Hypotheses

The major factors determining spatial patterns of crop–livestock pathways are agro-ecological, demographic and market conditions (Mortimore 1991; McIntire et al. 1992; Kristjanson et al. 2002; Staal et al. 2002; Thornton et al. 2002; Pender et al. 2004a; Manyong et al. 2006; Iiyama et al. 2007b). However, even within a small area, crop–livestock pathways have been highly heterogeneous among households (Shepherd and Soule 1998; Tittonell et al. 2005). Observation of heterogeneous pathways at farm scales indicates that causes of the variability are not only biophysical but also socio-economic. In-depth case studies are necessary to understand crop–livestock pathways from a perspective of the livelihood strategies of households.

The adoption of crops and livestock has been commonly analysed as independent components (Benin et al. 2004; Pender et al. 2004b; Kristjanson et al. 2005; Lacy et al. 2006). But, investment in resource management is not made in isolation from the preceding investment in crop and livestock activities. Farmers who have invested in valuable perennials (e.g. fruits) may find adoption of soil conservation practices more attractive than in the absence of such prior investments (Barrett et al. 2002). Improved breeds of animals are more likely to be stall-fed within farms and more integrated with crop production (Staal et al. 2002; Bationo et al. 2004). If synergies exist between components, giving incentives for better management, then it is important to adopt a system approach to analyse these synergies.

We assume that if a household is engaged in a CLD pattern involving crop [A] and livestock of type [B], then the household allocates proportionately more land to crop [A] and holds more livestock of type [B] than other types within its portfolio. Different CLD patterns have different levels of interactions between components (Kristjanson and Thornton 2004). CLD patterns associated with more intensive input use are interpreted as conservation pathways while those with less input use are interpreted as degradational pathways. Our main hypothesis is that households select CLD patterns to maximise utility under their constraints, i.e. resource endowments, access to off-farm income, availability of farming tools or characteristics of plots. Particular CLD patterns give households incentives to allocate land, labour and capital to resource management.[1]

More conservation CLD patterns may require labour, skills or capital intensive technologies, and thus are constrained by a household's human capital asset endowments[2] (Reardon and Vosti 1995; Benin et al. 2004; Pender et al. 2004b). Effects of off-farm income activities such as regular (e.g. formal employment and business) or casual income activities (e.g. charcoal making or day labour) and remittances are, however, ambiguous as they provide capital to invest in technologies while constraining labour availability (de Jager et al. 2001; Barrett et al. 2002; Tittonell et al. 2005; Perz et al. 2006; Morera and Gladwin 2006).

Degradational CLD patterns may be more constrained by the tenure or physical characteristics of land that households can access. Tenure characteristics refer to how land was acquired (Pender et al. 2004b). Households with large tracts of inherited land may not necessarily use all of it if they are not engaged in extensive cultivation. However, even under customary tenure systems where no plots are formally registered, households may purchase, hire or borrow plots to cultivate particular varieties of crops when they need more land than what they inherited. Physical characteristics of plots, i.e. slope, soil types and distance from

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[1] For more detail on the concept of CLD patterns see Iiyama et al. (2007a) who identified an optimal pathway with higher income and more manure application among five CLD patterns and examined household/homestead characteristics adopting the optimal CLD pattern. Our study examines plot-level resource management and inputs for all the plots and the relative effects of human capital asset endowments, off-farm income access and tenure/physical characteristics of plots for all the potential CLD patterns.

[2] The education of the household head should also be an important component of human capital assets for households. However, in the statistical analysis in Section 3.3, we did not include this variable in the regression models for investigating the determinants of CLD patterns to avoid multi-collinearity, because this is highly correlated with other key variables hypothesised to affect the choices of CLD patterns by households, such as the age of the household head (correlation ratio: –0.68) and access to regular off-farm income generating activities (correlation ratio: 0.40).

homesteads, also affect the choices households make in adopting particular crop and livestock varieties (Benin et al. 2004; Morera and Gladwin 2006; Herrero et al. 2007).

Given that theory does not tell us much about the relative weight of a household's capital asset endowments and plot characteristics in determining the choice of crop–livestock pathways, we take an empirical approach and examine the factors that help explain the variation seen in CLD patterns across a somewhat typical, semi-arid agropastoral district in East Africa.

Study Area

Keiyo District is located along the basin of Kerio River, which flows northwards to Lake Turkana, in the Rift Valley Province of western Kenya. Keiyo District can be roughly subdivided into three agro-ecological zones: the highlands (altitude 2,500–3,000 m) to the west, the escarpment (1,300–2,500 m) in the centre, and the valley floor (1,000–1,300 m) to the east (SARDEP 2002). This study focuses on households representing part of the valley floor community.

There are 16 sub-locations in Keiyo District, each occupied by a different clan. One of these, Rokocho Sub-location, consisting of 177 households, was randomly selected for this study to represent typical agropastoral communities in semi-arid regions in East Africa. The valley floor is hot for most of the year, with temperatures varying between 22˚C and 31˚C. Average annual rainfall ranges between 700 and 1,000 mm but high evaporation limits the LGP (Thornton et al. 2002; SARDEP 2002). A major tarmac road traverses the sub-location from north to south. Other infrastructural developments in Rokocho include a Christian mission with a training centre. The household survey was carried out between July and September 2006 using a structured questionnaire and field visits.

Before the early 1960s it was considered unviable to farm in the basin as there were no permanent sources of water. During the 1970s, in search of land, people slowly started to settle in the valley. Initially, expansion of grain production and extensive grazing in the lower valley led to serious soil degradation, with loss of natural vegetation and formation of gullies. Since 1985, the construction of the tarmac road has greatly transformed the livelihoods of people in the valley. Institutions such as churches and NGOs have also stimulated development initiatives by providing villagers with management training and capital for investing in horticulture and exotic livestock breeds. Some households have introduced horticulture and semi-zero grazing of exotic animal breeds on homestead plots in the upper parts of the valley. Furthermore, the development of water projects has allowed more people to adopt intensive farming on homesteads. Residents claim that soils in the upper valley have been healing due to manure application, terracing and mulching in contrast to the degraded soils in the lower valley.

These developments have also led to changes in land use and transactions. The land tenure system is primarily customary. Land from the valley floor up to the highlands mostly belongs to one clan. Even households located on the valley floor sometimes have plots on the escarpment and in the highlands. Clan land is subdivided among extended families and the family land is further subdivided into parcels owned by nuclear families through inheritance. However, some family plots are currently too small to be further subdivided. In such cases, one is encouraged to acquire land elsewhere by purchasing, hiring or borrowing it. While individual rights to land are well recognized, land is often used as an open access resource for grazing by clan members, unless it is properly fenced. Currently, some households that practise horticulture have started fencing their homestead plots for exclusive use.

Today, the households plant various types of crops either on single plots or on several plots spread over different agro-ecological zones and keep various kinds of livestock. We classified crops into four categories: (1) drought-resistant crops: sorghum, millet and cassava; (2) staple crops: maize, beans, cowpeas, green grams and groundnuts; (3) fruits: mangoes, pawpaws, citrus fruits, bananas and avocadoes; and (4) commercial crops: wheat, potatoes and carrots. We similarly classified livestock into four categories: (1) improved breeds of cattle (exotic and crossbred cattle); (2) dairy goats; (3) indigenous cattle; and (4) sheep and goats.

Analytical Methods

The first analytical step is to examine resource management at plot level. The total number of plots claimed by the 177 households was 386. These plots were either owned (inherited, purchased or given), rented (at a fee) or borrowed (at no fee). Most plots were located either on the lower or upper parts of the valley, while some were on the escarpment or highlands (Figure 1). The location proxies indicate the physical characteristics of farms. For example, the lower valley is flat and dry and contains sandy soils. Dominant crops include staple (maize and beans) and drought-resistant (sorghum and millet) crops, while livestock graze freely in open areas. The upper valley, where homesteads are located, is relatively flat to moderately sloped, with sandy and clayey soils, horticulture is currently practised here. Although the escarpment is very steep, drought-resistant crops or staple crops are cultivated there. The highlands are moderately sloped, cool and receive sufficient precipitation, and are ideal for commercial crops (see SARDEP 2002).

Secondly, we attempt to derive household-specific composite variables representing CLD patterns, from variables representing household shares of particular crop and livestock activities. Accurate calculation of areas cultivated to particular crops was difficult because households often had access to more than one plot, and planted different crops on the same plots, as is the practice in other parts of rural Africa (Benin et al. 2004; Pender et al. 2004b; Waithaka et al. 2006). In order to circumvent this difficulty, households were asked to approximate the percentages of plots used for each crop type. Then, principal component analysis was used to derive new sets of composite variables representing ‘CLD patterns’ from those variables describing shares of crop and livestock activities. The principal components can reveal complementary (positively correlated) or substitute (negatively correlated) crop and livestock activities (Iiyama et al. 2007a).

Thirdly, ordinary least squares (OLS) regressions were used to evaluate putative determinants of the CLD patterns. The dependent variables in these regressions were the principal component scores while the independent variables included household characteristics, access to various off-farm income streams, tenure and physical characteristics of the land which households had access to, and possession of specific farm implements. For tenure and physical characteristics of the land, we calculated shares of land owned by households by mode of acquisition and by location.

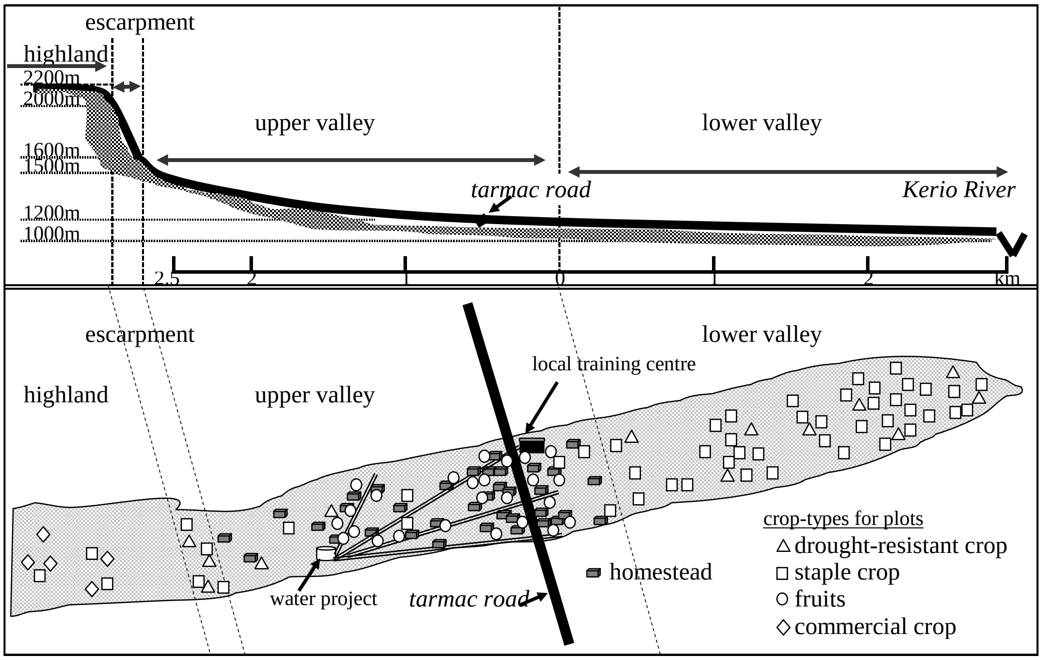

Figure 1. Land Use Patterns in the Study Area.

3.3. Results

Soil Management at Plot Level

At the time of the survey, the 177 households in the study area had access to 386 plots. Most of the plots were acquired through inheritance. Even before the 1970s, when only a few people had settled in the valley, the clan land in the upper valley, escarpment and highlands had already been subdivided into family plots, while the lower valley land remained communal. After the 1970s, the clan elders demarcated the lower valley for clan members resident in the valley, as demand for exclusive individual arable plots increased. Currently, there has been some transaction in plots through purchase or rental contracts between those who inherited large tracts of land and those who inherited little but are willing to expand cultivation.

Spatial distribution of the plots across the different agro-ecological sections is shown in Table 2. Among the 386 plots (the last row), more than half (57%) of the plots were in the upper valley (including 177 homestead plots) while the fewest (4%) were in the highlands, although the size of individual plots varied across/within a particular section. Across the sections (the last column), the most commonly crops planted were the staples, followed by fruits; 37% of the plots were not planted. Over 60% of plots in the lower valley or the escarpment were planted with staple crops. In the upper valley, 36% of plots were planted with fruits, mostly on the homestead plots, while 45% of plots were not planted. The highland plots were planted with commercial crops (wheat, tomatoes and vegetables), staple crops or an intercrop of these two categories. These spatial patterns indicate that choices of which crop types to plant is largely determined by the location of the plots, reflecting factors such as distance from homesteads, slope, soil type, temperature and water availability.

Table 2. Locations of 386 Plots by Crop-Type

	lower valley no. (%)	upper valley no. (%)	escarpment no. (%)	highland no. (%)	all sections no. (%)
CROP-TYPE					
drought-resistant	1(1)	13(6)			14(4)
Staple	77(68)	6(3)	20(61)	3(18)	106(27)
Fruits	2(2)	80(36)			82(21)
commercial				6(35)	6(2)
drought-resistant+staple	8(7)	9(4)			17(4)
with fruits and/or commercial		12(5)		4(24)	16(4)
nappier grass		2(1)			2(1)
not planted	26(23)	100(45)	13(39)	4(24)	143(37)
Total	114(100)	222(100)	33(100)	17(100)	386(100)

Table 3. Soil Fertility Management and Labour Inputs by Plot Level

	no. plots	terraced (yes=1, no=0)	manure (kg/acre)	fertiliser (ksh/acre)	family labor (mhrs/year)	hired labour (mhrs/year)
Crop-type						
drought-resistant	14	0.29	14	0	1 830	9
Staple	106	0.08	0	0	598	65
Fruits	82	0.74	522	0	1 245	101
commercial	6	0.17	5	1 167	150	1 051
drought-resistant+staple	17	0.18	0	0	1 098	31
with fruits and/or commercial	16	0.63	281	216	1 656	190
nappier grass	2	0	0	0	0	0
not planted	143	0.06	0	0	0	0
Total	386	0.25	123	27	614	65
F-value		38.92***	10.4***	41.6***	20.0***	11.9***

Plot-level applications of conservation measures (terracing and manure/fertiliser applied) and labour input (family and hired labour input) are presented in Table 3. Plots planted with fruits were more likely to be associated with intensive management (74% terraced, 522 kg/acre manure, 1,245 family man-hours/year [mhr]/year), followed by plots intercropped with fruits and/or commercial crops. Plots planted with commercial crops received little manure but a relatively large value of chemical fertilisers and hired labour (1,167 KSh/acre, 1,051 hired mhr/year). More family labour was used in plots planted with drought-resistant crops (1,830 mhr/year) than in other plots, probably because plots planted with millet and sorghum require supervision to keep wild animals away. In contrast, plots planted with staple crops were less associated with intensive management (8% terraced, no manure/fertiliser application and less labour). In general, crop types seem to affect levels of soil management, degrees of manure integration and labour input. Fruits can be associated with the conservation pathway, characterised by better soil management and higher manure and labour input, and staple crops with the degradational pathway where these factors are not applied.

Identification of Conservatory and Degradational Pathways

Household-level portfolios of crop–livestock activities are summarized in Table 4. The mean area of land used per household was 2.28 acres, of which 1.27 acres (55%) was used for cultivating staple crops, 0.80 acres (35%) was planted with fruits, while the remaining land was under drought-resistant and commercial crops. Households owned an average of 5.14 tropical livestock units (TLUs),[3] of which 2.69 TLUs (52%) comprised indigenous cattle, 1.64 TLUs (32%) consisted of sheep and goats and 0.79 TLUs (15%) were exotic and crossbred cattle. Dairy goats accounted for 1% of the total livestock holding. The averages, however, tend to mask heterogeneities in the adoption of certain crop/livestock types among households, in complementarities between crops and livestock (see Iiyama et al. 2007a) or the existence of certain patterns in crop–livestock combinations that we have explored further below.

Table 4. Household-Level Portfolios for Crop–Livestock Activities

Variables of crop-livestock activities	N	mean	Std.D	min	max	share
Proportion of land allocated to particular crop by households						
land with staple crop (acres/ratio)	177	1.27	2.59	0	21	0.55
land with fruits (acres/ratio)	177	0.80	1.29	0	10	0.35
land with drought-resistant crop (acres/ratio)	177	0.14	0.40	0	2	0.06
land with commercial (acres/ratio)	177	0.07	0.39	0	4	0.03
total acres used (acres)	177	2.28	2.99	0	24	
Proportion of particular animals kept by households						
no. of indigenous cattle (TLU/ratio)	177	2.69	5.31	0	38	0.52
no. of sheep/goats (TLU/ratio)	177	1.64	4.36	0	44	0.32
no. of improved cattle (TLU/ratio)	177	0.79	1.88	0	10	0.15
no. of dairy goats (TLU/ratio)	177	0.03	0.11	0	1	0.01
total animals owned (TLU)	177	5.14	7.45	0	44	

Table 5. Dominant CLD Patterns (Principal Components)

	Component

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[3] The TLU is calculated as follows: a bull is equivalent to 1.29 TLU; a cow to 1 TLU; a calf to 0.7 TLU; and sheep and goat to 0.11 TLU (Kristjanson et al. 2002).

	CLD I maize+ind cattle +staple crop +indigenous cattle -fruits	**CLD II imp cattle +fruits** +improved cattle +fruits, +land use -drought-resistant crop	**CLD III extensive crop** -indigenous cattle -fruits +land use	**CLD IV sheep/goats** +sheep& goats	**CLD V dairy goats** +dairy goats -commercial crop
Land Allocated to					
drought-resistant crop(%)	-0.04	**-0.66**	0.22	-0.34	-0.21
staple crop(%)	**0.80**	0.18	0.35	-0.06	0.20
fruits(%)	**-0.70**	**0.35**	**-0.48**	0.24	0.08
commercial crop(%)	-0.14	0.24	0.11	-0.40	**-0.50**
total acre used(acres)	0.15	**0.57**	**0.46**	0.11	-0.06
Animals Held in					
improved cattle(%)	-0.35	**0.66**	0.28	-0.14	-0.10
dairy goats(%)	-0.10	0.07	0.04	-0.30	**0.83**
Indigenous cattle(%)	**0.60**	0.07	**-0.67**	-0.06	-0.12
sheep/goats(%)	-0.16	-0.34	0.38	**0.74**	0.00
total animals(TLU)	**0.54**	0.30	-0.17	0.37	-0.11

To extract a new set of variables representing CLD patterns from the original large number of crop–livestock activities, principal component analysis was used. In choosing the number of components, we used two criteria: (1) we retained components sufficient to explain a high percentage (70% to 90%) of the total variation in the original variables; and (2) we excluded principal components whose eigenvalues were less than 1 (Everitt and Dunn 2001). We then attempted to interpret each principal component with factor weights exceeding 0.5 in absolute values, or less, if deemed necessary. Five principal components extracted from the original crop–livestock portfolio variables explained 71.5% of the total variation in the data in Table 5.

The five principal components are explained as follows. Staple crop (mainly maize) and indigenous cattle were positively associated with the first principal component, while growing fruits was negatively correlated with this component. Thus this principal component is interpreted as *CLD I [maize and indigenous cattle]*. The second component was strongly associated with the proportion of improved cattle and total land used and negatively associated with the proportion of land sown to drought-resistant crops. Although it was less than 0.5, the weight for fruits was higher than that for the other components (*CLD II [improved cattle and fruits]*). The third component was negatively associated with indigenous cattle and fruits while positively associated with total land used (*CLD III [extensive crop production]*). Proportion of sheep and goats in the total TLU was strongly associated with the fourth component (*CLD IV [sheep and goats]*). Finally, the fifth component was strongly associated with the proportion of dairy goats in the total TLU (*CLD V [dairy goats]*).

Determinants of Conservatory/Degradational Pathways

We examined the determinants of the different CLD patterns using econometric analysis. For the dependent variables, we used the principal component factor scores derived from the principal component analysis. Independent variables include capital asset variables, access to off-farm income, share in acres of land by mode of acquisition (tenure), share in acres of land by location and implements (Appendix 1). Share of land by mode of acquisition summed up to one. Therefore, we excluded the share of land acquired through inheritance, because this type of land may have been acquired by chance, e.g. your father happens to own large tracts of land to bequeath or you were his only male heir. Similarly, the sum of shares of land by location was one. We excluded shares of land on the escarpment, as the dominant crops are staple crops, similar to those in the lower valley. The results are presented in Table 6.

CLD pattern I (maize + indigenous cattle) was negatively associated with access to regular and casual off-farm income generating activities and share of land in the upper valley. CLD pattern II (improved cattle + fruits) was significantly associated with gender of the household head, family labour, participative years in a farmers' group, access to regular off-farm income, share of land in the highlands and plough ownership. CLD pattern III (extensive crop production) was strongly associated with age of the household head, share of land hired, share of land in the lower valley and highlands, and a plough. In CLD pattern IV (sheep and goats), gender of the household head, share of land purchased and share of land in the lower valley had positive effects, while experience of having stayed outside (due to temporal labour migration or permanent immigration), distance to training centre, share of land in the highlands and availability of tap water at the homestead had negative effects. Distance to a training centre, share of land in the highlands and availability of tap water were negatively associated with CLD pattern V (dairy goats).

3.4. Discussions

The second principal component, CLD pattern II (improved cattle and fruits), can be interpreted as a conservation pathway as plots cropped with fruits were more associated with terracing and application of manure/labour. In contrast, CLD patterns I (maize and indigenous cattle) and III (extensive crop production) are degradational pathways, as they are more associated with a higher share of plots devoted to staple crops and negatively associated with plots with fruits. However, we could not readily determine whether CLD patterns IV (sheep and goats) and V (dairy goats) are conservation or degradational pathways, as they are less associated with total land cropped. Dairy goats are more likely to be integrated with crops as they are managed intensively with more stall-feeding than free-range indigenous small ruminants.

Table 6. Determinants of the CLD Patterns (OLS results)

	CLD I			**CLD II**			**CLD III**			**CLD IV**			**CLD V**		
	maize+ind cattle			**impr cattle+fruits**			**extensive crop**			**sheep/goats**			**dairy goats**		
	B	standard error		B	standard error		B	standard error		B	standard error		B	standard error	
(Constant)	1.39	0.81	*	-1,19	0.74		-0.52	0.81		0.60	0.79		1.53	0.70	**
hh characteristics															
age	0.00	0.00		0.00	0.00		0.01	0.00	**	0.00	0.00		-0.01	0.00	
gender(male1,female0)	0.07	0.21		0.48	0.19	**	0.21	0.21		0.38	0.20	*	-0.25	0.18	
family labour(AE)	0.00	0.04		0.10	0.04	**	-0.03	0.04		0.05	0.04		0.02	0.04	
years in group	0.01	0.02		0.03	0.01	**	-0.01	0.02		-0.01	0.01		0.00	0.01	
experience outside	0.10	0.17		-0.17	0.16		-0.11	0.17		-0.32	0.16	*	-0.11	0.15	
min to training centre	0.00	0.00		-0.01	0.00		0.00	0.00		-0.01	0.00	***	-0.01	0.00	**
off-farm income access															
off-farm regular	-0.84	0.27	***	0.45	0.25	*	-0.20	0.27		0.14	0.27		-0.11	0.24	
off-farm casual	-0.55	0.25	**	-0.07	0.23		-0.22	0.25		-0.05	0.24		0.05	0.21	
remittance	-0.03	0.32		0.30	0.30		-0.21	0.33		0.51	0.32		0.07	0.28	
tenure characteristics(acquisition)															
share purchased	0.02	0.26		0.11	0.24		0.32	0.26		0.64	0.25	**	-0.10	0.23	
share given	2.24	1.61		-1.02	1.49		-1.25	1.62		-2.10	1.57		0.79	1.41	
share hired	0.46	0.40		-0.49	0.37		1.17	0.40	***	0.42	0.39		0.30	0.35	
share borrowed	-0.16	0.43		-0.19	0.39		0.68	0.43		0.62	0.42		-0.19	0.37	
physical characteristics(location)															
share upper valley	-1.16	0.51	**	0.23	0.47		0.33	0.51		0.79	0.50		-0.26	0.46	
share lower valley	0.34	0.53		0.56	0.49		1.17	0.53	**	0.89	0.52	*	-0.13	0.45	
share highland	-0.98	0.66		1.33	0.61	**	1.89	0.66	***	-1.23	0.64	*	-2.15	0.58	***
farming equipments															
a plough	-0.62	0.97		2.59	0.89	***	3.27	0.97	***	-0.15	0.95		-0.75	0.84	
tap domestic	-0.28	0.36		0.29	0.33		-0.57	0.36		-1.81	0.35	***	-0.61	0.31	*
R Square	0.32			0.42			0.30			0.31			0.22		
Adjusted R Square	0.24			0.35			0.22			0.23			0.14		
F	4.03 ***			6.26 ***			3.81 ***			3.89 ***			2.52 ***		

(note) total observation: 177 households. ***: statistically significant at <.01, **:<.05, *:<.1.

Let us first compare the two contrasting crop–livestock pathways, CLD pattern I (maize + indigenous cattle) and CLD pattern II (improved cattle + fruits). CLD pattern I was a degradational crop–livestock pathway, where maize and indigenous animal production are rarely integrated. This pattern was associated with lack of access to off-farm income activities. Conversely, CLD pattern II, a combination of improved cattle and fruits, was a conservation pathway. Fruits are mostly planted on homestead plots, while improved cattle are kept within or near the plots. This pattern was more strongly associated with human capital assets, e.g. labour and skills through experience in a farmers' group, and engagement in formal employment or business. Higher income from dairy products and fruits and regular off-farm activities allow households to invest in not only assets but also resource management, such as terracing. This implies that access to human capital assets and off-farm income are important factors making the role of livestock either negative or positive in the adoption of pathways.

Tenure characteristics of plots appear not to much affect the choices between CLD patterns I (maize + indigenous cattle) and II (improved cattle + fruits), although they do influence choices of crop–livestock patterns III (extensive crop; associated with more hired land) and IV (sheep and goats; associated with more purchased land). Households engaged in pattern III may need to hire land for extensive cultivation, while those engaged in CLD pattern IV purchase land if they initially have little. With respect to land access by location, households in CLD patterns III and IV have more access to land in the lower valley, ideal for staple crops, but this effect is not significant for CLD pattern I (maize + indigenous cattle) although households in pattern I allocated more land to staple crops. Maize is more extensively grown on plots in the lower valley, far away from homesteads, while indigenous cattle and small ruminants are extensively grazed on open plots. These cultivation and grazing patterns may lead to fewer incentives to invest in soil conservation measures.

Factors influencing the adoption of soil conservation measures by poor agropastoralists in fragile ecosystems have also attracted the attention of other researchers. However, these researchers pay little attention to complementary relationships between crops and livestock. As a result, their findings are often contradictory to ours. For example, Clay et al. (2002) found that in Rwanda terracing was associated with physical characteristics of land and smaller landholdings. In contrast, our results indicated that adoption of soil conservation measures had to do with particular combinations of crops and animals (CLD patterns II [improved cattle + fruits; more adoption] vs. CLD III [extensive crop; less adoption]; both are associated with larger areas under use and share of land in the highlands). Freeman and Coe (2002) suggested that in eastern Kenya farmers with larger livestock holdings were more likely to adopt soil fertility measures. Our study showed that it was not the number of animals but types of animals and their levels of integration with crops (CLD pattern I [maize + indigenous cattle; less adoption] vs. CLD pattern II [improved cattle + fruits; more adoption]) that were associated with the use of soil fertility measures.

Our findings confirm what Barrett et al. (2002) suggested about investment in soil conservation not being made in isolation with the preceding investment in portfolio of crop and livestock activities (Barrett et al. 2002; Place et al. 2002; Tittonell et al. 2005). Our results suggest that livestock can be a cause of degradation or an opportunity for sustainable management in semi-arid regions, and that this depends on the overriding importance of household capital asset endowments and reliable off-farm income over physical/tenure characteristics of plots.

In the study area, the CLD patterns of staple crops with indigenous animals turned out to be degradational pathways. These CLD pathways may contribute to food security and higher income in the short term, thus providing households with incentives to undertake these pathways. However, these pathways, without proper soil management, have economic–environment trade-offs that lead to degraded resource bases. In fact, these pathways were similar to the scenario predicted by McIntire et al. (1992) for semi-arid agropastoral communities in Africa in response to the growing population. Conversely, CLD pattern II (improved cattle + fruits) was identified as a conservation crop–livestock pathway. This pathway has embedded incentives to integrate components through providing fodder and manure reciprocally within the farms, and their high economic return ensures that households invest in maintaining the fertility and sustainability of the resource bases they depend on.

This case study from a small area indicates that the cause of degradation is not only biophysical but also socio-economic, and could be reversible through better incorporation of livestock with human wisdom. Inferred policy suggestions are to provide proper extension services for technology dissemination and to ensure educational and better return diversification opportunities for households to invest in better soil management.

4. CONCLUSION

This chapter has reviewed the challenges that Africa has faced in rural development and natural resource management. As describing African exceptionalism and understanding its causes are prerequisites to policies and solutions for reducing African poverty, we highlighted two dimensions of Africa's rural poverty and stagnant agricultural growth. The inherent heterogeneity in agro-ecological/farming systems has prevented agricultural technological breakthroughs. In turn, emerging factors such as population growth and climate change have further burdened inherently fragile soil and resource bases and can exacerbate the vicious cycle of stagnant agricultural growth, persistent rural poverty, soil depletion, resource degradation, and accelerated deforestation, unless some urgent measures to halt and reverse this cycle are taken. The heterogeneity in agro-ecological/ farming systems in SSA requires researchers, policy makers and all those concerned to search for policies and solutions which reflect the different causes, problems, and opportunities for specific contexts and places.

Agricultural intensification through better utilisation of locally available resources through integration of system components, i.e. crop, livestock and agroforestry, is especially desirable considering the poverty of rural populations. Therefore the major research agenda for researchers and scientists is to identify diverse agricultural development and resource management pathways in particular agro-ecological zones/farming systems and to examine factors affecting respective pathways so as to better formulate policies to promote sustainable development pathways with optimal resource management practices. We propose a conceptual framework to guide the examination of (a) multi-dimensional aspects of agro-ecological and farming systems, i.e. interactions, complementarities or trade-offs, of multiple system components (among crop, livestock, agroforestry, nutrients, natural resources, etc.); and (b) certain layers of analytical scales (at farm-level, meso-level).

We also reviewed the meso-level study from Uganda by Pender et al. (2004) in Section 2.3 and presented the farm-level empirical case study from a Kenyan Rift Valley community in Section 3, to see how to apply the conceptual framework and to implement empirical case studies by employing the concept of “development pathways” in an integrated framework. The meso-level analysis showed that the extent to which economic development is consistent with sustainable use of natural resource bases depends upon, among other things, the development pathways being pursued in different locations, which are then affected by agro-ecological, demographic and market conditions. In turn, the micro-level study showed that there exists extensive heterogeneity even within a small community, in the patterns of the technology portfolios with different levels of incentives for sustainable resource use, and that households’ capital asset endowments as well as off-farm income diversification affect the patterns.

Both the meso-level and farm-level case studies imply that some ‘‘win-win-win’’ opportunities, or conservation pathway, may exist to promote more sustainable development; for example, by promoting [3] the banana–coffee development pathway in Uganda and [CLD pattern II: improved cattle and fruits] in the Kenyan Rift Valley. Interestingly, both pathways are associated with the inclusion of agroforestry into the farming systems. To promote such conservation development pathways, policies not only need to identify optimal technology portfolios best suited to local conditions and exploit the complementarities but also to provide education and training with farmers to augment their human capital assets and to promote stable non-farm/off-farm income opportunities in order to encourage investment in resource management. Concurrently, there are degradational pathways entailing substantial trade-offs between promoting economic development vs. conserving natural resources. Both [1] expansion of cereal production in Uganda and [CLD pattern I: maize and indigenous cattle]/[CLD pattern III: extensive crop production] in the Kenyan Rift Valley apparently lack the embedded incentives for sustainable resource management. Such trade-offs should be adequately considered as development strategies.

Newly Emerging Challenge and Future Research Agenda

Along with population pressure and climate change, another factor has recently emerged—rising food prices—which might exacerbate the hardship that SSA countries and rural populations face (Von Braun 2007; Ghambari 2008). The price of corn has more than doubled in the last two years along with that of other staple food crops and prices for basic staples will remain high for an extended period of time due to multiple factors. The soaring cost of food and fuel has already led to riots in Haiti and Egypt and a general strike in Burkina Faso in mid-April 2008.Various factors have been blamed for raising the food prices, including droughts in Australia and Europe, financial market speculators, and increased demand for food and a changing diet in large developing countries such as China and India. Yet increasing demand for biofuels and expansion of ethanol production in USA, Europe and Brazil is referred to among the most significant causes. There are some predictions that the planned biofuel expansion would increase international prices 26-72 percent for maize and by 19-44 percent for oilseeds by the year 2020 and that the increase in crop prices is accompanied by a net decrease in availability and access to food by the poor (Von Braun 2007).

Considering that many poor households in rural SSA are deficient in food, the rising prices of basic staple food crops will aggravate the poverty and increase the risk of hunger and starvation. Poverty might drive the poor rural population to seek for alternative sources of income to obtain food at markets by exploiting natural resources, further accelerating resource degradation and deforestation. Furthermore, searching for vast land and cheap labour for the stable supply of imported feedstocks, private companies and capitals from developed countries have recently rushed into SSA countries to invest in plantation for biofuel feedstocks, not only for bioethanol such as maize and sugarcane but also for biodiesel from non-edible oilseed plants such as Jatropha curcas. The trade-offs between food and fuel will actually be accelerated when biofuels become more competitive under the circumstances of skyrocketing petroleum prices in relative to food and when consequently land, water, and capital are diverted to them. It is even not certain what consequences biofuel production would have on environment, soil, resource bases, and biodiversity. To soften the trade-off and mitigate the growing price burden for the poor in SSA, it is necessary to accelerate investment in food and agricultural technologies as well as in research to assess the socio-economic and environmental impacts of biofuel provisions.

We conclude this chapter by proposing a future agenda for the research contributing to development and poverty alleviation in Africa. This paper has proposed a conceptual framework for guiding integrated research and analysis on agricultural development and natural resource management at meso-level and at farm-level. Yet, there is also a significant need to facilitate the analyses at sector-/macro-level. Most countries in SSA are poor and have severe resource constraints. Therefore balancing attention between favoured and less-favoured sub-sectors, regions and households is one of the toughest policy dilemmas and requires guidance based on sound scientific data/analyses on sector linkages, growth, employment and environmental effects of agricultural development and sustainable resource management (World Bank 2007). Sector-level/macro-level analyses will be especially important to predict/assess the socio-economic and environmental impacts of rising food/fuel prices, to act promptly to identify the most vulnerable/affected, and to formulate policy interventions to the poor to adapt themselves to ever more challenging circumstances.

APPENDIX 1: EXPLANATORY VARIABLES FOR THE CLD PATTERNS

	N	Mean	Std.D	Min	Max
Household characteristics					
age of the head	177	46.85	17.63	20	102
gender of the head(male=1,female=0)	177	0.78	0.42	0	1
family labour(Adult Equivalent)	177	3.30	1.76	1	8.14
participation in farmers group(years)	177	2.50	5.03	0	26
minute distance to training centre(min)	177	28.06	24.08	1	195
experience of having stayed outside(yes=1, no=0)	177	0.28	0.45	0	1
Access to off-farm income					
regular off-farm income(yes=1, no=0)	177	0.30	0.46	0	1
casual off-farm income(yes=1, no=0)	177	0.50	0.50	0	1
remittance (yes=1, no=0)	177	0.12	0.33	0	1

Total land owned(acres)	177	7.55	18.12	0.50	201
Share of land access by mode of acquition(tenure characteristics)					
land inherited(share)	177	0.75	0.39	0	1
land purchased(share)	177	0.13	0.30	0	1
land given(share)	177	0.00	0.04	0	0.50
land hired(share)	177	0.07	0.19	0	0.92
land borrowed(share)	177	0.04	0.18	0	1
Share of land access by location(physical characteristics)					
land in lower valley/Endo[flat, dry, hot](share)	177	0.28	0.30	0	1
land in upper valley[moderate slope, hot](share)	177	0.63	0.31	0	1
land in escarpment[steep,warm](share)	177	0.05	0.14	0	1
land in highland[moderate slope, wet, cool](share)	177	0.04	0.15	0	1
Farming implements					
a plough	177	0.01	0.08	0	1
tap domestic	177	0.94	0.24	0	1

REFERENCES

Amissah-Arthur, A.,. & Miller, R.B. (2002). Remote Sensing Applications in African Agriculture and Natural Resources: Highlighting and Managing the Stress of Increasing Population Pressure. *Advances in Space Research, Vol. 30(11)*, 2411-2421.

Barrett, C.B., Reardon, T., & Webb, P. (2001). Nonfarm Income Diversification and Household Livelihood Strategies in Rural Africa: Concepts, Dynamics and Policy Implications, *Food Policy, Vol.26*, 315-331.

Barrett, C.B., Place, F., & Aboud, A.A. (2002). *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices*. Oxon and New York: CABI publishing.

Barrios, S., Bertinelli, L., & Strobl, E. (2006). Climatic Change and Rural–urban Migration: The Case of Sub-Saharan Africa. *Journal of Urban Economics, Vol.60(3)*,357-371.

Bationo, A., Nandwa, S.M., Kimetu, J.M., Kinyangi, J.M., Bado, B.V., Lompo, F., Kimani, S., Kihanda, F., & Koala, S. (2004). Sustainable Interaction of Crop-Livestock Systems through Manure Management in Eastern and Western Africa: Lessons Learned and Emerging Research Opportunities. In T.O. Williams, S. Tarawali, P. Hiernaux, & S. Fernández-Rivera. (Eds.), *Sustainable Crop-Livestock Production for Improved Livelihoods and Natural Resource Management in West Africa* (pp.173-198). Nairobi: International Livestock Research Institute.

Beg, N., Morlot, J.C., Davidson, O., Afrane-Okesse, Y., Tyani, L., Denton, F., Sokona, Y., & Thomas, J.P. (2002). Linkages between Climate Change and Sustainable Development. *Climate Policy, Vol.2*, 129–144.

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, Vol.31*, 197-208.

Bullock, P. (1997). Agro-ecological Characterisation, Food Production and Security. *Perspectives for Agronomy, Vol. 25*, 29-37.

Chen, S., & Ravallion, M (2007). Poverty and Hunger Special Feature: Absolute Poverty Measures for the Developing World, 1981–2004. *PNAS (Proceedings of the National Academy of Sciences of the United States of America), Vol.104 (43)*, 16757–16762.

Chidumayo, E.N., & Kwibisa, L. (2003). Effects of Deforestation on Grass Biomass and Soil Nutrient Status in Miombo Woodland, Zambia. *Agriculture, Ecosystems & Environment , Vol.96(1-3)*, 97-105.

Christiaensen, L., Tollens, E., & Ezedinma, C. (1995). Development Patterns under Population Pressure: Agricultural Development and the Cassava-Livestock Interaction in Smallholder Farming Systems in Sub-Saharan Africa. *Agricultural Systems, Vol. 48(1)*, 51-72.

Clay, D.C., Kelly, V., Mpyisi, E., & Reardon, T. (2002). Input Use and Conservation Investments among Farm Households in Rwanda: Patterns and Determinants. In C.B.Barrett, F. Place, & A.A.Aboud. (Eds.), *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices* (pp.103-114). Oxon and New York: CABI publishing.

Cline-Cole, R.A., Main, H.A.C., & Nichol, J.E. (1990). On Fuelwood Consumption, Population Dynamics and Deforestation in Africa. *World Development ,Vol.18(4)*, 513-527.

Collier, P. (2007). Poverty Reduction in Africa. *PNAS (Proceedings of the National Academy of Sciences of the United States of America), Vol.104 (43)*, 16763–16768.

Dar ,W.D., & Twomlow, S.J. (2007). Managing Agricultural Intensification: The Role of International Research. *Crop Protection, Vol.26(3)*, 399-407.

De Jager, A.., Onduru, D., van Wijk, M.S., Vlaming, J., & Gachini, G.N. (2001). Assessing Sustainability of

Low-External-Input Farm Management Systems with the Nutrient Monitoring Approach: A Case Study in Kenya. *Agricultural Systems,Vol.69,* 99-118.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., & Courbois, C. (1999). *Livestock to 2020: The Next Food Revolution*. Food Agriculture, and Environment Discussion Paper 28. Washington D.C.: International Food Policy Research Institute.

Dorward, A., Kydd, J., Morrison, J., & Urey, I. (2004). A Policy Agenda for Pro-Poor Agricultural Growth. *World Development, Vol.32(1),* 3-89.

Ellis, F. (2000). *Rural Livelihoods and Diversity in Developing Countries*. Oxford: Oxford University Press.

Ellis, F., & Freeman, H.A. (2005). *Rural Livelihoods and Poverty Reduction Policies*. London and New York: Routledge.

Erskine, J.M. (1991). Agroforestry: Its Development as a Sustainable, Productive Land-use System for Low-resource Farmers in Southern Africa. *Forest Ecology and Management. Vol.45(1-4),* 281-291.

Evans, H.E., & Ngau, P. (1991). Rural-Urban Relations, household Income Diversification and Agricultural Productivity. *Development and Change, Vol.22,* 519-545.

Everitt, B.S., & Dunn, G. (2001). *Applied Multivariate Data Analysis: Second Edition*. London: Arnold.

Franzel, S., Coe, R., Cooper, P., Place, F., & Scherr, S.J. (2001). Assessing the Adoption Potential of Agroforestry Practices in Sub-Saharan Africa. *Agricultural Systems*, *Vol. 69(1-2)*, 37-62.

Freeman, A.H., & Coe, R. (2002). Smallholder Farmers' Use of Integrated Nutrient-Management Strategies: Patterns and Possibilities in Machakos District of Eastern Kenya. In C.B.Barrett, F. Place, & A.A.Aboud. (Eds.), *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices* (pp.143-154). Oxon and New York: CABI publishing.

Frost, P., Campbell, B., Luckert, M., Mutamba, M., Mandondo, A., & Kozanayi, W. (2007). In Search of Improved Rural Livelihoods in Semi-Arid Regions through Local Management of Natural Resources: Lessons from Case Studies in Zimbabwe. *World Development*, *Vol. 35(11)*, 1961-1974.

Ghanbari, H.N. (2008). World Bank Chief Biofuels Boosting Food Prices. NPR News April 11, 2008. http://www.npr.org/templates/story/story.php?storyId=89545855.

Herrero, M., González-Estrada, E., Thornton, P.K., Quirós, C., Waithaka, M.M., Ruiz, R., & Hoogenboom, G. (2007). IMPACT: Generic Household-Level Databases and Diagnostics Tool for Integrated Crop- Livestock System Analysis. *Agricultural Systems*, *Vol.92*, 240-265.

Iiyama, M., Maitima, J., & Kariuki, P. (2007a). Crop-Livestock Diversification Patterns in Relation to Income and Manure Use: A Case Study from a Rift Valley Community, Kenya. *African Journal of Agricultural Research*, *Vol. 2(3)*, 58-66.

Iiyama, M., Kaitibie, S., Kariuki, P., & Morimoto, Y. (2007b). The Status of Crop-Livestock Systems and Evolution toward Integration: A Review Paper. *Annals of Arid Zones*, *Vol.46 (3&4)*, 301-323.

Iiyama, M., Kariuki, P., Kristjanson, P., Kaitibie, S., & Maitima, J. (2008). Livelihood Diversification Strategies, Incomes and Soil Management Strategies: A Case Study from Kerio Valley, Kenya. *Journal of International Development*, *Vol.20*, 380-397.

IPCC (Intergovernmental Panel on Climate Change). (1988). *The Regional Impacts of Climate Change: An Assessment of Vulnerability*. Cambridge: Cambridge University Press.

Karekezi, S. (2002). Poverty and Energy in Africa- A Brief Review. *Energy Policy*, *Vol.30(11-12)*, 915-919.

Karekezi, S., & Kithyoma, W. (2002). Renewable Energy Strategies for Rural Africa: Is a PV-led Renewable Energy Strategy the Right Approach for Providing Modern Energy to the Rural Poor of Sub-Saharan Africa? *Energy Policy, Vol. 30(11-12)*, 1071-1086.

Kates, R W., & Dasgupta, P. (2007). African Poverty: A Grand Challenge for Sustainability Science. *PNAS (Proceedings of the National Academy of Sciences of the United States of America)*, *Vol. 104 (43)*, 16747–16750.

Kristjanson, P., Okike, I., Shirley, A., Tarawali, R., Kruska, V.M., & Singh, B.B. (2002). Evaluating Adoption of New Crop-Livestock-Soil-Management Technologies using Georeferenced Village-Level Data: The Case of Cowpea in the Dry Savannahs of West Africa. In C.B.Barrett, F. Place, & A.A.Aboud. (Eds.), *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices* (pp.169-180). Oxon and New York: CABI publishing.

Kristjanson, P.M., & Thorton, P.K. (2004). Methodological Challenges in Evaluating Impact of Crop-Livestock Interventions. In T.O. Williams, S. Tarawali, P. Hiernaux, & S. Fernández-Rivera. (Eds.), *Sustainable Crop-Livestock Production for Improved Livelihoods and Natural Resource Management in West Africa* (pp.160-172). Nairobi: International Livestock Research Institute.

Kristjanson, P., Radney, M., Baltenweck, I., Ogutu, J., & Notenbaert, A. (2005). Livelihood Mapping and Poverty Correlates at a Meso-Level in Kenya. *Food Policy, Vol.30*, 568-583.

Kruseman, G., Ruben, R., & Tesfay, G. (2006). Diversity and Development Domains in the Ethiopian Highlands. *Agricultural Systems, Vol.88*, 75-91.

Kruska, R.L., Reid, R.S., Thornton, P.K., Henninger, N., & Kristjanson, P.M. (2003). Mapping Livestock- oriented Agricultural Production Systems for the Developing World. *Agricultural Systems, Vol. 77(1),* 39-63.

Lacy, S.M., Cleveland, D.A., & Soleri, D. (2006). Farmer Choice of Sorghum Varieties in Southern Mali, *Human Ecology, Vol.34(3),* 331-353.

Manyong, V.M., Okike, I., & Williams, T.O. (2006). Effective Dimensionality and Factors Affecting Crop-livestock Integration in West African Savannas: a Combination of Principal Component Analysis and Tobit Approaches. *Agricultural Economics, Vol.35 (2),* 145–155.

McIntire, J., Bourzat, D., & Pingali, P. (1992). *Crop-Livestock Interaction in Sub-Saharan Africa.* World Bank Regional and Sectoral Studies). Washington D.C.: The World Bank.

Morera, M.C., & Gladwin, C.H. (2006). Does Off-Farm Work Discourage Soil Conservation? Incentives and Disincentives Throughout Two Honduran Hillside Communities. *Human Ecology,Vol.34(3),* 355-378.

Morgan, W.B., & Moss, P.A. (1985). Biomass Energy and Urbanisation: Commercial Factors in the Production and Use of Biomass Fuels in Tropical Africa. *Biomass, Vol.6(4),* 285-299.

Mortimore, M. (1991). *A Review of Mixed Farming Systems in the Semi-Arid Zone of Sub-Saharan Africa*. Working Document No.17. International Livestock Centre for Africa, Addis Ababa.

Mwampamba, T.H. (2007). Has the Woodfuel Crisis Returned? Urban Charcoal Consumption in Tanzania and its Implications to Present and Future Forest Availability. *Energy Policy,Vol.35*, 4221-4234.

Ndiaye, S.M., Sofranko, A.J. (1994). Farmers' Perceptions of Resource Problems and Adoption of Conservation Practices in a Densely Populated area. *Agriculture, Ecosystems & Environment, Vol. 48(1)*, 35-47.

Okwi, P., Ndeng'e, G., Kristjanson, P., Arunga, M., Notenbaert, A., Omoloa, A., Henninger, N., Benson, T., Kariuki, P., & Owuor, J. (2007). Spatial Determinants of Poverty in Rural Kenya. *PNAS (Proceedings of the National Academy of Sciences of the United States of America), Vol.104 (43)*, 16769–16774.

Ong, C.K., Anyango, S., Muthuri, C.W., & Black, C.R. (2007). Water Use and Water Productivity of Agroforestry Systems in the Semi-arid Tropics. *Annals of Arid Zone. 46(3&4)* in press.

Pell, A.N. (1999). Integrated Crop–livestock Management Systems in Sub-saharan Africa. *Environment, Development and Sustainability, Vol.1,* 337-248.

Pender, J., Jagger, P., Nkonya, E., & Sserunkuuma, D. (2004a). Development Pathways and Land Management in Uganda. *World Development*, *Vol.32(5)*, 762-792.

Pender, J., Nkonya, E., Jagger, P., Sserunkuuma, D., & Ssali, H. (2004b). Strategies to Increase Agricultural Productivity and Reduce Land Degradation: Evidence from Uganda. *Agricultural Economics, Vol.31,* 181-195.

Perz, S.G., Walker, R.T., & Caldas, M.M. (2006). Beyond Population and Environment: Household Demographic Life Cycles and Land Use Allocation Among Small Farms in the Amazon. *Human Ecology*, *Vol.34(4)*, 829-849.

Place, F., Franzel, S., DeWolf, J., Rommelse, R., Kwesiga, F., Niang, A., & Jama, B. (2002). Agroforestry for Soil-Fertility Replenishment: Evidence on Adoption Processes in Kenya and Zambia. In C.B.Barrett, F. Place, & A.A.Aboud. (Eds.), *Natural Resources Management in African Agriculture: Understanding and Improving Current Practices* (pp.155-168). Oxon and New York: CABI publishing.

Place, F., Barrett, C.B., Freeman, H.A., Ramisch, J.J., & Vanlauwe, B. (2003). Prospects for Integrated Soil Fertility Management Using Organic and Inorganic Inputs: Evidence from Smallholder African Agricultural Systems. *Food Policy*, *Vol.28,* 365-378.

Place, F., Kristjanson, P., Staal, S., Kruska, R.L., deWolff, T., Zomer, R., & Njuguna, E.C. (2006). Development Pathways in Medium-high Potential Kenya: A Meso-level Analysis of Agricultural Patterns and Determinants. In J. Pender, F. Place, & S. Ehui. (Eds.), *Strategies for Sustainable Land Management in the East Africa Highlands*.Washington D.C.: International Food Policy Institute.

Reardon, T., & Vosti, S.A. (1995). Links between Rural Poverty and the Environment in Developing Countries: Asset Categories and Investment Poverty. *World Development, Vol.23(9),*1495-1506.

Sanchez, P.A., & Leakey, R.R.B. (1997). Land Use Transformation in Africa: Three Determinants for Balancing Food Security with Natural Resource Utilization. *Perspectives for Agronomy, Vol. 25,* 19-27.

Sanchez, P.A. (2000). Linking Climate Change Research with Food Security and Poverty Reduction in the Tropics. *Agriculture, Ecosystems and Environment*, *Vol.82 (1-3)*, 371-383.

SARDEP. (2002). *SARDEP Keiyo/Marakwet, Participatory Land Use Plans for Community-based Natural Resource Management, Transect E*. Iten: The Semi-Arid Development Programme.

Seré, C., & Steinfeld, H. (1996). *World Livestock Production Systems: Current Status, Issues and Trends*. FAO Animal Production and Health Paper 127. Rome: FAO.

Shepherd, K.D., & Soule, M.J. (1998). Soil Fertility Management in West Kenya: Dynamic Simulation of Productivity, Profitability and Sustainability at Different Resource Endowment Levels. *Agriculture, Ecosystems and Environment*, *Vol.71*, 131-145.

Staal, S.J., Baltenweck, I., Waithaka, M.M., deWolff, T., & Njoroge, L. (2002). Location and Uptake: Integrated Household and GIS Analysis of Technology Adoption and Land Use, with Application to Smallholder Dairy Farms in Kenya. *Agricultural Economics*, *Vol.27*, 295-315.

Steinfeld, H., Wassenaar, T., & Jutzi, S. (2006). Livestock Production Systems in Developing Countries: Status, Drivers, Trends. *Rev.sci.tech.Off.int.Epiz. Vol.25(2)*, 505-156.

Thangata, P.H., & Alavalapati, J.R.R. (2003). Agroforestry Adoption in Southern Malawi: the Case of Mixed Intercropping of Gliricidia Sepium and Maize.*Agricultural Systems, Vol.78(1)*, 57-71.

Tiffen, M., Mortimore, M., & Gichuki, F. (1994). *More People, Less Erosion: Environmental Recovery in Kenya*. Chichester: John Wiley & Sons.

Thorne, P.J. (1998). Crop Livestock Interactions. A Review of Opportunities for Developing Integrated Models. (Unpublished Consultants Report to the ILRI-SLP). Llangefni, UK: Stirling Thorne Associates.

Thornton, P.K., & Herrero,] M. (2001). Integrated Crop-Livestock Simulation Models for Scenario Analysis and Impact Assessment. *Agricultural Systems*, *Vol.70*, 581-602.

Thornton, P.K., Kruska, R.L., Henninger, N., Krisjanson, P.M., Reid, R.S., Atieno, F., Odero, A.N, & Ndegwa, T. (2002). *Mapping Poverty and Livestock in the Developing World.* Nairobi: ILRI (International Livestock Research Institute).

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Rowe, E.C., & Giller, K.E. (2005). Exploring Diversity in Soil Fertility Management of Smallholder Farms in Western Kenya I. Heterogeneity at Region and Farm Scale. *Agriculture, Ecosystems & Environment*, *Vol.110*, 149-165.

Von Braun, J. (2007). *The World Food Situation: New Driving Forces and Required Actions*. IFPRI's Bi-Annual Overview of the World Food Situation presented to the CGIAR Annual General Meeting, Beijing December 3, 2007.

Waithaka, M.M., Thornton, P.K., Herrero, M., & Shepherd, K.D. (2006). Bio-economic Evaluation of Farmers' Perceptions of Viable Farms in Western Kenya. *Agricultural Systems*, *Vol.90*, 243-271.

Williams, T.O., Tarawali, S., Hiernaux, P., & Fernández-Rivera, S. (2004). *Sustainable Crop-Livestock Production for Improved Livelihoods and Natural Resource Management in West Africa*. Nairobi: International Livestock Research Institute.

Wolde-Rufael, Y. (2006).Electricity Consumption and Economic Growth: a Time Series Experience for 17 African Countries. *Energy Policy, Vol. 34(10)*, 1106-1114.

World Bank (2007). *World Development Report 2008: Agriculture for Development*. Washington DC: The World Bank.

Zhang, Q., Justice, C.O., & Desanker, P.V. (2002). Impacts of Simulated Shifting Cultivation on Deforestation and the Carbon Stocks of the Forests of Central Africa. *Agriculture, Ecosystems &Environment, Vol.90(2)*, 203- 209.