# Strategies for Sustainable Land Management and Poverty Reduction in Uganda

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# Contents

# Tables

# Figures

# Foreword

Poverty reduction is one of the overarching objectives of most of Sub-Saharan Africa and other low-income countries. Accordingly, one of IFPRI's major research themes focuses on policies and strategies for poverty reduction. This research report contributes knowledge to that theme. It also contributes to IFPRI's ongoing investigation of policies and strategies that foster broad-based and environmentally sustainable agricultural and rural development.

In Uganda, where soil erosion and depletion of soil nutrients are widespread, land degradation is a major cause of declining productivity and increasing poverty. In this study, Ephraim Nkonya and his colleagues measure the relative merits of various household income strategies and land management practices in Uganda to determine which most effectively improve agricultural production, household income, and the condition of the land. They determine the causes of land degradation, examine the impacts of policies and programs on income strategies and land management decisions, and assess the trade-offs and complementarities among different objectives.

Most policies that boost income and productivity while reducing adverse effects on the environment involve trade-offs. For example, improved education is shown to lead to higher incomes and better soil nutrient balances, but it may also reduce crop production and increase soil erosion, as a result of reduced farm labor intensity. No single solution will improve all outcomes simultaneously: different solutions are required for different situations and localities.

Although opportunities for wins all around the board are few, this report provides a wealth of information to help the farmers and policymakers of Uganda and other diverse nations weigh their options for increasing agricultural productivity and sustainability. Its analysis of the complex relationships among different interventions will surely prove useful in designing policies and strategies for addressing land degradation and poverty sustainably.

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Director General, IFPRI

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# Summary

The government of Uganda, with help from its development partners, is designing and implementing policies and strategies to address poverty, land degradation, and declining agricultural productivity. Land degradation, especially soil erosion and depletion of soil nutrients, is widespread in Uganda and contributes to declining productivity, which, in turn, increases poverty.

## Objectives of the Study

One of the challenges that the government faces in confronting these problems is lack of information to empirically support policy recommendations. To address this information gap, the authors of this research report analyze the policy-relevant determinants of households' income strategies and land management practices in Uganda and their impacts on agricultural production, household income, and land degradation. To obtain basic data, they surveyed 107 communities and 451 households and conducted a plot-level survey to investigate the land management and productivity of each plot. As indicators of sustainability of land management, soil nutrient flows and balances were estimated for a subsample of 58 households in eastern Uganda, and the determinants of these flows and balances were also investigated.

The contribution of this research to the literature is its analysis of the complex relationships among different policy and program interventions, households' livelihood strategies and land management decisions, and impacts on agricultural productivity, poverty, and land degradation. The study offers policy-related insights for addressing poverty and land degradation sustainably.

The report has four major objectives: (1) to examine the causes of land degradation in Uganda; (2) to identify the determinants of income strategies and land management decisions and their impacts on agricultural productivity, soil erosion, and household income; (3) to assess the trade-offs and complementarities among these different objectives; and (4) to analyze the soil nutrient depletion in eastern Uganda to determine the factors that influence it.

## Sustainable Land Management and Poverty Reduction Strategies

The communities and households surveyed vary widely in agro-ecological potential, access to markets and infrastructure, population density, presence of programs and organizations, education, household capital, and other factors. Although some of the results were expected, others challenged common assumptions.

Access to markets and roads did not have as much impact on income strategy and crop choice, land management, labor intensity, value of crop production, or soil erosion as expected, but it did contribute to the depletion of soil nutrients, at least in the near term.

Where population was dense, farms tended to be smaller and farmed more intensively and productively. But, higher population density also contributed to soil erosion, contrary to the "more people, less erosion" hypothesis.

Income strategies also had a strong impact on the value of crop production and the level of income: higher value was associated with livestock production, nonfarm activities (because farmers used nonfarm earnings to buy agricultural inputs), and greater specialization in higher-value crops, such as bananas. However, differences in household income levels for households pursuing different income strategies were statistically insignificant, except for livestock producers, who earned significantly more than crop producers. Income strategies also affected land degradation: for example, households more focused on nonfarm activities or livestock production had lower rates of soil nutrient depletion.

Participation in agricultural extension and programs sponsored by nongovernmental organizations (NGO) had mixed results across locations, which seemed to be the result of differences in the technologies promoted in each location. Agricultural extension was associated with higher productivity, but also with more erosion in the highlands and more soil nutrient depletion, due to the promotion of yield-increasing varieties without adequate adoption of soil conservation or fertility replenishing practices. By contrast, NGO programs focusing on agriculture and environmental issues helped to reduce land degradation but had less favorable near-term impacts on production, especially outside of the highlands.

Access to credit did not appear to affect income or purchase of inputs, such as fertilizer, but it increased the intensity of labor.

Land tenure and land title affected crop choice and land management practices somewhat, but had no significant impact on the value of crops produced, soil erosion, or household income.

Education significantly influenced households' income strategies, land management practices, and labor use in crop production. As expected, higher education contributed to significantly higher household income and reduced soil nutrient depletion, but it also led to less labor intensity in crop production.

Households headed by women had higher incomes than did those headed by men, and they depended more on nonfarm activities. This suggests that women are more likely to be employed off the farm and that their labor productivity is higher than that of men, which supports a common view that men are underemployed relative to women in rural Uganda.

## Policy Implications

These results suggest that the most promising strategies for reducing rural poverty are improvement in farmers' education and development of livestock production. Strategies to help increase the value of crop production include establishment of agricultural extension and training programs, development of banana and livestock production, specialization in cash crops, increased nonfarm activities, and improved access of small farmers to land. Reducing land degradation is more likely to be achieved by supporting NGOs that focus on agriculture and the environment, promoting nonfarm activities, and controlling population growth or facilitating emigration from the highlands, thus reducing soil erosion and nutrient depletion.

In efforts to reduce poverty and increase agricultural production sustainably, it is important to realize that many strategies involve trade-offs among these objectives and that their impacts are often context-specific. For example, improved education leads to higher incomes and better soil nutrient balances, but it may also reduce crop production and increase soil erosion, as a result of reduced labor intensity in farming. Agricultural extension and training increases productivity but also contributes to increased soil erosion and soil nutrient depletion, by promoting increased production of annual crops without sufficient promotion of soil fertility improvements or soil and water conservation measures. Similarly, improvements in market access can help to increase fertilizer adoption and reduce use of slash and burn, but they also contribute to soil nutrient depletion.

In general, these results imply that there are few "win-win-win" opportunities to simultaneously increase production and household income and reduce land degradation. Different instruments are needed to achieve different objectives, and trade-offs among these objectives must be expected. Just as no single solution exists to improve all outcomes simultaneously, different approaches are needed in different locations. There is no "one-size-fits-all" solution to the complex problems of small farmers in the diverse circumstances of Uganda.

## CHAPTER 1

# Introduction

Land degradation, low and declining agricultural productivity, and poverty are severe interrelated problems in Uganda, as in much of sub-Saharan Africa (SSA). Although poverty declined and the economy recovered during the 1990s as a result of improved security, macroeconomic stabilization, and market liberalization in Uganda, sustainable development has not yet been achieved (Collier and Reinikka 2001). Poverty is still severe, especially in rural areas (Appleton 2001a; UPPAP 2002), and problems of low agricultural productivity and land degradation appear to be getting worse. Farmers' yields are typically less than one-third of the yields obtained on research stations, and yields of major crops have been stagnant or declining for most farmers since the early 1990s (Deininger and Okidi 2001). Most communities in rural Uganda perceive that crop productivity is declining, and that food insecurity and land degradation have increased since the early 1990s (Pender et al. 2001b). This perception is supported by agricultural statistics, which show that per capita food production in Uganda is declining. This trend is putting at stake the food security of the rural and urban poor (NEMA 2001; UBOS 2002c).

Land degradation is a serious problem that contributes to the low and declining agricultural productivity and to food insecurity (NEMA 2001). Evidence of land degradation in Uganda is widespread. The major forms of land degradation in Uganda are soil erosion, soil fertility mining, soil compaction, waterlogging, and surface crusting (Zake et al. 1997). Soil erosion and soil fertility mining are believed to be the most important causes of land degradation. In some regions of Uganda, 60 to 90 percent of the total land area is affected by soil erosion (NEAP 1992). Soil fertility mining in Uganda is occurring at among the highest rates in SSA, with an estimated average annual rate of total nutrient depletion of 70 kilograms of nitrogen (N), phosphorus (P), and potassium (K) per hectare in the 1980s (Stoorvogel and Smaling, 1990). Wortmann and Kaizzi (1998) estimated even higher rates of soil nutrient depletion for several farming systems in central and eastern Uganda in the mid-1990s.

The high rate of soil nutrient depletion in Uganda is attributed to the limited and declining use of fallow, low use of inorganic or organic sources of soil nutrients, and other poor fertility management practices. For example, fewer than 10 percent of smallholder farmers in Uganda use inorganic fertilizer, one of the most likely technologies to improve soil fertility (Pender et al. 2001b). It has been estimated that smallholder farmers in Uganda apply an average of only 1 kilogram of soil nutrients per hectare (NARO and FAO 1999). This rate is among the lowest fertilizer application rates in SSA, where the total average fertilizer application is 13 kilograms of NPK nutrients per hectare (Heisey and Mwangi 1996), and is well below that in other developing regions of the world.[1]

Given the low application rates of purchased input, it is critical that other low-cost inputs are identified that can address soil fertility problems. The use of such organic practices as manuring, composting, mulching, and leguminous crops for biological nitrogen fixation is relatively limited. For example, in 2000, only 23 percent of households in our survey used animal manure, 20 percent used mulching, 18 percent reported incorporating crop residues, and 10 percent used compost (Table A1). Use of animal manure, mulching, crop rotation, and composting have increased significantly since 1990 (Table A2). However, many of the organic methods for improving soil fertility, such as application of manure and compost, are very labor-intensive and therefore not practical for farmers operating more than a few acres of land or working on distant parcels. Furthermore, the impacts of such technologies depend critically on how they are applied. For example, inadequate storage and application of manure can limit its effectiveness, due to the loss of nitrogen content or an increase of weeds and pests.

The land degradation problem affects all three elements of the critical triangle of development goals, namely, agricultural growth, poverty reduction, and sustainable resource management (Vosti and Reardon 1997). The interrelationships among these three goals are multifaceted and complex. Although they can be compatible long-term goals, in the short term there are often trade-offs (Lee et al. 2001). For example, expansion of agricultural production into previously forested or fallow land may increase food production and help to mitigate poverty, but can also contribute to soil erosion, soil fertility depletion, and depletion of water catchment areas and biodiversity, among other problems. Conversely, efforts to promote or enforce use of land conservation measures may increase agricultural production in the long run, but reduce incomes in the short run, because such measures require scarce land and labor that may have produced higher income if allocated for other activities. In the longer term, however, land degradation is likely to lead to further impoverishment, and conservation efforts may be critical to preventing this.

Poverty and food insecurity can in turn contribute to land degradation. Poor and food-insecure households may be forced to plant crops on steep slopes or may be unable to keep land fallow, invest in land improvements, or use such costly inputs as inorganic fertilizer (Reardon et al. 2001a). Poverty and credit constraints may also cause farmers to take a short-term perspective (Pender 1996; Holden et al. 1998). However, poor people may have more incentive to conserve their land, because it may be their only significant asset, and the opportunity cost of investing in land improvements may be lower for them. Nevertheless, the constraints imposed by poverty and food insecurity may outweigh these factors, thus completing a vicious cycle of land degradation–declining productivity–poverty–further land degradation. Understanding the complex relationships between growth, poverty, and sustainable resource use is central to identifying effective strategies to sustainably improve the livelihoods of rural Ugandans. This report seeks to improve that understanding.

The major challenge for the government and its development partners is to identify policies to effectively address land degradation, low agricultural productivity, and

[1]The amount reported by Heisey and Mwangi (1996) compares well with that of 14 kg of NPK per hectare used in SSA in 2000, reported by FAOSTAT (http://apps1.fao.org). Weight and Kelly, 1998 reported a lower amount of 9 kg of NPK per hectare used in 1995. Different authors report various figures for different years, but they all reflect the low fertilizer use in SSA.

poverty in a sustainable and equitable way. Finding and implementing policies to help farmers break out of the cycle of land degradation–declining productivity–poverty is an urgent need in Uganda, as is the case in many other developing countries. The government of Uganda has responded to this challenge by designing the Plan for Modernization of Agriculture (PMA), which is one of the strategies of the Poverty Eradication Action Program (PEAP) (MAAIF and MFPED 2000). The goal of the PMA is to transform the largely subsistence agriculture in Uganda into commercially oriented farming, to contribute to government's efforts to alleviate poverty, and to address the land degradation problem in the country (MAAIF and MFPED 2000). This and other strategies call for clear policy guidance, which can only be developed when policymakers and their development partners are equipped with well-researched information. A major goal of this study is to provide empirical information that will help policymakers, development practitioners, and other stakeholders to formulate policies and strategies for sustainable land management, increased agricultural productivity, and reduced poverty in Uganda.

## Contributions to the Literature

In addition to providing empirical information useful to policymakers and other stakeholders in Uganda, this study contributes to the broader literature on sustainable rural development and natural resource management in several ways. First, it develops a conceptual framework that elucidates the complex set of relationships among policies, programs, and other external and local factors and the livelihood strategies pursued by rural households; the relationships between households' livelihood strategies and their agricultural and land management practices; and the impacts of those underlying factors and household decisions on Vosti and Reardon's (1997) "critical triangle" of outcomes—productivity, economic growth, and natural resource conditions. Although developed independently, this framework shares much in common with the now-popular "sustainable livelihoods" framework (Carney 1998; Scoones 1998). Both frameworks consider the broad set of physical, human, natural, social, and financial capital endowments of households and communities and their implications for household decisionmaking, as well as the role of such contextual factors as agro-climatic conditions, access to markets, population pressure, and the development of local institutions. Unlike the existing literature on sustainable livelihoods, however, we develop a rigorous formulation of a theoretical dynamic household decisionmaking model, and use it to guide our empirical specification and hypotheses, drawing on the theoretical literature on agricultural household models (for example, Singh et al. 1986; de Janvry et al. 1991).

The most important contributions of this study to the literature are its empirical methodology and results. Vosti and Reardon (1997) largely set out the agenda of this research, but the studies reported in that volume provided only a starting point in assessing the empirical evidence, based mostly on secondary data. Although there is a rapidly growing empirical literature that draws on the sustainable livelihoods framework (for example, Rakodi 1999; Ellis 2000; Adato and Meinzen-Dick 2002; Ellis and Bahiigwa 2003; Ellis and Mdoe 2003; Ellis et al. 2003; Meinzen-Dick et al. 2003; Reddy and Soussan 2003), there is still a dearth of solid empirical evidence on the impacts of key causal factors on the livelihood strategies of households in different contexts; the appropriate portfolio of public interventions for different contexts; and the implications of different interventions and livelihood strategies for agriculture and land management, agricultural productivity, poverty, and land degradation. Most of the available literature on sustainable livelihoods is largely anecdotal in nature or uses only descriptive information to describe the access of households to different types of assets and income sources, without testing relationships among these factors or their relationship to natural resource management or outcomes.[2]

There is a large literature on determinants of adoption of agricultural technologies (for example, Feder et al. 1985 and Feder and Umali 1993), and a rapidly growing literature on determinants of adoption of natural resource management practices (for example, Lee and Barrett 2001; Barrett et al. 2002a). However, most of this literature does not relate natural resource management decisions to the livelihood strategies of households and focuses mostly on household-level factors, with little information on the impacts of community and higher-level factors; few studies show the impacts of resource management decisions on poverty, food security, or other outcomes of interest (Place et al. 2002b). There is a well-developed literature on the impacts of property rights and land tenure on technology adoption and natural resource management and implications for agricultural production (for example, Feder et al. 1988; Place and Hazell 1993; Bruce and Migot-Adholla 1994; Otsuka and Place 2001; Meinzen-Dick et al. 2002). Much less of the literature reports on the impacts of other policy relevant factors, such as access to roads, markets, and community-based organizations, and there is little exploration of the relationship of these issues to livelihood strategies. The work of Fan and colleagues (for example, Fan et al. 1999) investigates the impacts of various public investments on agricultural production and poverty, but does not investigate the impacts of such investments on the livelihood strategies of households, land management practices, or natural resource conditions. There is also a rapidly growing literature on rural nonfarm income and livelihood diversification in developing countries (for example, Reardon 1997; Ellis 2000; Barrett et al. 2001; Reardon et al. 2001b), but little of this investigates the implications of livelihood diversification for natural resource management.

This report begins to address these gaps in the empirical literature. It represents a rare attempt to assess causes and effects of livelihood strategies and land management in an integrated framework, using micro-level data from a large number of households and communities, representing different contexts in terms of agro-ecological potential, access to markets and infrastructure, population density, presence of programs and organizations, and other factors. We investigate not only the factors determining livelihood strategies and adoption of different agricultural and land management practices, but also the implications of these decisions for outcomes of interest, taking special care to address problems of endogenous variables and other econometric issues affecting our inferences. In investigating these implications, we consider the numerous channels of indirect and direct impacts of various policy-relevant factors, using a simulation approach based on the econometric results. We also present the first study that we are aware of to investigate the underlying causes of variation across households in soil nutrient balances using multiple regression analysis.[3]

The results of this research challenge some common assumptions. For example, we find more soil nutrient depletion in areas of better market access and among more commercialized farmers, raising questions about the assumptions of the PMA and many policymakers that increasing commercializa-

[2]Recent work by the Consultative Group for International Agricultural Research (CGIAR) to assess impacts of agricultural research on poverty is an exception (Meinzen-Dick et al. 2003).

[3]Numerous studies have estimated soil nutrient balances at different levels since this approach was pioneered by Stoorvogel and Smaling in the early 1990s (for example, Smaling 1998).

tion and investment in roads will solve the land degradation problem in Uganda (at least in the near term). We find that, even though education increases household income, it is associated with more soil erosion, as it reduces farmers' emphasis on labor-intensive conservation measures. We also find that access to agricultural extension increases crop productivity but apparently leads to more soil nutrient depletion and soil erosion, especially in highland areas. Rather than suggesting a shift in paradigm, these results suggest that further research is needed to better understand the causes of such trade-offs and to find ways to avoid or ameliorate them.

## Objectives

This report has three major objectives. The first is to review the proximate and underlying causes of land degradation. The second objective is to identify determinants of income strategies and land management and analyze their impacts on agricultural productivity, soil erosion, and household income. Based on these, policy scenarios will be simulated to measure their potential impacts on agricultural production, soil erosion, and household income, and to assess trade-offs or complementarities among these different objectives. The third objective is to analyze the soil nutrient depletion in one region of Uganda and the factors influencing it.[4]

## Organization

This report is organized as follows. The second chapter identifies the key proximate and underlying causes of land degradation in Uganda, based on a review of the available literature and some results of community and household surveys conducted in Uganda for this research. The third chapter presents the conceptual framework, empirical model, hypotheses, and methods used to collect and analyze the data for this study. Chapter 4 uses econometric analysis to identify and analyze the determinants of income strategies, land management, income, crop productivity, and soil erosion. That chapter also discusses potential impacts of these factors on agricultural productivity, soil erosion, and household income under several policy scenarios. In Chapter 5, we analyze the sustainability of land management practices, using soil nutrient balances as the key indicator of sustainability. The final chapter discusses the conclusions and their policy implications.

[4]Sustainable land management can be defined as land use practices that ensure land, water, and vegetation adequately support land-based production systems for the current and future generations. However, in this study, we focus specifically on impacts of land management on soil erosion and soil nutrient depletion, because these factors have been identified as the most critical land degradation problems in Uganda.

# CHAPTER 2

# Causes of Land Degradation in Uganda

To design policies and strategies that address the land degradation problem in a sustainable manner, the causes of land degradation and their underlying factors need to be identified and understood. In this chapter, we review both the proximate and underlying causes of land degradation. This analysis is based on a review of available literature, as well as evidence from our own surveys.

## Proximate Causes of Land Degradation

Land degradation in Uganda is directly attributed to biophysical factors and unsustainable land management practices, which we will consider in turn.

### Biophysical Factors

The important biophysical factors that affect land degradation include topography, land cover, climate, soil erodibility, pests, and diseases. The magnitude of soil erosion is a function of slope length and steepness (Wischemeier 1976; Voortman et al. 2000). Sloped lands are vulnerable to soil erosion if they have inadequate vegetative cover and no physical barriers to runoff. For example, Magunda and Tenywa (1999) note that the densely populated areas on steep slopes of the southwestern and eastern highlands (including parts of Kabale, Kisoro, Bundibugyo, Kasese, Kabarole, Kapchorwa, and Mbale districts) are severely affected by soil erosion. However, in most cases, the highlands experience good rains, which contribute to good vegetative cover and high soil organic matter. These attributes improve the water-holding capacity of the soil, reduce surface runoff, and increase the soil's physical stability, all of which help to reduce soil erosion (Voortman et al. 2000).

Climate is also an important biophysical factor that affects land degradation. Scherr (1999) and Voortman et al. (2000) note that high temperatures and intense rainstorms in the tropics subject soils to climate-induced degradation. Magunda and Tenywa (1999) note that rainfall intensity is one of the most important determinants of soil erosion in Uganda, as it is very intense in some parts of the country. Intensities of more than 300 millimeters per hour have been recorded (Magunda and Tenywa 1999; Zake et al. 1997). Even in drier areas, rainfall often occurs in intense bursts, and because vegetative cover is poor in these areas, the soil is exposed to severe water and wind erosion. High and intensive rainfall may cause considerable leaching, which also leads to land degradation. In such high rainfall areas as the southwestern highlands, the eastern highlands, and the Lake Victoria crescent region, leaching is a significant problem, especially in sandy and loamy soils (NEMA 1998). Recent work by Ssali (2002) shows that, in the central and eastern regions of Uganda, soil acidification and depletion of bases caused by leaching are serious land degradation problems.

Soil physical characteristics also affect land degradation by influencing the susceptibility of the soil to erosion and other forms of degradation. For example, soil erodibility depends on topsoil texture, shear strength, aggregate stability, and organic-matter content (Morgan 1995).

Pest and disease pressure can also contribute to land degradation. For example, the practice of using coffee husks for mulching as a means of soil erosion control and recycling of soil nutrients has been discouraged countrywide, for fear that the practice spreads coffee wilt disease (CWD). Pests and diseases may also limit the response of crop yield to fertilizer, thus reducing farmers' use of such inputs. For example, such pests as nematodes that attack the root system of crops limit the ability of plants to absorb nutrients, thereby decreasing the returns to fertilizer and discouraging its use. Use of manure may increase the risk of pest attack by creating favorable breeding conditions for pests. However, failure to use replenishing inputs (manure and inorganic fertilizers) depletes the soil of its fertility, making crops more susceptible to disease and pest attack (Sserunkuuma et al. 2001). Thus, soil fertility and disease and pest problems may need to be addressed concurrently.

### Unsustainable Land Management Practices

Traditionally, soils in Uganda were cultivated until crop yields deteriorated to unacceptable levels and the "tired" pieces of land were then fallowed to restore fertility. This helped to increase soil organic matter, recycle leached nutrients, improve soil physical properties, and restore soil fertility (Jones 1972). However, fallowing is becoming less common as population pressure increases. Due to extreme land scarcity in the densely populated areas of the country, such as the southwest highlands region, fallowing for one year or more is no longer commonly practiced. Only 6 percent of households used fallow strips in the late 1990s, and average fallow times decreased from 2.2 years in the late 1980s to 0.7 years in the late 1990s (Pender et al. 2001b).

In addition, various soil conservation measures were widely practiced prior to the 1970s, promoted by educational programs and often enforced by local administrators. These practices helped to maintain the fertility of Uganda's soils, which were considered to be among the most fertile in the tropics (Chenery 1960). However, a combination of several factors (including two decades of political turmoil) led to the neglect or destruction of old investments (for example, terraces) and discouraged new investments in soil conservation, resulting in serious soil erosion (Zake 1992). Cultivating steep slopes and hilltops without adequate protection of the soil from erosion has contributed to increased soil erosion, particularly in the densely populated southwestern mountain regions (Sserunkuuma et al. 2001).

As noted earlier, a small proportion of smallholder farmers use inorganic or organic fertilizer or other fertility management technologies. The total NPK fertilizer use in Uganda of 5,800 metric tons per year (in 2001), although higher than in the recent past, is much lower than it was 30 years ago, and is very low by international standards (for example, Kenya and Malawi used about 144,542 and 22,756 metric tons, respectively, in 2001)[5] (IFDC 2001; FAO 2004). Worse still, 95 percent of the total fertilizer use in Uganda is by large-scale farmers and the

[5]Malawi's population of 10.7 million is less than one-half of Uganda's population of 24.7 million and Malawi's per capita income is 50 percent that of Uganda's.

operators of tea and sugar estates (NARO and FAO 1999). The low adoption by small landholders of soil fertility management technologies contributes to soil fertility mining and soil erosion.

In addition to decreasing agricultural productivity directly, low fertility creates a conducive environment for weeds, such as witch weed (*Striga* spp.). *Striga* is a parasitic weed found in marginal, semiarid areas (Esilaba et al. 1997). In Africa as a whole, *Striga* infestation causes an estimated annual loss of US$311 million per year (Sauerborn 1991; Ransom 2000). *Striga* infestation is becoming a serious problem among cereal producers in the semiarid areas in the eastern and northeastern parts of Uganda.

Deforestation is an important determinant of land degradation, as it leads to reduced vegetation cover. Deforestation also reduces water-catchment potential and promotes landslides and siltation of water bodies (NEMA 2001). It is estimated that 0.8 percent of forest area is lost annually in Uganda. Most of this loss occurs in woodlands, which are not gazetted (NEMA 2001). Increased demand for charcoal and fuel wood (for cooking, brick making, curing tobacco, and other uses) is contributing to deforestation and causing soil erosion in many areas.

Other major problems that contribute to land degradation are overgrazing and bush burning. There is evidence of overgrazing in the cattle corridor that runs from northeastern to southwestern Uganda. NEMA (2001) and Muhereza and Otim (2002) note increasing emergence of unpalatable grass species in some parts of the cattle corridor. This is a sign of overgrazing, which contributes to soil erosion and compaction, because it reduces land cover (NEMA 2001). Farmers also burn bushes to encourage growth of new grass for their livestock or to clear land for cultivation. Bush burning destroys perennial vegetation and other vegetative matter, exposing the soil to water and wind erosion (NEAP 1992).

## Underlying Causes of Land Degradation

We now review the factors that underlie the proximate causes discussed above. The underlying causes of land degradation are less well understood, but understanding their impacts is key to designing strategies to address the land degradation problem, increase agricultural production, and reduce poverty.

Many socioeconomic and policy-related factors are commonly hypothesized as affecting the proximate causes of land degradation, including population pressure; poverty; agricultural commercialization; high purchased-input costs; lack of access to rural finance, markets, and public services; decentralization; privatization of the delivery of basic services, including technical assistance; land-tenure relationships; and general policy reforms (Sserunkuuma et al. 2001). We consider the available evidence related to these issues in this subsection.

### Population Pressure

Population growth is considered to be one of the most important factors behind the declining use of fallow and increased land fragmentation in Uganda (Sserunkuuma et al. 2001). Uganda's total population increased by 121 percent between 1969 and 1991, with the urban population growing at a faster rate (198 percent) than the rural population (66 percent) (UBOS 2002a). Provisional results of the 2002 Population and Housing Census show that Uganda's population grew at an average annual rate of 3.5 percent between 1991 and 2002 (UBOS 2002a). Growing urban populations can increase soil nutrient depletion, as more production is sold to urban consumers, unless farmers adequately replenish the nutrients being exported through commodity sales. In many countries, urban population and demand growth prompts farmers to apply excessive amounts of fertilizer to produce surplus agricultural products to meet their growing urban demand.[6] This situation is observed in the European Union, Japan, and North America. However, in sub-Saharan Africa, urban population growth has not been matched with corresponding fertilizer consumption. Fertilizer consumption in the continent has continued to lag behind other regions (Reardon et al. 2001a). Africa currently accounts for only 2 percent of the world's fertilizer consumption, whereas the region accounts for 12 percent of the world's population (IFA 2003). Low fertilizer use is particularly notable in Uganda, which has the lowest fertilizer consumption in Africa (IFA 2003).

Rural population growth increases the pressure on arable land, resulting in land fragmentation, reduced fallow periods, and, in many cases, continuous cultivation of land. This also likely contributes to soil nutrient mining, as well as increasing erosion. Population pressure is likely to be severe in areas that are more fertile. In sub-Saharan Africa, such areas are concentrated in the young volcanic soils on the slopes of mountains, such as the eastern and western highlands of Uganda (Voortman et al. 2000).

Although population growth is commonly hypothesized to lead to land degradation, such negative impacts are not inevitable. Evidence from other parts of the world indicates that farmers may intensify and improve land management in response to population pressure, as originally argued by Boserup (1965; see also Tiffen et al. 1994; Templeton and Scherr 1999; Pender 2001). However, such favorable responses are not automatic. For example, evidence from Ethiopia indicates that population pressure is contributing significantly to land degradation in the highlands (Grepperud 1996; Pender et al. 2001a).

Evidence of the impact of population pressure on resources in Uganda and east Africa in general is not clear, however. For example, in Rwanda, larger farms in areas of low population density were found to be less likely to adopt conservation investments (Clay et al. 2002). Place et al. (2001b) found that population growth leads to conversion of land to agricultural use in Uganda, but also found a positive association between population growth and changes in tree cover on nonagricultural land, and an insignificant association between population growth and tree cover on agricultural land. Place et al. (2001b) also observed a negative impact of farm size on tree planting, but a positive impact on the use of fuel wood from the farmers' own lands, and an insignificant effect on fallowing in Uganda, implying mixed impacts of farm size on resource outcomes. Pender et al. (2001b) found insignificant associations between population growth and perceived changes in resources in Uganda. A long-term study of changes in fallow practices in the Kabale district in the southwest highlands found evidence of increased fallowing between 1945 and 1996, despite a doubling of the population in this period (Lindblade et al. 1996). Whether the increase in fallow indicates improved land management or land abandonment due to population-induced land degradation is not clear.

Further research is needed at the household and plot level to identify what impacts population pressure and associated conditions (such as small farm sizes) are having on land management and land degradation.

### Poverty

Poverty is a serious problem in Uganda, and is predominantly concentrated in rural areas. Nationwide, the percentage of Ugandans living in poverty is estimated to have declined from 56 percent in 1992–93 to 35 percent in 1999–2000. However, poverty reduction has been more significant in urban areas (Appleton 2001a). The effect of

[6]We thank an anonymous reviewer for suggesting this point.

poverty on land management is hard to predict. On one hand, poverty reduces farmers' ability to pay for investments in land improvement and accentuates the short-term perspective of farmers, which may limit their interest in making long-term investments in soil and water conservation (Pender 1996; Holden et al. 1998). On the other hand, poor people may have more incentive to conserve their land, because they own little else than the land they occupy, unlike their wealthy counterparts, because they may have few alternative investments available to them, and because the opportunity costs of their labor in making labor-intensive investments in land improvement may be lower than the labor costs of wealthier households (Pender and Kerr 1998; Clay et al. 2002).

In general, evidence on the relationship between poverty and natural resource degradation is ambiguous (Leach and Mearns 1996; Prakash 1997; Scherr 2000). Evidence from recent studies in east Africa also confirms that the effect of poverty on land management is ambiguous. In Ethiopia, Holden and Shiferaw (2002) and Shiferaw and Holden (2000) observed that poorer households had less ability to invest in soil- and water-conservation measures, implying that poverty contributes to land degradation. However, Holden et al. (2002) also noted that improved off-farm income opportunities are likely to reduce investments in soil and water conservation and increase soil erosion, while substantially increasing household income. Woelcke et al. (2002) found that commercially oriented farmers in the Mayuge district of Uganda deplete soil nutrients at a faster rate than do their less wealthy, subsistence-oriented counterparts. Other studies have found insignificant or mixed impacts of different forms of wealth or income on adoption of improved land management practices (for example, Benin 2002; Gebremedhin and Swinton 2002; Pender et al. 2002). The impacts of poverty on land management and land degradation thus appear to be very complex and context specific, and may vary depending on the nature of the poverty experienced (Reardon and Vosti 1995), as well as the type of land degradation considered. Further research is thus needed to identify such relationships in the context of Uganda.

### Agricultural Commercialization

Recent studies show that the growth in agricultural commercialization and urban development continued throughout the 1990s, driven by structural adjustment and market liberalization policies. Larson and Deininger (2001) note that in 1992–93, 20 percent of farm output was sold off the farm. However, the marketed surplus varies greatly from one crop to another, with coffee and cotton having the highest share of marketed surplus (over 90 percent) and sweet potato having the lowest share (6 percent). Between 1992 and 2000, many households became more integrated into the agricultural market due to decreasing transaction costs (Larson and Deininger 2001). This is likely to have increased the share of the marketed surplus, which, in turn, increased farmers' income-earning opportunities both on and off the farm. But it has probably contributed to land degradation, because (1) exported plant nutrients through commercialization are not adequately replenished, and (2) farmers are less willing to invest in labor-intensive land management and conservation practices due to the reduced availability of farm labor following the increase in nonfarm income-generating opportunities. The findings of Woelcke et al. (2002) cited above regarding the higher rate of nutrient depletion by more commercialized farmers are consistent with this expectation, and suggest that the assumption of the Plan for Modernization of Agriculture (PMA) (MAAIF and MFPED 2000) that agricultural commercialization will lead to improved land management may not be true, at least in the near term.

### High Purchased-Input Prices

As we have already noted, the inability of smallholders to replenish soil nutrients is seriously inhibiting sustainable land management in Uganda. The high cost of inputs, particularly fertilizer, may be the most important reason for their limited use. Omamo (2002) observes that the low rate of fertilizer use in Uganda and other SSA countries is not only because of poor knowledge and understanding of fertilizer-based cultural practices among smallholders, but also because of the systematic exclusion of smallholders from fertilizer markets due to prohibitively high prices. Recently liberalized markets often deliver fertilizer to rural areas at prices that render its use unprofitable; hence the low demand. Simultaneously, faced with low demand for fertilizer, agricultural input traders appear reluctant to invest in measures that might reduce farm-gate prices to increase the profitability and demand for fertilizer. Real input prices have fallen in the past decade due to market liberalization and greater competition in the market (Balihuta and Sen 2001). For instance, urea and diammonium phosphate (DAP) prices fell from US$26.25 and US$31.25 in late 1998 to US$16.70 and US$20.55 per 50-kilogram bag, respectively, in December 2000. However, fertilizer prices remain relatively high and unaffordable to the majority of farmers. Substantial improvement of the marketing environment is required to give farmers sufficient incentive to use fertilizer and other sustainable land management practices (Woelcke et al. 2002). Kaizzi (2002) also noted that application of fertilizer is not profitable in low-potential soils in eastern Uganda, although fertilizer use for maize was found to be profitable in some high-fertility soils of this region.

Demonstration plots conducted by the Sasakawa Global 2000 (SG2000) in Uganda showed that the yields of improved maize varieties fertilized with DAP and urea were 70–120 percent higher than those using traditional farming practices, which includes unimproved maize varieties and application of animal manure. The marginal rate of returns (MRR) per Ush. invested in the SG2000 technological package ranged from 0.7 to 2.15 (Foster et al. 2002).[7] This suggests that fertilizer can be profitable under high-input management practices, where complementary technologies, such as improved seeds, are used. However, use of a package of technologies is less feasible than the use of one component of a technological package for resource-poor farmers, given credit constraints.

Underlying the high fertilizer prices are inefficiencies in the distribution system, characterized by inefficient procurement, high transportation costs, and imperfect competition due to a few big traders dominating the market. These factors combine to increase the transaction costs of fertilizer marketing; hence the high farm-gate prices. Reducing transactions costs of fertilizer trading through an efficient transport infrastructure and market-information collection and dissemination services is possible. The low volume of fertilizer imported into Uganda also contributes to the high transaction costs. It has been estimated that the cost, insurance, and freight (c.i.f.) price of fertilizer in Kampala could fall by a quarter only by increasing the volumes shipped to levels that would justify shiploads and trainloads (IFDC 2001). Another way to reduce fertilizer prices may be for Ugandan traders to import fertilizer directly from manufacturers overseas rather than via Kenyan traders. By importing directly from overseas, it is

[7]This implies that for each shilling invested, the farmer will recover the invested shilling and earn a profit ranging from Ush. 0.7 to 2.15.

possible to save at least Ush. 65 per kilogram of DAP (about US$36 per metric ton) from circumvention of Kenya-based handling and storage costs, which would translate into a 10 percent reduction in DAP prices in both Kampala and Mbale (Omamo 2002). However, the small volume that the Ugandan traders import may not be cost effective to import directly from overseas. The lack of a widespread agricultural extension and input credit system (discussed below) also undoubtedly limits farmers' awareness of the potential benefits of fertilizers and other technologies, as well as their ability to finance such purchased inputs.

### Access to Rural Finance

The absence of a well-functioning rural financial system may be a significant obstacle to agricultural development in Uganda. This is because lack of credit not only contributes to an emphasis on the short-term perspective of farmers—which fuels overexploitation and degradation of the natural resource base (Pender 1996; Holden et al. 1998)—it also reduces the farmers' ability to acquire and use purchased inputs needed for sustainable agricultural development (Larson and Frisvold 1996). Following increased activities of microfinance institutions (MFI) in rural areas, access to credit appears to have increased. In 2000, 95 percent of households had access to some form of credit (Tables A3 and A4). Only about 20 percent of households had access to formal credit, and access varied widely among zones of agricultural potential.[8] Approximately 75 percent of households had access to informal credit. Among those with access to credit, the amounts borrowed vary widely, with formal credit amounts tending to be larger than informal credit. This is expected, as formal credit institutions tend to give bigger loans to fewer, wealthier borrowers (Table A3). There seems to be a clear pattern of informal credit evolving where formal credit is not available. Where formal credit availability declined or remained stagnant, informal credit increased. In addition, most households were saving for emergencies in 2000 (Table A4). However, the impact of access to credit on use of agricultural inputs is likely to be ambiguous, because such access may not directly translate to purchase of inputs. For example, Deininger and Okidi (2001) found that only 15 percent of loans in 1999 were used to purchase inputs, and only 7 percent of loans were used for agricultural investments in land and livestock. The largest share of loans was used to establish nonagricultural enterprises, and for health and education expenditures.

### Access to Markets and Public Services

Lack of access to good infrastructure—particularly roads—is viewed as the most significant constraint to subsistence farmers' access to markets (MAAIF and MFPED 2000). Road infrastructure in Uganda, although improving, is still underdeveloped.[9] More than 90 percent of Uganda's road network consists of earth and gravel roads, and about 25 percent of the rural feeder roads are impassable during the rainy seasons. In addition, there is a myriad of community roads that are in poor condition but are very important for linking local communities with the market (Sserunkuuma et al. 2001). Furthermore, the mountainous terrain in many parts of Uganda hinders the development of roads, so that the smallholders in the high-

[8] Formal credit is issued by formal, registered financial institutions, such as banks. Informal credit is available from such sources as friends, relatives, or any other unregistered money lender.

[9] The roads program, which was among the earliest focuses of government efforts on poverty reduction, has had some impact. This effort was focused on "classified" (trunk) roads, 70 percent of which are now estimated to be in fair-to-good condition, compared with 50 percent of feeder roads (Foster and Mimjubi 2002).

lands who face the most extreme land degradation may be far removed from markets. Due to these unfavorable market conditions, it is estimated that about 70 percent of the total marketed surplus in Uganda is transported as head loads, 20 percent by bicycle, 8 percent by motorized vehicles, and 2 percent by animals (donkeys and ox-carts) (MAAIF and MFPED 2000).

Lack of infrastructure can also deter the transmission of price signals to farmers and render the production of agricultural products insensitive to price incentives (Rashid 2002). Poor infrastructure also impedes farmers' access to modern agricultural inputs, which are usually imported (or produced in urban areas). To the extent that input demand and output supply are price elastic, improvements in road conditions may induce farmers to increase both the cultivated area (production) and the use of yield-enhancing inputs, which in turn increase agricultural output.

Areas with better market access are likely to receive higher prices for their outputs and pay lower prices for inputs due to lower transaction costs. It is also evident that better market-access areas are benefiting from privatization and market liberalization, which make inputs cheaper and easier to obtain (Omamo 2002). This is likely to promote increased use of inputs and increased participation in the market, and may promote more investment in land improvement. With better market access, farmers may be able to shift to producing higher-value perishable crops or livestock products, which can also increase returns to using inputs and offer new land management opportunities (such as the use of manure from intensive livestock production).

Between 1990 and 1999, there was a considerable increase in the use of public and private services (Pender et al. 2001b). For example, the use of motorbike transport (locally known as *boda boda*) increased throughout Uganda. There were also increases in the use of other private services, such as grain mills, coffee processing plants, and input-supply dealers. Liberalization of the telecommunications sector allowed the private sector to provide mobile phone and Internet services. Telecommunications was the fastest growing sector in 2002 (MFPED 2002). This growth increased the teledensity in Uganda by about tenfold, from 0.27 percent in 1997 to about 2.5 percent in 2003 (MFPED 2002; unpublished Uganda Bureau of Statistics data, 2003). Currently there are three cellular phone companies operating in Uganda. The companies have a total of about 893,035 subscribers, compared with only about 65,793 landline connections in December 2003 (UCC 2004). The mobile phone companies have established a wide coverage that ensures connectivity in all district town headquarters, in many rural trading centers, and along major roads. In addition to increasing the general information flow, some mobile companies have specific price dissemination services that may improve agricultural market information flow.

There have been significant increases in attendance of primary and secondary schools and in the use of health clinics. Primary education in Uganda has benefited from foreign assistance arising from debt relief and other bilateral support, which has allowed for the implementation of the Universal Primary Education (UPE) policy (Fan and Rao 2003).[10] The UPE policy led to a substantial increase in primary school enrollment, from 2.7 million pupils in 1996 to 6.6 million pupils in 1999 (Fan and Rao 2003). Improved access to education and health services may contribute to greater agricultural productivity by increasing farmers'

[10]The UPE policy provides free primary education for four children per family, and emphasizes gender equality in education.

awareness and ability to adopt new technologies and by improving the health of the agricultural labor force. However, such improvements may discourage labor-intensive investments in agriculture and land improvement, as they also increase the value of labor invested in nonfarm activities.

The impact of access to markets and public services is thus ambiguous. Although areas with good market access are associated with higher agricultural intensification, average yields for several crops are reported to be stagnant or declining in most places, including high market-access areas (Pender et al. 2001b). The declining yields for several crops suggest that land degradation in such areas is still a problem. Therefore, although improved market access may increase efficiency of agricultural marketing, low profitability of outputs may still limit farmers' willingness and ability to apply adequate inputs to counter land degradation.

### Decentralization, Technical Assistance, and Privatization of Basic Service Delivery

As is the case in many other SSA countries, Uganda decentralized its government activities beginning in 1993 to empower local actors to participate in planning and managing their development strategies and livelihoods. The devolution involved transferring most political, legislative, and executive powers to local governments, which include cities, municipalities, town councils, districts, and subcounties. The Local Government Act of 1997 gives local governments authority to plan, mobilize, and manage financial resources (Onyach-Olaa 2003). One aspect of the devolution strategy that is unique to Uganda is the decentralization of agricultural extension delivery service. The National Agricultural Advisory Service (NAADS) was initiated to establish a decentralized farmer-owned and private-sector–serviced extension delivery system. Implementation of NAADS started in 2001 in six of the 54 districts of Uganda and was working in 15 districts by 2003 (NAADS 2003). However, since NAADS had not begun to be implemented at the time of our survey, our results and discussion related to extension services in Chapters 4–6 refer to the traditional extension approach.

Decentralization has greatly affected the local institutions, which are increasingly being viewed as important in natural resource management (Rasmussen and Meinzen-Dick 1995; Baland and Platteau 1996; Blackburn and Holland 1998; Raussen et al. 2001). Both the National Environment Action Plan (NEAP) and the National Environmental Management Authority (NEMA) have taken advantage of decentralization and the development of local institutions to manage local natural resources and the environment. District and local environmental committees have been formed to enact and enforce environmental and natural resources ordinances and by-laws (Lind and Cappon 2001).

Alhough this strategy is appealing, decentralization faces daunting challenges related to limited financial and human resources. For example, Reinikka (2001) observed that decentralization reduced school funding and staff for rural schools. Extension services under decentralization have also been negatively affected, due to the lack of resources and job security for extension officers (Bashaasha 2001; Enyipu et al. 2002). Household-level data indicate that only 50 percent of households received agricultural extension or agricultural training between 1990 and 2000, and during this time, perceived improvements in extension contact were minimal (Table A5). Deininger and Okidi (2001) corroborate this finding, showing that approximately 65 percent of villages were not reached by extension services in 1999.

Decentralization also presents challenges with respect to the transfer of information on technologies from research stations to farmers in the far reaches of the country. The local governments face the problem of poor recruitment to and retention of qualified staff in remote areas. The weak private sector and civil society in remote areas compound the problem. This will make implementation of the NAADS program difficult, because the program was intended to be implemented by the private sector and civil society (Onyach-Olaa, pers. comm.).

Of particular importance in the provision of rural services are the nongovernmental organizations (NGO) and community-based organizations (CBO).[11] Decentralization has taken advantage of the roles that NGOs and CBOs play in rural areas. NGOs and CBOs (hereafter referred to as organizations) that have a stake in natural resource management are represented on the local environmental and natural resource committees. In turn, the organizations are required to sensitize local populations and assist them in using sustainable and improved resource management strategies and observing environmental by-laws and other regulations (Onyach-Olaa, pers. comm.). This has given the organizations an important role in influencing land management at the local level.

The most common types of organizations operating in communities are those focused on poverty reduction, infrastructure and services, and agriculture and the environment. Since the late 1980s, there has been a remarkable increase in the number of organizations operating in communities in Uganda. NGOs include both externally organized and financed organizations (for example, CARE, African Highlands Initiative, World Vision) and locally organized groups that identify and register themselves as NGOs (Jagger and Pender 2003). During the 1990s, the communities surveyed had an average of one NGO per community (Pender et al. 2001b). Approximately 15 percent of households reported having at least one member involved with an NGO during this period (Table A6). Over 80 percent of households in our sample were involved with a CBO between 1990 and 2000; approximately 30 percent reported involvement with an organization whose primary focus was agriculture or environment (Pender et al. 2001b; Table A7). High levels of involvement in these grassroot organizations may be an opportunity for disseminating information about land use technologies.

One factor that could be hampering the use of agricultural technologies is conflicting messages from different programs and organizations involved in technical assistance. For example, some NGOs are promoting the use of inorganic fertilizer, whereas others argue that this will damage the soil (Bashaasha 2001). This example implies that decentralization and the extensive involvement of NGOs in technical assistance may preclude the promotion of coherent extension messages on such issues (Sserunkuuma et al. 2001). Decentralization may also affect enforcement of laws and bylaws related to natural resource management.[12] Poor enforcement of ordinances and bylaws may occur, because the level of awareness of such bylaws or their importance at the community level may be limited (Nkonya et al. 2001). Additionally, local councilors may be reluctant to pursue rigorous enforcement of by-laws, for fear of political repercussions (APSEC 2001).

### Land Tenure

Land tenure security can influence land management, because it may affect farmers' incentive or ability to invest in land

[11]NGOs are registered organizations established to provide services to communities or districts. They include both international and indigenous organizations. They are autonomous, but are required to conform to the government's regulatory requirements stipulated in their registration conditions. CBOs are organizations that evolve and are administered, financed, and managed at the local level. CBOs are not required to register with the government.

[12]As pointed out by an anonymous reviewer, many environmental laws and bylaws were enacted in Uganda before decentralization. However, enforcement of these laws may be affected by the decentralization.

improvements. Farmers holding land under insecure tenure are less likely to invest in such long-term investments as building soil and water conservation structures and planting trees. Land tenure may also affect farmers' access to credit (affecting their ability to invest) (Feder et al. 1988; Place and Hazell 1993), and their ability to lease or sell land (affecting incentives to invest) (Pender and Kerr 1999).

In Uganda, there are four major land tenure systems that are recognized by the Land Act of 1998. These are the customary, freehold, leasehold, and *mailo* land tenure systems (Republic of Uganda 1998). Customary land tenure is a traditional land holding system that is governed by the customs, rules, and regulations of the community. This is the most common land tenure system in Uganda (Baland et al. 1999; NEMA 2001). Holders of land under the customary system do not have a formal land title, but generally have secure tenure. Under this tenure, land is divided among clans, which in turn divide it among households. Households holding land under customary tenure are granted an indefinite tenancy, but they are expected to bequeath land to their children (Baland et al. 1999). This is likely to create a strong sense of ownership, security, and continuity; but it also contributes to land fragmentation, as such land is subdivided among children from generation to generation. Customary land tenure also has some restrictions that are imposed and enforced by clan leaders and elders. These restrictions are likely to affect land management. For example, landowners may not sell their parcels without consultation with clan leaders and family members.

Freehold tenure is a system whereby landowners hold registered land indefinitely. The landowner is allowed to use the land in any manner consistent with the laws governing land use in Uganda. This type of tenure also provides landholders with complete rights, including rights to use, sell, lease, transfer, subdivide, mortgage, or bequeath the land as the owner sees fit (Republic of Uganda 1998). Hence, this tenure system is supposed to confer the most rights and security. The Land Act of 1998 (Republic of Uganda 1998) requires that all freehold landholders acquire a title to remove doubts and tenure insecurity. However, because land titling is expensive—requiring cadastre expertise—only a few farmers have land titles under freehold tenure.

The third tenure system is leasehold tenure, under which, the owner grants the tenant exclusive possession of land, usually for a specific period of time. In return, the tenant usually pays rent or service under specified terms and conditions that vary widely (Republic of Uganda 1998). This category of tenure includes leasehold contracts with formal land titles and those that do not have such formal agreements. Because the terms and conditions vary widely, it is not easy to generalize the land rights and security held by tenants under leasehold. However, the length of the lease is likely to be strongly correlated to rights and security; that is, holders of short-term leases have fewer rights and their tenancy is less secure. For example, landlords always forbid short-term lease landholders to make long-term investments, such as planting trees or perennial crops and building houses. However, during the lease, landholders are usually allowed to sublet, bequeath, mortgage, or use the land as collateral for loan applications (ULA 2000).

The leasehold and freehold tenure systems are the least common (UBOS 2001), but are increasingly being implemented in peri-urban areas. Wealthy urban elites are buying more land in peri-urban areas to develop or use it as collateral for loans and speculation. Buying land for speculation has created a high percentage of absentee landlords (Barrows and Roth 1989).

The fourth land tenure system is *mailo,* which was established in 1900 by the British colonial government, when it gave legal land titles to the royal family (*Kabaka*) and other nobles. The tracts of land allocated to the nobles were so large that they had to be measured in square miles (*mailo;* hence the name of this tenure system). The landlords then divided their land into smaller parcels (*kibanja*) that were rented out to tenants (*bakopi*). In addition to the annual land rent, the *bakopi* were required to pay a tribute (*envujjo*) in the form of beer, crops, or, in a few cases, money (NEMA 2001). The rent and tribute payments entitled the tenants to cultivate crops, plant trees, and reside on the *mailo* land. The tenants were also allowed to bequeath their parcel to their children, but were not allowed to sublet the parcels. However, there were some restrictions, such as tenants were not allowed to plant more than 0.4 hectares of coffee or grow cotton on *mailo* land. The tenants also were not allowed to cut and sell trees for profit. This provision included even the trees that the tenants might have planted on the parcel. However, the *mailo* tenure also had provisions that protected the tenants from arbitrary eviction: *mailo* owners were not allowed to evict tenants unless such eviction was in the interest of the public or was sanctioned by court order, or both. In cases where the landlord decided to evict the tenant, he or she was required to compensate the tenant for investments that the tenant had made on the parcel (NEMA 2001).

The 1998 Land Act ensured further security for the *mailo* bona fide and lawful tenants[13] by giving them or their successors freehold status for all parcels held since 1986. Tenure security of the customary land holders was also enhanced by the Land Act, as it recognizes the laws and regulations governing customary tenure and provides for conversion of land from customary to freehold status (subject to approval by the District Land Boards created by the Land Act). The 1998 Land Act also requires land holders to manage their land in observance of the Forest Act, National Environmental Statutes, Water Statutes, Uganda Wildlife Statute, Mining Act, Town and Country Planning Act, and any other laws related to land use (NEMA 2001). Most of these provisions are aimed at enhancing resource and environmental conservation. However, these laws are weakly enforced, which is one of the shortcomings of the Land Act. The Land Act also lacks a clear policy on equitable access to land among family members (NEMA 2001; Gashumba 2001).

### Policy Reforms

Some of the factors discussed so far that underlie land degradation are related to specific government policies. The discussion in this section therefore focuses on a review of the broader policies that resulted in some of the specific policies discussed above, as well as other policies. Since 1986, when the Museveni regime came into power, there has been a series of policy reforms that may have affected land management. The policy changes implemented by the Museveni government addressed two major challenges: peace and security, and poverty (Collier and Reinikka 2001). Uganda experienced a series of civil wars from 1971 to 1986. Therefore, the new government was first and foremost preoccupied with building up political stability and security, and initially much less concerned with economic recovery. A recent study by Pender et al. (2001b) observed that peace and security have been improving in Ugandan communities since 1990. This has helped to win back the confidence of investors and producers.

Major economic reforms in Uganda started in 1993, when the government agreed to implement a second phase of its structural

[13]A bona fide person is one who, before the Land Act of 1998, had occupied and utilized or developed any land unchallenged by the registered owner for 12 or more years or was settled on the land by the government. A lawful occupant is one who holds land by virtue of the repealed Buganda, Ankole, and Tororo land laws or who has entered into an agreement with a registered owner to occupy the land (Republic of Uganda 1998).

adjustment program (SAP II) under the auspices of the International Monetary Fund (IMF) and the World Bank. This led to the liberalization of marketing of export and other crops. The government also withdrew most of its subsidies for crops, farm inputs, and credit provision. Exchange and interest rates were liberalized. Consequently, participation of the private sector in agricultural marketing and the establishment of civil society increased tremendously.

The major policy reforms that may have affected land management in Uganda are summarized in four major categories: agricultural policy reforms, international trade and financial sector reforms, trade liberalization and privatization, and decentralization (APSEC 2001; Balihuta and Sen 2001). We discuss these policies in turn. However, we do not discuss decentralization further, as it has already been discussed above.

*Agricultural policy reforms.* The major agricultural policy reforms are the agricultural market liberalization that was implemented in the 1990s and the Plan for Modernization of Agriculture (PMA) (MAAIF and MFPED 2000) that was launched in 2000. In the 1990s, several public institutions were restructured or divested to conform to the general policy reforms.[14] The reforms were geared toward enhancing the growth of the private sector and reducing the role of the public sector in production and marketing. One major institutional reform that is likely to have affected land management is the divestiture or total abolition of crop-marketing boards. For instance, the Coffee Marketing Board and the Lint Marketing Board were both abolished, paving way for the more efficient private sector.[15] The Production Marketing Board, which was responsible for food-crop marketing control, was also abolished. Consequently, participation of the private sector in agricultural input and output trading increased significantly (Balihuta and Sen 2001; Nkonya 2002). Due to the market liberalization, the farmers' share of the international prices of major traditional export crops increased from 30 percent to about 79 percent (Balihuta and Sen 2001).[16] Undoubtedly, these changes impacted land management, because they affect production incentives.

The PMA is a holistic, strategic framework that is part of Uganda's poverty eradication action plan (PEAP). The PMA's vision is poverty eradication through a profitable, competitive, sustainable, and dynamic agricultural and agro-industrial sector. The mission of the PMA is eradicating poverty by transforming agriculture from a subsistence to a commercial orientation. To achieve its mission, the PMA is working toward facilitating the creation of an efficient, competitive system for the processing and marketing of agricultural commodities and developing rural financial markets and rural infrastructure—roads, communication links, and electrification. Other PMA areas of focus are the development of high-yielding and labor-saving technologies, and diversification of agricultural exports through the production of nontraditional, high-value commodities for export. The overall impact

[14]Since 1993, 93 public companies were divested or liquidated. By 2000, only 46 public enterprises were yet to be privatized. The public enterprise reforms have resulted in increased revenue collection, employment, income, and productivity (MFPED 2001).

[15]The government formed public organizations aimed at providing public marketing and production services mainly for export crops. The organizations are also responsible for regulating and facilitating their respective crop marketing and production. Examples are the Uganda Coffee Authority, the Cotton Development Organization, the Uganda Tea Authority, and the Uganda Ginners and Cotton Exporters Association.

[16]However, falling world coffee prices retard this local price increase (Ponte 2002).

of a successful implementation of these policies is increased marketed agricultural surplus, which is likely to affect soil nutrient balances, as noted by Woelcke et al. (2002).

*International trade and financial sector reforms.* The government abolished or substantially reduced export taxes on crops and other goods. To compensate for the loss of revenue and provide protection for local products, the government increased the import tax (Collier and Reinikka 2001). However, in the late 1990s, the government reduced the import taxes to between 0 and 15 percent, making Uganda's tax rates one of the lowest in the SSA (Collier and Reinikka 2001). The import tax for such export commodity inputs as fertilizer, seeds, and agrochemicals was also removed. This may have contributed to the increased use of fertilizer that has been observed in the past decade (Pender 2001b) and has influenced the export volumes of coffee, cotton, and other crops. The changes in tax regimes also may have contributed to an increase in the number of private coffee exporters from a few in the early 1990s to over 100 in 2000 (Uganda Coffee Development Authority, unpublished raw data).

Foreign exchange liberalization in the early 1990s also implicitly reduced the tax rate hidden in the overvalued exchange rate of the local currency. This exchange rate liberalization is likely to have increased the competitiveness of export crops. The government also liberalized the financial sector by allowing private banks and foreign exchange bureaus to operate. MFIs were also allowed to operate; hence, likely increasing credit access among the rural farmers. To facilitate smooth functioning of private banks and MFIs, the government liberalized interest rates. The government also adopted an austerity budget to reduce the budget deficit, control the money supply, and reduce inflation and seignorage. The overall budget deficit fell from 14 percent of the gross domestic product (GDP) in 1992 to about 10.9 percent in 2000. These fiscal reforms reduced inflationary pressure and contributed to the reduction of interest rates (World Bank 1996; MFPED 2001). Following the austerity budget and other economic reforms, the government qualified for the World Bank–sponsored Highly Indebted Poor Countries (HIPC) debt relief program. This debt relief allowed the government of Uganda to use its savings on debt servicing to improve essential public services, such as schools and health services. These international trade and financial sector reforms are likely to have affected land management.

*Market liberalization and privatization.* The trade liberalization and divesture of public enterprises mentioned above opened up the economy to private investors, who improved the production and marketing efficiency in many sectors of the economy. Between 1993 and 1995, the number of new companies being formed grew at a rate of 33 percent. From 1991 to 2000, 2,021 private companies worth US$1.43 billion were licensed to operate in the country. The manufacturing sector accounted for 52 percent of these companies, whereas agriculture accounted for only 6 percent (UIA 2000). Most of the manufacturing industries are based on agriculture; hence, they create forward linkages to the agricultural sector (UIA 2000).

This chapter shows that, unlike the relatively well-understood proximate causes of land degradation, the impacts on land management of underlying socioeconomic and policy factors, such as population pressure, poverty, high cost of inputs, limited access to markets and infrastructure, and increased commercialization, remain unclear. Hence, there is a need for detailed analysis to provide a better understanding of these factors and their impacts on poverty alleviation, economic growth, and sustainable resource use. These relationships appear to be complex and context-specific, and the trade-offs among the potential outcomes are not well understood. Addressing these issues is a major methodological challenge. In the next chapter, we present our conceptual framework, empirical model, and hypotheses regarding the impacts of these underlying factors on farmers' income strategies and land management decisions; the outcomes of these decisions on agricultural productivity, land degradation, and poverty; and the methods used to study these relationships.

## CHAPTER 3

# Research Questions and Methodology

The key research questions for this study are:

- What are the dominant income strategies of households and their relationship to land management in the study region of Uganda?
- What factors determine the income strategies and land management practices of households? In particular, how do government policies, technical assistance programs, and other policy-relevant factors affect these decisions?
- What are the implications of alternative policies and programs for agricultural production, land degradation, and household income, considering their impacts on livelihoods and land management? What trade-offs or synergies among these outcomes are likely to result from alternative policy strategies?
- What factors determine the soil nutrient balances on farms (an indicator of land use sustainability)?

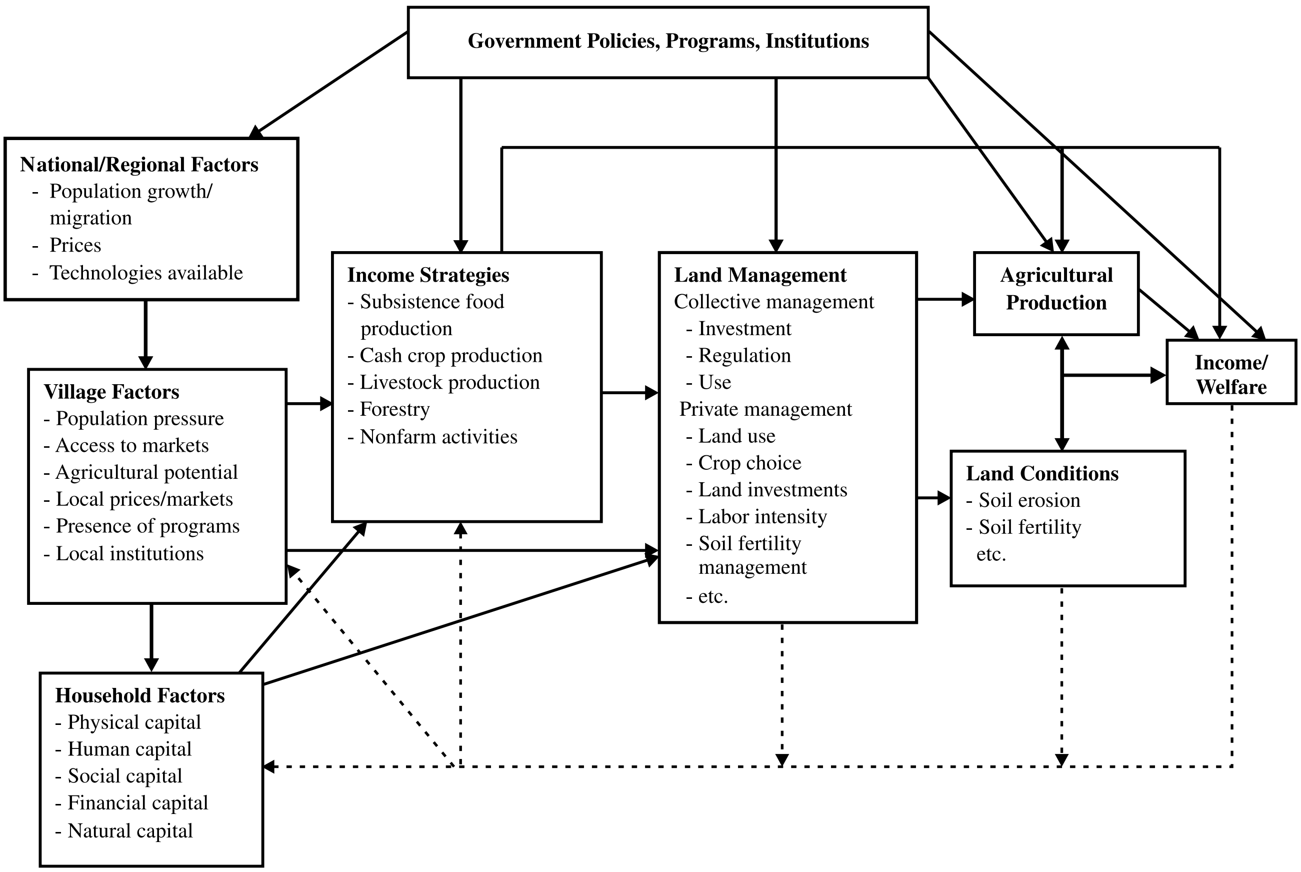
To address these questions, we have developed a broad conceptual framework to guide our development of hypotheses and choice of research methods.

## Conceptual Framework

Land management is determined by private decisions made by farm households and by collective decisions made by groups of farmers and communities (Figure 3.1). For example, farm households choose whether to fallow, what crops to plant, what investments to make, and how to manage soil fertility on their own land; but these decisions may be affected by regulations on land use set by local councils. Communities may also regulate the use of communal grazing areas or other common lands or may make collective investments in improving resources, such as planting improved grasses or trees. We focus on private land use and land management decisions of households; collective decisions are beyond the scope of this study.

Household and collective decisions determine current agricultural production and affect land resources (thus influencing future agricultural production), which, in turn, affect the level of farm income and household welfare. It is important to recognize that such outcomes (production, resource conditions, and household income)—not the adoption of specific land management practices per se—are likely to be of most concern to rural people and policy makers. It is thus critical to consider the ultimate impacts of any policy or program on these outcomes and the extent to which there may be trade-offs among these objectives. For example, a strict regulatory approach (for example, preventing farmers from planting annual crops on steep

**Figure 3.1 Factors affecting income strategies, land management, and their implications**




lands) may be effective in reducing soil erosion but may also have significant implications for agricultural production, food insecurity, and poverty. However, there may be "win-win-win" strategies available that promote greater production and incomes, as well as improve resource conditions.

Land management decisions are determined by many factors operating at different scales (plot, household, village, regional, national, and international). Many of these factors influence land management directly; for example, the type of soil, topography of the land, and the climate will have a large impact on whether soil erosion is likely to be a problem and what options are feasible to address it. Demographic and socioeconomic factors—such as population density and access to markets and infrastructure—also influence land management. Some of these effects are direct; for example, access to markets and roads may affect the profitability of alternative practices. But some effects are indirect. For example, population pressure leads to smaller farm sizes and often to more fragmented holdings, which may reduce farmers' ability or incentive to fallow or to invest in land improvements.

One important indirect way in which biophysical and socioeconomic factors affect land management is by determining which income strategies households pursue (Reardon and Vosti 1995). Income strategies are activities that households pursue to acquire income and goods; such strategies include subsistence production of food crops, production of perishable cash crops, livestock production, forestry, and nonfarm activities.[17] In this study, we seek to understand the relationships between such income strategies and land management decisions and the implications of both types of decisions.

Income strategies may be influenced by many village-level factors, such as agricultural potential, access to markets, and population density (Pender et al. 1999, 2001c). These factors largely determine the comparative advantage of a location by determining the costs and risks of producing different commodities; the costs of and constraints on marketing, local commodity, and factor prices; and the opportunities for and returns to alternative activities, such as farm vs. nonfarm employment.[18] These factors may have generalized village-level effects on income strategies, such as through their impact on village-level prices of commodities or inputs, or they may affect farm household-level factors, such as average farm size. Income strategies may also vary among households, because of differences in cultural experiences and preferences. If markets are imperfect, production decisions are not separable from consumption preferences (Singh et al. 1986; de Janvry et al. 1991); as a result, preference of a particular ethnic group for a certain type of staple food may greatly affect the agricultural production system, independently of considerations of profitability and comparative advantage.[19]

Such household-level factors as endowments of physical assets (for example, livestock and equipment), "human capital" (assets embodied in people's knowledge and abilities, such as education, experience, and training), "social capital" (assets embodied in social relationships, such as through participation in organizations or networks), "financial capital" (access to liquid assets, including credit and savings), and "natural capital" (assets embodied in natural resources, including the quantity and quality of land and access to other resources) may also determine the income strategy and land management practices pursued by particular households.

Government policies, programs, and institutions may influence income strategies

[17]This definition of income strategies is very similar to the definition of livelihood strategies offered by Ellis (2000, pp. 40–41), who defines livelihood strategies as the "activities that generate the means of household survival," including the collection of natural resource products (for example, forestry, fishing, mining), cultivation of food or nonfood commodities, livestock rearing; and activities not based on natural resources (for example, rural trade, services, manufacturing, remittances, other transfers). Other authors have provided broader definitions of livelihood strategies. For example, Adato and Meinzen-Dick (2002, p. 10) define livelihood strategies of individuals as "the choices they employ in pursuit of income, security, well-being, and other productive and reproductive goals." Such an all-encompassing definition would be difficult to use to test relationships between livelihood strategies and other concepts, such as land management. Thus we use the more narrow concept of income strategies.

[18]"Comparative advantage" refers to the profitability of the economic activities (or more broadly, income strategies) that a group of people may pursue, relative to other activities that could be pursued by that group (Stiglitz 1993, p. 61). Having a comparative advantage in a given activity does not imply that the group earns more profit from the activity than could other groups (that would be absolute advantage); rather, it means that the group profits more by pursuing that activity than other activities, and by trading with others who have comparative advantage in pursuing other activities. Comparative advantage can be defined for groups of different sizes at different scales (for example, nation, region, community, household, individual), although it is most commonly discussed at the national scale in discussions of trade theory and policy. In this study, we focus on comparative advantage of income strategies at the household level.

[19]Such differences may reflect variations in human and social capital across households, as well as differences in preferences. Choice of income strategy can also lead to differences in human and social capital, as the experience of households and their social interactions become influenced by the income strategies they pursue.

and land management and their implications for production, resource conditions, and household income at many levels. Macroeconomic, trade, and market liberalization policies affect the relative prices of commodities and inputs in general throughout a nation. Agricultural research policies affect the types of technologies that are available and suitable to farmers in a particular agroecological region. Infrastructure development, agricultural extension, conservation technical assistance programs, land tenure policies, and rural credit and savings programs affect awareness, opportunities, or constraints at the village and household levels. Policies or programs may seek to promote particular income strategies (for example, nontraditional export cash-crop production), or may seek to address constraints within a given income strategy (for example, credit needs arising from cash-crop production). Programs may attempt to address land management approaches directly; for example, by promoting particular soil fertility management practices. Policies and programs may also be designed to affect development outcomes directly, for example, through direct management of land by the government or through nutrition- or income-enhancement programs.

Currently available information does not provide policymakers with much guidance as to which of these intervention points will be most effective in achieving better land management, increasing agricultural production, ensuring sustainable use of resources, and increasing incomes and welfare. Much public action aimed at improving land management focuses on influencing household adoption of particular technologies. Yet this may be ineffective if the technologies are not suited to the income strategies that have potential in a given location, or it may miss opportunities for achieving larger impacts by focusing on other areas of intervention. Furthermore, the trade-offs of different interventions in their impacts on development outcomes need to be assessed. The methodology developed in this study seeks to help address these information gaps in the context of rural Uganda.

In the next section, we present the empirical model[20] that is used to investigate relationships among the causal factors, responses and outcomes in this conceptual framework.

## Empirical Model

The key outcomes of interest in this study are agricultural production, land degradation, and household income. We consider the proximate causes of each of these, including household choices regarding income strategies, land management, and other decisions, and the underlying determinants of these choices.

### Value of Crop Production

For agricultural production, we focus on the value of crop production. We assume that the value of crop production by household $h$ on plot $p$ ($y_{hp}$) is determined by the vector of shares of area planted to different types of crops ($C_{hp}$); the amount of labor used ($L_{hp}$); the vector of land management practices used ($\mathbf{LM_{hp}}$); the natural capital of the plot ($\mathbf{NC_{hp}}$), including its biophysical characteristics and presence of land investments; the tenure characteristics of the plot ($\mathbf{T_{hp}}$); the household's endowments of physical capital ($\mathbf{PC_h}$), human capital ($\mathbf{HC_h}$), and social capital ($\mathbf{SC_h}$); the household's income strategy ($\mathbf{IS_h}$); village level factors that determine local comparative advantages, including

[20]This empirical model is derived from a theoretical dynamic household model, which is presented in Appendix B to limit the mathematical details in the main body of this report.

agro-ecological conditions, access to markets and infrastructure, and population density ($\mathbf{X_v}$); and random factors ($u_{yhp}$):[21]

$$y_{hp} = y(\mathbf{C_{hp}}, L_{hp}, \mathbf{LM_{hp}}, \mathbf{NC_{hp}}, \mathbf{T_{hp}}, \mathbf{PC_h}, \mathbf{HC_h}, \mathbf{SC_h}, \mathbf{IS_h}, \mathbf{X_v}, u_{yhp}) \quad (1)$$

Equation (1) is not strictly a production function, since we are focusing on the value, not quantity, of production. We do this because many different crops are produced in Uganda, often on the same plot, making estimations of single-crop production functions difficult. The value of crop production depends on the choice of crops and the farm-level prices of these crops, the inputs and land management practices used in producing them, and the natural conditions of the plot. Because the choice of crops planted varies among households and regions in Uganda, we do not explicitly include crop prices as determinants of the value of crop production. Instead, we assume that farm-level prices are determined by village-level factors determining local supply, demand, and transportation costs of commodities ($\mathbf{X_v}$) and household-level factors affecting transactions costs and marketing abilities ($\mathbf{HC_h}$, $\mathbf{SC_h}$, $\mathbf{IS_h}$).

Household endowments of physical capital ($\mathbf{PC_h}$) can also affect crop production if there are imperfect factor markets. For example, if there are imperfect land and oxen rental markets, households with greater endowments of oxen per unit of land may be able to attain higher productivity than can other households. In addition, agro-ecological conditions (part of $\mathbf{X_v}$), the human and social capital of households and their experience, as reflected by particular income strategies, may also influence agricultural productivity, even if these factors had no impact on local prices.

As noted in Chapter 2, land rights and tenure characteristics ($\mathbf{T_{hp}}$) may influence crop production by affecting tenure security, land marketability, land values, and/or access to credit, hence affecting farmers' incentive and ability to invest in land improvements or to apply inputs (Feder et al. 1988; Place and Hazell 1993; Besley 1995; Pender and Kerr 1999). Land tenancy may also affect incentives to apply labor or other inputs by affecting the marginal return that households receive from their efforts in the case of sharecropping (Shaban 1987; Otsuka and Hayami 1988), or by increasing the need for short-term returns to be able to pay land rental costs. Many of these effects will be reflected in impacts on labor use, land investments, and land management practices. Thus, tenure may have no impact on the value of crop production, after controlling for these inputs and practices. However, there may also be effects on the productivity with which such inputs and practices are used; we investigate this possibility.

### Crop Choice, Labor Use, and Land Management

In equation (1), crop choice, labor use, and land management are all choices in the current year,[22] determined by the natural capital and tenure of the plot; by the household's

[21]In Appendix B, $\mathbf{T_{hp}}$ is included as part of $\mathbf{NC_{hp}}$ and $\mathbf{IS_h}$ is part of $\mathbf{HC_h}$, for notational convenience. Here we indicate these variables separately, to emphasize their presence in the empirical model, because we test hypotheses about the impacts of these variables. Also in Appendix B, the household subscripts (*h*) are not included, because the theoretical model is developed by considering one particular household. Those subscripts are included in the empirical model, because the model is to be applied using cross-sectional data from different households. The time subscripts in the theoretical model are not included in the empirical model, for analogous reasons.

[22]"Crop choice" refers to choice of type and area of crop to plant. Planting of perennial crops is treated as an investment, and we treat the share of area already planted to perennial crops at the beginning of the current year as part of the natural capital stock of the plot (as that is defined to include the stock of land investments).

endowments of physical, human, social, and financial capital and of family labor ($L_{fh}$) at the beginning of the year; by the household's income strategy; and by agro-ecological conditions, access to markets and infrastructure, and population density ($\mathbf{X_v}$):[23]

$$\mathbf{C_{hp}} = C(\mathbf{NC_{hp}}, \mathbf{T_{hp}}, \mathbf{PC_h}, \mathbf{HC_h}, \mathbf{SC_h}, \mathbf{FC_h}, \mathbf{IS_h}, L_{fh}, \mathbf{X_v}) \quad (2)$$

$$L_{hp} = L(\mathbf{NC_{hp}}, \mathbf{T_{hp}}, \mathbf{PC_h}, \mathbf{HC_h}, \mathbf{SC_h}, \mathbf{FC_h}, \mathbf{IS_h}, L_{fh}, \mathbf{X_v}) \quad (3)$$

$$\mathbf{LM_{hp}} = LM(\mathbf{NC_{hp}}, \mathbf{T_{hp}}, \mathbf{PC_h}, \mathbf{HC_h}, \mathbf{SC_h}, \mathbf{FC_h}, \mathbf{IS_h}, L_{fh}, \mathbf{X_v}) \quad (4)$$

Most of the determinant factors in equations (2)–(4) are either exogenous to the household (for example, $\mathbf{X_v}$) or are state variables that are predetermined at the beginning of the current year (for example, $\mathbf{NC_{hp}}$, $\mathbf{T_{hp}}$, $\mathbf{PC_h}$, $\mathbf{HC_h}$, and $\mathbf{FC_h}$). However, some of the factors, including income strategies ($\mathbf{IS_h}$) and participation in programs and organizations ($\mathbf{SC_h}$), may be at least partly determined in the current year, and hence partly endogenous to current decisions about crop choice, labor use, and land management. Thus, we need to consider how these variables are determined.

### Income Strategies and Participation in Programs and Organizations

Because changes in income strategies usually require time and investments in human and social capital (for example, the development of new skills and investments in developing market connections are needed to shift from subsistence to cash-crop production), and because these investments are irreversible (the costs of these investments cannot be recouped by selling human or social capital), changes in income strategies usually do not occur rapidly (Dixit and Pindyck 1994). The retarding effect of irreversibility is even more pronounced when credit markets are imperfect and indivisible investments are required, because households may be unable or very slow to self-finance such investments (Fafchamps and Pender 1997). As a result, households may become locked-in to a particular income strategy, even when more remunerative strategies could be pursued as a result of profitable investments in human and social capital.

These considerations suggest that household income strategies are not determined solely by current asset levels and market opportunities. There is likely to be a substantial degree of inertia, or "path dependency," in the choice of income strategies, regardless of how market opportunities may be changing. Furthermore, in the context of imperfect markets and high transaction costs, income strategies depend on household consumption preferences, as noted above. Thus, we assume that current income strategies are determined by fixed cultural factors, reflected by the ethnicity of the household ($\mathbf{Eth_h}$), which may influence consumption preferences and some aspects of social and human capital, as well as the labor, human, and natural capital available and factors determining local comparative advantages:[24]

[23]The specification of equations (2)–(4) is derived in Appendix B.

[24]We also could assume that current income strategies depend on past income strategies, to account for path dependence in such strategies. Investigation of such an empirical model revealed that the income strategies pursued 10 years in the past are very strong predictors of current income strategies, to such an extent that statistical estimation of the multinomial logit model for income strategies was not feasible in this case, because too many outcomes were completely determined. Although this demonstrates the importance of path dependence, this model is of limited usefulness in assessing the importance of other determinants of income strategies. Thus, we decided to use the specification in equation (5), which explains such strategies as determined by fixed or relatively slowly changing factors, recognizing that the impacts of such factors may not be on the current income strategy independently of the past income strategy. Rather, these factors may have determined the income strategy in the past, and this may not have changed for some time.

$$\mathbf{IS_h} = IS(\mathbf{Eth_h}, L_{fh}, \mathbf{HC_h}, NC_h, \mathbf{X_v}) \quad (5)$$

We assume that current social capital, as indicated by participation in programs and organizations, depends on the same set of factors:

$$\mathbf{SC_h} = SC(\mathbf{Eth_h}, L_{fh}, \mathbf{HC_h}, NC_h, \mathbf{X_v}) \quad (6)$$

The determinants of value of crop production will be estimated using the structural model represented by equation (1), as well as in reduced form. The reduced form is obtained by substituting equations (2)–(6) into equation (1):

$$y_{hp} = y'(\mathbf{NC_{hp}}, \mathbf{T_{hp}}, \mathbf{PC_h}, \mathbf{HC_h}, \mathbf{FC_h}, L_{fh}, \mathbf{X_v}, \mathbf{Eth_h}, u_{yhp}) \quad (7)$$

Similarly, the reduced forms for determinants of crop choice, labor use, and land management are obtained by substituting equations (5) and (6) into equations (2)–(4), and depend on the same explanatory factors as in equation (7).

### Household Income

Household income is the sum of income from crop production, livestock production, net wage income (income from labor hired out minus costs of labor hired in), net income from leasing out other assets (for example, land and equipment), income from nonfarm activities (for example, trading, selling handicrafts, beer brewing, making bricks, selling poles or charcoal), and transfers. Decisions about allocation of labor and other assets to these different activities determine the household's income. Those decisions depend upon the same factors that determine labor allocation decisions in crop production; that is, the household's income strategy, its endowments of labor, physical, human, natural, social, and financial capital, and the factors determining local comparative advantage (agro-ecological conditions, access to markets and roads, and population density).[25] Thus, household income depends upon those same factors:

$$I_h = I(NC_h, T_h, \mathbf{PC_h}, \mathbf{HC_h}, \mathbf{SC_h}, \mathbf{FC_h}, \mathbf{IS_h}, L_{fh}, \mathbf{X_v}, u_{Ih}) \quad (8)$$

The main difference between the explanatory factors in equation (8) and those in equations (2)–(4) is that household income depends on the household's entire endowment of natural capital ($NC_h$) and the tenure characteristics of all land operated by the household ($T_h$), rather than the natural capital and tenure characteristics of a specific plot ($\mathbf{NC_{hp}}$ and $\mathbf{T_{hp}}$). In the empirical specification, we use the shares of the land operated by the household having different soil quality and tenure characteristics as measures of $NC_h$ and $T_h$. Income also depends on random factors ($u_{Ih}$). As with the value of crop production, the reduced form for income will be estimated, as well as the structural model in equation (8).

### Soil Erosion

Many of the factors determining the value of crop production also are expected to influence land degradation. For example, we assume that erosion on a given plot ($e_{hp}$) is determined by crop choice, land management practices, labor use, the natural capital of the plot, agro-ecological conditions, and random factors:

$$e_{hp} = e(\mathbf{C_{hp}}, L_{hp}, \mathrm{LM_{hp}}, \mathbf{NC_{hp}}, \mathbf{X_v}, u_{ehp}) \quad (9)$$

Because we have not been able to measure erosion on the plots studied in this research, we use predicted erosion based on the revised universal soil loss equation (RUSLE), calibrated to soil conditions in Uganda (Renard et al. 1991; Tukahirwa 1996; Lufafa et al. 2003; Majaliwa 2003; Mulebeke 2003). The RUSLE estimates

[25] These decisions and their dependence on the factors mentioned are elaborated in Appendix B.

annual soil loss based on several factors, including rainfall intensity, soil erodibility, topography (slope, slope length and curvature), land cover, and land management practices. The RUSLE model is deterministic, providing deterministic predictions of erosion. As such, it is not so useful in estimating the statistical relationships between land management practices and actual erosion, as specified in equation (9). However, the predictions of RUSLE can be useful in estimating the relationships between underlying socioeconomic and biophysical factors that determine land management and hence, affect erosion. Substituting equations (2)–(4) into equation (9), and assuming that the error term is additive,[26] we have the following expression for erosion:

$$e_{hp} = e'(\mathbf{NC_{hp}}, \mathbf{T_{hp}}, \mathbf{PC_h}, \mathbf{HC_h}, \mathbf{SC_h}, \mathbf{FC_h}, \mathbf{IS_h}, L_{fh}, \mathbf{X_v}) + u_{ehp} \quad (10)$$

Suppose that actual erosion is equal to erosion predicted by RUSLE ($e^p_{hp}$) plus a randomly distributed error term:

$$e_{hp} = e^p_{hp} + v_{ehp} \quad (11)$$

Then substituting equation (11) into equation (10), we have:

$$e^p_{hp} = e'(\mathbf{NC_{hp}}, \mathbf{T_{hp}}, \mathbf{PC_h}, \mathbf{HC_h}, \mathbf{SC_h}, \mathbf{FC_h}, \mathbf{IS_h}, L_{fh}, \mathbf{X_v}) + u_{ehp} - v_{ehp} \quad (12)$$

Thus, we can estimate equation (10) using equation (12), as long as the prediction error ($v_{ehp}$) is not correlated with the explanatory factors. We maintain this as an assumption, recognizing that violation of this assumption would lead to biased estimates of the parameters in equation (10). Data for actual erosion rates are needed to test this assumption; this would be a useful topic for future research.[27]

### Soil Nutrient Depletion

In addition to investigating the determinants of erosion, we also investigate the severity and determinants of soil nutrient depletion using soil nutrient balances. Soil nutrient balance is defined as the balance of inflows of soil nutrients minus the outflows in a given period (Stoorvogel and Smaling 1990; Wortmann and Kaizzi 1998). Soil nutrient depletion can be measured by determining the amount of nutrients removed from the soil as a proportion of the nutrient stock in the soil. However, we do not have reliable estimates of the nutrient stock in the soils where this study was conducted, so we focus on the soil nutrient balance as the indicator of depletion.

To understand the economic impact of soil nutrient depletion, the consequent agricultural productivity loss needs to be determined. However, we are not aware of any study that has measured agricultural productivity loss due to soil nutrient depletion in Uganda. Given this limitation, we use a simpler measure, called the "economic nutrient depletion ratio" (ENDR) (der Pol 1993). ENDR is defined as the share of farmers' income derived from mining soil nutrients. This is a measure of the economic cost—not the benefit—of avoiding nutrient depletion.

If farmers are not fully investing in preventing soil nutrient depletion, this suggests that the benefits are less than the costs of doing so; thus, the ENDR may be an overestimate of the benefits of avoiding nutrient depletion (or equivalently, the costs of depletion). This could be the case if current soil

[26]In the empirical work, we use the logarithm of erosion as the dependent variable; thus the assumption that the error term in equation (10) is additive is equivalent to assuming a multiplicative error in the extent of erosion. This assumption is consistent with the multiplicative form of the RUSLE.

[27]In discussing our results in Chapter 4, we refer to estimated impacts on "predicted erosion," to emphasize that we are not sure that these are impacts on actual erosion.

nutrient stocks are high and depletion has little impact on productivity. However, there are several reasons why farmers may fail to invest in soil nutrients, even if the benefits exceed the costs.

One reason is that farmers may not be aware of the impacts of soil nutrient depletion on future productivity. This is quite plausible, given that soil scientists and agronomists do not adequately understand the dynamics of soil nutrient depletion and its impacts on productivity (H. van Keulen, pers. comm.). There may be nonlinear responses to nutrient depletion, in which little impact on productivity is observed until depletion passes some critical threshold, beyond which productivity falls precipitously, and farmers may not be aware of such threshold effects.

Even if farmers are aware of the impacts of future productivity losses, they may not be able to invest due to cash and credit constraints. Such constraints can cause poorer farmers to heavily discount the future (Pender 1996), undermining their investments. The retarding effect of credit constraints is especially severe for irreversible investments (including many investments in soil conservation or fertility improvement) in the presence of uncertainty about future benefits (Fafchamps and Pender 1997), due to imperfect land markets (Pender and Kerr 1999). Even if there are no credit constraints, irreversibility and uncertainty imply that economically rational investors may not invest, even when the expected present value of benefits exceeds the costs, due to the "option value" of waiting for uncertainty to be resolved (Dixit and Pindyck 1994).

Considerations of credit constraints, irreversibility of investment, and uncertainty imply that the economic benefits may exceed the costs of avoiding nutrient depletion (or equivalently, the economic costs may exceed the benefits of allowing depletion), as measured by the ENDR, even if farmers are not investing and are economically rational. Further research to attempt to quantify the economic costs of soil nutrient depletion would be valuable; however, such research is beyond the scope of this study.

Soil nutrient balances may be computed at different scales, starting from the plant level and moving through the plot, household, watershed, village, district, national, regional, and international levels (Stoorvogel et al. 1993). The most common scale used by soil scientists is the household level (de Jager et al. 1998; Wortmann and Kaizzi 1998), as this is an important level for storing and transferring nutrients, as well as making farm management decisions (Defoer et al. 2000). The time interval commonly used for computing rates of nutrient flow is one year, because this period completes the seasonal and crop production cycles (Defoer et al. 2000). We therefore use this convention of estimating the soil nutrient balance at the household level for one year (2000).

Nutrient balance at the household level is an aggregation of balances at the plot level; that is, the amount of nutrients added less nutrients removed from each plot. In addition to plot-level nutrient balances, household-level nutrient balance also takes into account the nutrient flows that are not plot-specific; for instance, flows of feed nutrients to livestock. The sources of nutrient inflows and outflows used in this study are from Smaling et al. (1993) and de Jager et al. (1998). The plot-level nutrient inflows are fertilizers, organic inputs, atmospheric deposition, biological nitrogen fixation, and sedimentation. The organic inputs include any biomass applied to the plot.

The plot-level nutrient outflows are harvested crop products, leaching, erosion, removal of crop residues, trees, shrubs and other noncrop biomass, and gaseous losses. The inflows that take place at household level are purchased or donated food (crop or animal products), grazing animals outside the farm, and purchased animal feeds and concentrates. The outflows that take place at household level are sales or donation of crops, animals, and their products; exportation of manure and crop residues, including trees and other biomass transferred out of the household; and grazing animals from other households on the study household's land.

As with plot-level outflows, nutrient outflows that take place at household level also affect soil nutrient availability, because such nutrients are not available for recycling as organic inputs to crop plots. For example, soil nutrients contained in food sold or donated leaves the farm and hence, are unavailable for recycling in plots. This reduces the soil nutrient stock for crop production. However, the impact of household-level soil nutrient inflows on soil nutrients is not always clear, as it depends on how these inflows are applied. It is generally assumed that soil nutrients contained in waste from food, feeds, forage, fiber, and other biomass imported into the household will be disposed on homestead plots and other crop plots close to the homestead. Household waste includes human waste; animal manure; sweepings; and waste collected from in and around the house, such as ashes from fuelwood and other cooking energy sources, food leftovers, and bran from pounded cereal. However, not all such household waste is applied to crop plots. For example, human waste deposited in deep-pit latrines will not be available for recycling to crop production. We accounted for this in our estimation of nutrient flows by assuming human waste does not contribute to soil nutrient inflows when households have such structures. In our survey, however, only 15 percent of households reported having structures for human waste disposal. Likewise, the estimated contribution of other types of household waste depended on how farmers managed such wastes.

For the case of livestock waste, we asked farmers to report how they graze, feed, and rest their animals. Farmers reported the duration and location of animal grazing and resting. Farmers were also requested to report the type of forage and feeds that their animals eat. This information was used to compute the amount of organic manure and urine deposited on plots belonging to respondents and on neighboring plots.

Strictly speaking, the soil nutrient balance analyzed in this research and many others is a partial nutrient balance, because it considers only the major nutrient flows (nitrogen [N], phosphorus [P], and potassium [K]). There are many other soil nutrient flows at the farm level, and an attempt to measure all of them would be an endless and costly process. Therefore, soil scientists compute nutrient fluxes and balances using the major inflows and outflows that capture a large proportion of the total soil nutrient flows (Defoer et al. 2000). In some cases (for example, leaching, atmospheric deposition), the flows could not be measured, and we estimate such flows using the range of values in the literature for conditions similar to those found in Uganda. Such estimates, although imperfect, are expected to be close to the total soil nutrient balances and thus adequate for determining the rate of nutrient depletion of a production system (Defoer et al. 2000).

The soil nutrient study is based on a study of 58 maize-producing households in eastern Uganda. Because the sample for our investigation is much smaller than that used for the other analyses discussed above, a more parsimonious specification of the regression model was used. Our analysis of the determinants of nutrient flows focuses on inflows and outflows that the farmer controls, omitting those that the farmer cannot significantly influence.

The inflows that the farmer controls are mineral fertilizers, organic inputs from outside the farm, animal feeds and concentrates, external grazing, purchased food, and biologically fixed nitrogen obtained by planting legumes. The controlled nutrient outflows are harvested crop products, erosion, animal products, crop residue, and exported manure. The determinants of the overall nutrient balances for the major macronutrients (N, P, and K) are also analyzed, to measure the sustainability of land management practices. We give a complete description of how each of the inflows and outflows was measured in the research method section.

The explanatory variables used in this analysis are similar to those discussed in the previous section. We include the village-level factors of agricultural potential and market access.[28] The household assets included are farm size and size of livestock herd (measured in tropical livestock units [TLU]). The human capital variables are education and family labor. Contact with extension services was included as the measure of access to technical assistance. The average distance of the plots to the residence was included as a measure of land fragmentation.

We also included two other variables, namely, income strategy (primary activity of household head) and crop biodiversity (number of crops grown).[29] To minimize the number of variables, we divided the income strategies into only two categories: farm and nonfarm activities. As discussed earlier, income strategies may have a large impact on land management, which, in turn, has a significant influence on nutrient flow. Crop diversity is one of the variables found in other studies to significantly influence nutrient flows (Keeney 1982; Bruce et al. 1991; Giller et al. 1997; de Jager et al. 1998). For example, inclusion of legumes in a cereal plot fixes atmospheric nitrogen, reduces nitrate losses, whereas deep-rooted crops and cover crops reduce nitrate leaching (Keeney 1982; Bruce et al. 1991). Farmers who practice intercropping are also more likely to have better soil coverage than those who practice monocropping. For example, in Uganda, farmers growing perennial crops (coffee and banana) tend to plant companion crops, which improve soil cover, which, in turn, reduces soil erosion. Similarly, in the maize-cropping system that we studied in eastern Uganda, farmers normally intercrop maize with legumes, which provide better soil cover and fix atmospheric nitrogen. Intercropping is also likely to include shallow and deep-rooted crops. Deep-rooted crops reduce leaching (Keeney 1982; Bruce et al. 1991). We did not collect data on cropping density, because this is difficult to measure, given that most farmers do not plant in rows and that they intercrop many crops on one plot. Because we used only 58 observations in the soil nutrient balance case study, we did not control for the type of crops planted, as this would have introduced many additional variables, using up precious degrees of freedom.

We use the same explanatory variables to estimate the determinants of nutrient flows and balances:

$$\text{In}_i = f(\mathbf{x_1 b_1} + e_1) \tag{13}$$

$$\text{Out}_i = f(\mathbf{x_2 b_2} + e_2) \tag{14}$$

$$\text{Nutbal}_i = f(\mathbf{x_3 b_3} + e_3) \tag{15}$$

Where:

$\text{In}_i$ is *i*th source of nutrient inflow; namely, chemical fertilizer, organic fertilizer, external grazing, purchased food, and biological nitrogen fixation (BNF);

$\text{Out}_i$ is *i*th channel of nutrient outflow; namely, crop harvest, animals from other farmers grazing in household plots, crop residues exported out of the household, soil erosion, and animal manure exported;

$\text{Nutbal}_i$ is balance of the *i*th nutrient; namely, N, P, K, and total nutrient balance (NPK);

[28]Because our sample for this analysis is small, we did not include the population density, as we thought its effect would be captured in the farm-size variable; that is, farmers living in densely populated areas would have smaller farms.

[29]Biodiversity is manifested by the variety of living organisms found in a given place at a given time (Mugabe 1998).

$\mathbf{x}_i$ is column vector of factors that affect nutrient flow and their balances;
$\mathbf{b}_i$ is the associated row vector of coefficients; and
$e_i$ is the error term for the *i*th nutrient flow or balance.

## Research Hypotheses

A very large number of hypotheses could be suggested and tested concerning the complex set of relationships illustrated in Figure 3.1 and equations (1)–(15). We do not attempt to discuss all of the possible relationships, but focus on the impacts of several policy-related factors on the decision variables (income strategy, crop choice, labor use, and land management practices) and outcomes (value of crop production, income, and land degradation) in this system. The causal factors considered include agro-ecological zones, access to markets and roads, population pressure and farm size ($\mathbf{X_v}$ and part of $NC_h$), access to irrigation (part of $\mathbf{NC_{hp}}$), access to credit ($\mathbf{FC_h}$), participation in technical assistance programs (part of $\mathbf{HC_h}$) and organizations ($\mathbf{SC_h}$), land rights and tenure ($T_h$), education (part of $\mathbf{HC_h}$), and physical assets, such as livestock and equipment ($\mathbf{PC_h}$).

### Agro-Ecological Zones

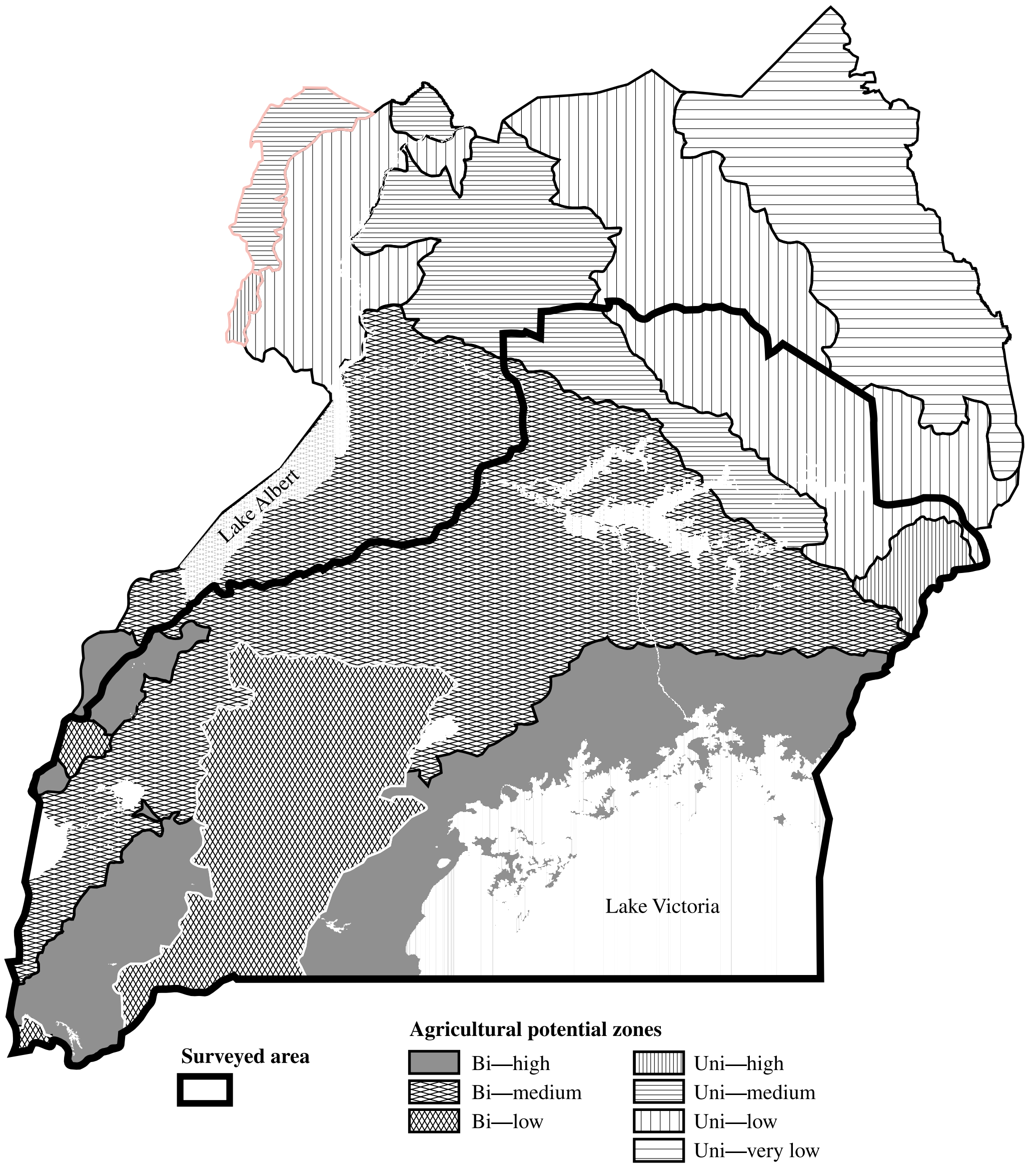
For the research project of which this study is a part, Ruecker et al. (2003) classified the agro-climatic potential for perennial crop (banana and coffee) production in Uganda, based on the average length of growing period, rainfall pattern (bimodal vs. unimodal), maximum annual temperature, and altitude (Figure 3.2). Potential for maize production was also mapped, and the maps were found to be very similar. Thus, the zones in Figure 3.2 are representative of agro-climatic potential for the most important crops in Uganda.[30] Seven zones were identified: the high-potential bimodal rainfall area at moderate elevation near Lake Victoria (the "Lake Victoria crescent"), the medium-potential bimodal rainfall area at moderate elevation (most of central and western Uganda), the low-potential bimodal rainfall area at moderate elevation (lower elevation parts of southwestern Uganda), the high-potential bimodal rainfall area in the southwestern highlands, the high-potential unimodal rainfall area in the eastern highlands, the medium-potential unimodal rainfall region at moderate elevations (parts of northern and northwestern Uganda), and the low- and very low-potential unimodal rainfall region at moderate elevations (much of northeastern Uganda).

If all markets were perfect and transactions were costless, farmers' production choices would be based on maximizing profits from current production and on maximizing the net present value of investments (Singh et al. 1986; de Janvry et al. 1991). In such an idealized scenario, choices about crop choice, labor intensity in crop production, and land management would depend only on exogenous prices and such biophysical factors as rainfall, topography, and soil conditions, which together would determine the profitability of alternative agricultural decisions. Other factors would be important in determining prices, but these would not vary across households in the context of perfect markets. Thus, variations in agro-ecological conditions would be the primary determinant of variations among households in agricultural decisions.

In the perfect-markets scenario, one would expect all land to be allocated to its most profitable uses. Recognizing that different agro-ecological conditions are suit-

[30]Although soil conditions are also important in determining agricultural potential, no attempt was made to include soils in the classification, due to limitations in the available soils data and the high degree of spatial variability in soil quality. Thus, the map in Figure 3.2 does not fully represent agricultural potential, although it represents agro-climatic zones.

**Figure 3.2 Agroclimatic potential for perennial crops**




Source: Classification by Ruecker et al. 2003; map by J. Chamberlin.

able for different types of commodities, we would expect different commodities (and hence income strategies and crop choices) to be favored in different conditions. For example, such perennial crops as coffee and bananas generally grow better in bimodal, higher rainfall areas, such as the high-potential bimodal zones, than in the drier, unimodal zones. However, many annual crops, such as many cereals and cotton, grow better in less humid environments with a single long growing period, as in much of northern Uganda. This suggests that perennial crops are likely to be found in the more humid bimodal rainfall zones, and that many annual crops would be found in northern Uganda. However, these choices also depend on prices; for example, if prices of cereals were high enough, they might be grown throughout Uganda.

In areas of generally higher agricultural potential, such as in highland areas having favorable rainfall and fertile volcanic soils, we would expect the highest value commodities—such as horticultural crops,[31] tea, and coffee—to be produced. Lower-value commodities, such as cereals, are more likely to be grown in areas of lower potential, along with complementary livestock production (McIntire et al. 1992). Extensive livestock grazing is a lower-value land use, and thus, is likely to be found in lower-rainfall areas not well suited to continuous crop production. In a more realistic market context, production of some of these high-value commodities, particularly perishable vegetables and fruits, may be limited by reduced access to markets and infrastructure, whereas food crops may need to be grown in areas of poor market access to satisfy subsistence requirements, regardless of profitability (Omamo 1998).

If insurance markets are missing or imperfect, agro-ecological conditions may also influence income strategies and crop choices by affecting risks (Binswanger and McIntire 1987). For example, households may seek to diversify their income sources and crops as a means of coping with production or price uncertainty (Binswanger and McIntire 1987; Ellis 2000; Barrett et al. 2001). Such considerations may lead to greater diversification or to the adoption of less profitable but less risky crops in drought-prone areas. Risks of pests and diseases may also lead to similar risk-management strategies.

Agro-ecological conditions also influence labor intensity and land management practices. In general, higher agricultural potential is expected to be associated with the adoption of more labor- and input-intensive practices, by increasing the marginal return and/or reducing the risks of these inputs (Barrett et al. 2002b). For example, fertilizer use is likely to be less profitable and more risky in low-rainfall areas, because nutrient uptake may be limited by inadequate soil moisture. Higher-rainfall areas may be associated with more widespread adoption of vegetative land management practices, such as the use of agroforestry, live barriers, and mulching, because of higher biomass productivity in such areas. By contrast, adoption of some soil and water conservation (SWC) measures may be more profitable and less risky in low-rainfall areas, as they may have a larger impact on yields in the short run by conserving scarce soil moisture, and may be less prone to harboring pests and weeds than in high rainfall environments (Herweg 1993).

The impacts of more favorable agro-ecological conditions on crop production and incomes are expected to be positive. Higher agricultural potential is expected to promote more intensive and productive use of inputs and the production of higher-value crops, as noted above, leading to higher income. Livestock incomes may be higher in such areas, due to the greater availability of feed sources. However, farmers in high-potential areas may have less comparative advantage in livestock production, due to the higher profitability of crop production and the increased problems of animal pests and diseases typical of more humid environments. Nonfarm opportunities linked to agricultural production may be greater in higher-potential areas (Haggblade et al. 1989; Reardon 1997; Barrett et al. 2001); although households may be less prone to pursue such opportunities, given the higher profitability of farming in these areas. Overall, we expect household incomes to be higher in higher-potential environments.

The expected impacts on land degradation are mixed. In higher-potential areas, there is likely to be more planting of perennial crops and more vegetative cover of the

[31]Horticultural crops are those that produce fruits, vegetables, flowers, or ornamental plants. In this report, however, banana is not categorized as a fruit crop, even though some of its varieties produce fruit.

soil in general, which helps to limit soil erosion. However, the higher rainfall in such areas may be more erosive, especially in steeply sloping areas, such as the highlands. Soil nutrient depletion may be higher in such areas, as a result of more extensive cultivation encouraged by the increased sales of crops to food-deficient areas, especially if the use of fertilizer or other means of soil fertility restoration is limited. Thus, some aspects of land degradation may be worse in higher-potential zones, even if other aspects are better.

### Access to Markets and Roads

Given the substantial transaction costs of storing, transporting, and marketing commodities, access to markets and roads is critical for determining the comparative advantage of a location, given its agricultural potential. For example, a community in an area of high agricultural potential may have an absolute advantage in producing perishable vegetables (that is, high productivity in vegetable production), but no comparative advantage (low profitability compared with alternative activities in that location) in vegetables if it is far from roads and markets. Even if high value crops are profitable, farmers faced with high transport costs may need to produce low-value crops for subsistence purposes rather than higher-value cash crops (Omamo 1998; Key et al. 2000).

A classification of market access into areas of low and high access, using an index of potential market integration based on estimated travel time to the nearest five markets, weighted by their population, is shown in Figure 3.3. Market access in Uganda is highest in the Lake Victoria crescent (especially in those areas close to the major urban centers of Kampala and Jinja), in parts of the densely populated highlands, and near the highway network in the rest of the country.

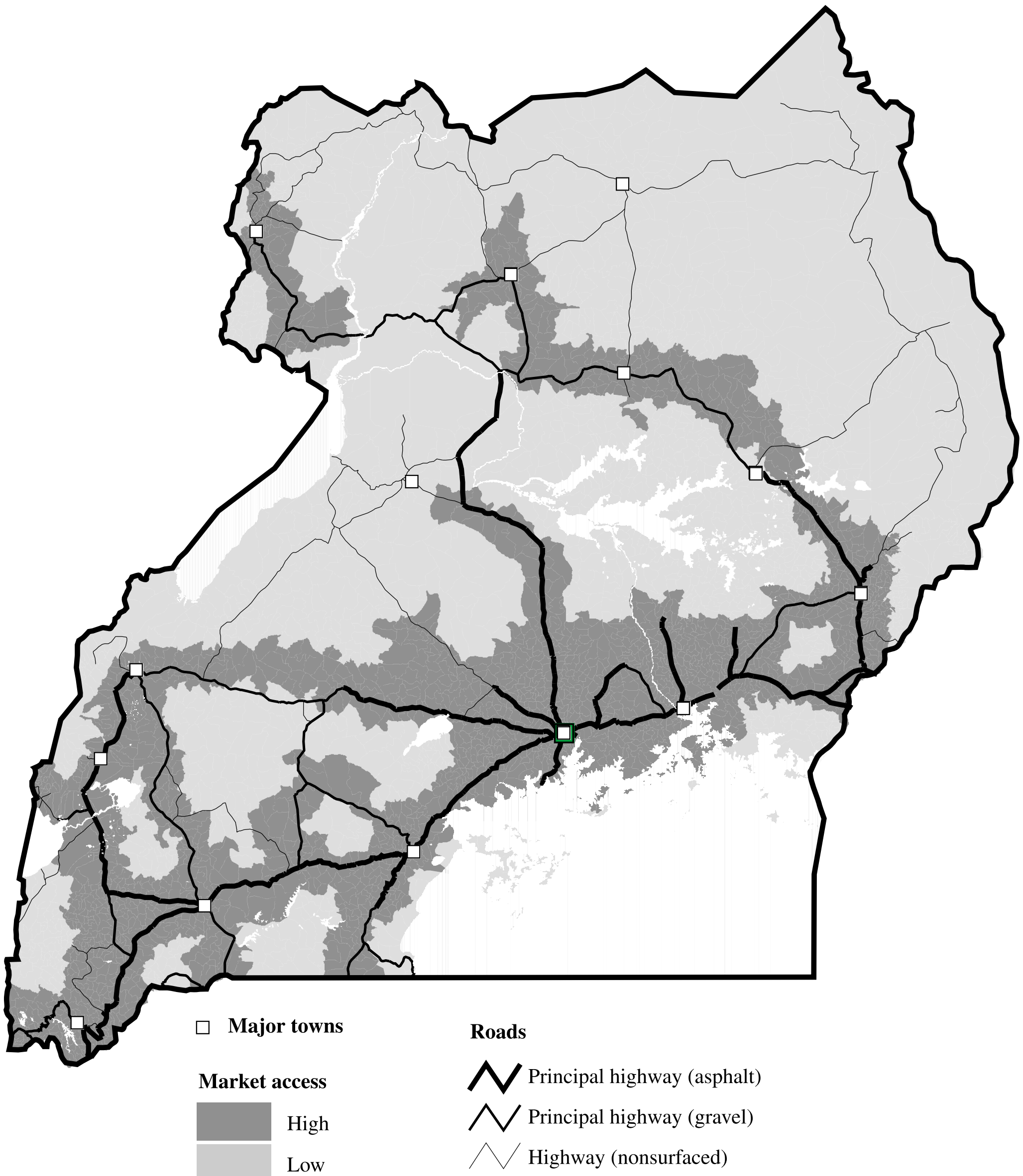
In areas with high access to markets and roads, production of perishable high-value crops, such as horticultural crops, is likely to be profitable if agro-ecological conditions are suitable. These may displace other less-perishable and less-profitable cash crops, such as coffee, to areas somewhat more remote from markets, because such crops can be transported over greater distances at lower costs than perishable commodities. Other bulky food crops (for example, *matooke* [food bananas], cassava, sweet potatoes) may also have a comparative advantage close to urban areas, given their high transport costs, or they may be grown for subsistence purposes in more remote areas. More readily storable and transportable crops, such as cereals and legumes, are likely to have a comparative advantage farther from markets and roads, as they can be stored and transported over longer distances than can other commodities.

Dairy production and other intensive livestock operations, such as the intensive production of pigs and poultry, are also more likely to be found close to urban areas, due to economies of scale in production and marketing, high transport costs, perishability of the products, and the need for market access to purchased compound feeds. Extensive production of livestock that are relatively easy to transport, such as cattle and small ruminants, can occur in areas far from markets, and is likely to have a comparative advantage in areas that are low in potential for crop production.

Opportunities for rural nonfarm activities are also likely to be greater closer to urban markets and roads (Haggblade et al. 1989; Reardon 1997; Barrett et al. 2001). This includes activities linked to agriculture, such as processing agricultural commodities, commodity trading, and provision of agricultural inputs, as well as other activities stimulated by higher demand resulting from higher incomes in areas of better market access. Employment opportunities in urban industries are also likely to be greater for people who live closer to urban centers.

Better access to markets and roads is expected to increase the use of purchased inputs and the capital intensity of agriculture by increasing the profitability and availability of such inputs and increasing access to

**Figure 3.3 Classification of market access in Uganda**




Source: Ruecker et al. 2003, based on Wood et al. 1999.

credit (Binswanger and McIntire 1987). However, the impacts of market and road access on labor intensity and land management are ambiguous. For example, the level of commodity prices has a theoretically ambiguous impact on soil conservation investments (LaFrance 1992; Pagiola 1996). Higher access implies that the marginal return to labor invested in crop production and land management is higher (because output and land prices are increased) (Binswanger and McIntire 1987), but the opportunity costs of labor are also likely to be higher. The net impact depends on which effect is stronger. The positive effect of market and road access on input use may have further impacts on the use of labor-intensive practices, depending on whether capital- and labor-intensive practices are complements or substitutes. For example, the use of improved seeds and fertilizers may promote complementary use of labor for irrigation, land preparation, weeding, and the like; but may also reduce use of manure or SWC investments (because fertilizer use may mask the negative effects of soil degradation) (Holden et al. 2002).

The impacts of market and road access on the value of crop production are also ambiguous. To the extent that better access promotes production of higher-value crops, increases the local prices of crops, and promotes more intensive use of inputs, it tends to increase the value of crop production. However, as mentioned above, better access also may reduce the labor intensity of crop production, and thus could reduce the value of the output.

Given the ambiguous effects of market and road access on land management, the impacts on land degradation are also, not surprisingly, ambiguous. By increasing the profitability of agricultural production, greater market access promotes expansion of production into forest areas or other fragile lands, if the costs of productive factors and output prices are unaffected by market access (Angelsen 1999), which will increase land degradation in such areas. However, if costs rise because of constrained supply or prices fall due to inelastic demand, a reduction in agricultural area (and hence, the pressure on forests and other fragile lands) is possible, as productive factors are concentrated on the most profitable lands (Angelsen 1999). Market-driven intensification may also contribute to land degradation by leading to reduced fallowing (Binswanger and McIntire 1987), which contributes to declining soil fertility and increased erosion (due to reduced vegetative cover), unless sufficiently offset by adoption of more intensive soil fertility management and soil conservation practices. Improved market access may contribute to increased use of animal draught power for tillage (Binswanger and McIntire 1987), which may contribute to soil erosion on sloping lands. Commercialization of agricultural commodities can also contribute to the depletion of soil nutrients, if the nutrients being exported from the farming system in the form of commodity sales are not adequately replenished by fertilizers or other nutrient sources (de Jager et al. 1998). However, market-driven intensification may lead to reduced erosion and improved soil fertility management, as a result of the increased incentive to invest in land improvements, given the rising value of land (Tiffen et al. 1994).

Regardless of its net impacts on crop production, better market and road access are expected to have a positive impact on income, because access increases income-earning opportunities, whether through increased agricultural production or nonfarm activities.

### Population Pressure

Population pressure (increasing population density) is expected to induce higher labor intensity in agriculture, by increasing the availability (hence, reducing the costs) of labor relative to land (Boserup 1965). Higher labor intensity in agriculture can take the form of production on more marginal lands, less use of fallow, adoption of more labor-intensive methods of cultivation, labor-intensive investments in land improvement, and/or adoption of more labor-intensive commodities (such as horticultural crops and intensive livestock production) (Pender 2001). Income strategies that are land and resource intensive, such as forestry and intensive livestock production, are likely to be less viable in more densely populated settings. There may be greater opportunities for rural nonfarm activities in more densely populated settings, because of larger markets and lower transactions costs, which will facilitate diversification of economic activities (Tiffen et al. 1994).

Population pressure may also induce increases in the capital intensity of agriculture, if capital is complementary to labor (for example, the use of draft animals in place of human labor) (McIntire et al. 1992), or there are increases in the "knowledge intensity" of agriculture, through adoption or adaptation of technologies (such as the use of improved seeds or integrated pest or soil nutrient management). Population pressure may also have more indirect (but still important) effects by stimulating migration, investments in infrastructure, or technical or institutional change (Pender 2001).

Population-induced intensification is likely to lead to higher yields and higher value of crop production per hectare, unless greater intensity is offset by land degradation (Salehi-Isfahani 1988; Pender 2001). However, labor intensification may lead to lower labor productivity and per capita income (as a result of diminishing returns to labor), unless offset by technical change, improvement in infrastructure and market access, or other improvements in opportunities (Ibid.; Binswanger and McIntire 1987; Salehi-Isfahani 1988; Pender 2001).

The impacts of population pressure on land degradation may be mixed. Land degradation may increase, due such practices as the cultivation of fragile lands, reduced use of fallow, increased tillage, and mining of soil nutrients. However, investments in land improvements and more intensive soil fertility management practices may improve land conditions (Scherr and Hazell 1994; Tiffen et al. 1994; Pender 2001).

## Income Strategy

Income strategy and crop choice influence land management and labor intensity. For example, the production of high-value horticultural crops or other cash crops promotes greater use of purchased inputs, labor, and the adoption of labor-intensive land improvements (such as terraces), because higher-value production increases the value of these inputs and the ability to finance them (see, for example, Tiffen et al. 1994; Barrett et al. 2002a). Mixed crop-livestock producers are more likely to apply manure to their crops, because they have better access to this bulky resource. When credit is constrained, households with better access to off-farm income may be more prone to use inputs or make investments that require cash, such as fertilizer or hired labor (Reardon et al. 1994, 2001a; Clay et al. 1998; Pender and Kerr 1998). However, households with greater off-farm opportunities may be less prone than others to invest labor in crop production or labor-intensive land management practices, because their opportunity costs of labor may be higher (if labor markets are imperfect) (Scherr and Hazell 1994; Pender and Kerr 1998).

By influencing crop choice and the level of input use, income strategies affect the value of crop production. Income strategies may also affect the value of crop production by affecting the ability of households to produce and market their crops, independently of their impact on crop choice or input use. For example, households that specialize in production of certain crops may develop better ability to produce and market their crops than do more diversified households. Livestock producers may obtain better production because of deposition of animal manure on their fields (even if they are not investing effort in collecting and applying manure). Households involved in nonfarm activities may have advantages in liquidity and risk management that enable them to obtain better prices for their crops (for example, by not being forced to sell right at harvest).

Income strategies may also have impacts on land degradation. For example, households producing higher-value crops or having nonfarm income may be more likely to replenish soil fertility by using fertilizer, or may invest more (or less) in SWC measures, as argued above. The impacts on land degradation depend on the net effects of decisions concerning crop choice, input use, and land management practices.

Income strategies are also expected to affect household incomes and poverty.

Households able to rely on high-value crops, livestock, or remunerative nonfarm activities are likely to earn higher incomes than those confined to subsistence food crop production (Tiffen et al. 1994; Barrett et al. 2001). Households dependent upon low-wage, off-farm employment may be poorer than even subsistence farm households.

### Irrigation

As with improvements in market access, irrigation can enable production of higher-value crops, such as horticultural crops. Irrigation likely contributes to labor intensity by enabling production of multiple crops per year and by increasing the return and/or reducing the risk of labor invested in crop production. If this intensification increases the costs of productive factors (that is, if wages rise as a result of increased labor demand), irrigation may limit the expansion of agricultural production, as in the case of improved market access. Irrigation may promote investments in complementary SWC investments and practices, such as investments in soil bunds and drainage (Pender and Kerr 1998). It may also encourage farmers to adopt complementary productive inputs, such as fertilizer, particularly where soil moisture constraints limit farmers' willingness to use fertilizer (Pender et al. 1999). As a result of these impacts, irrigation is likely to increase the value of crop production and incomes.

The impacts of irrigation on land degradation may be mixed. Irrigation increases the incentive to invest in land improvement and soil fertility management by increasing the value of such investments. However, irrigation may contribute to problems of soil erosion or salinity if runoff and drainage are not adequately managed. Irrigation can also contribute to increased soil nutrient mining by increasing the production and commercialization of crops, unless adequate efforts are made to replenish such nutrients. Irrigation may also have negative effects on people downstream, as a result of reduced access to water or contamination of water by agrochemicals.

### Technical Assistance Programs and Organizations

Since natural resource management (NRM) technologies are knowledge-intensive (Barrett et al. 2002a), technical assistance is likely to be an important determinant of their adoption. The presence of programs and organizations is likely to improve delivery of NRM technologies (Swinkels and Franzel 1997). However, the impacts of participation in such programs and organizations depends on their focus. Programs and organizations focusing on technical assistance related to agriculture or environment in Uganda are promoting different types of technologies and land management practices. In some cases (for example, Sasakawa Global 2000, the IDEA project, the Ministry of Agriculture extension program [Bashaasha 2001]), these programs are promoting the increased use of purchased inputs, such as improved seeds and fertilizer. In other cases, programs (especially those of nongovernmental organizations) are promoting low external input agricultural technologies, such as mulching, composting, leguminous cover crops, and agroforestry practices. The net impact of such programs on land management and their ultimate impacts on production, land degradation, and income is an empirical question to be investigated. Programs focusing on production inputs may have a greater impact on production and income in the short run, whereas programs focusing on sustainable land management and environment may have a greater impact on reducing land degradation. To the extent that such programs help to increase crop production, they may increase income as well. However, income may also be negatively affected (in the short run, at least) by programs that encourage labor-intensive agricultural practices, if those practices do not increase production significantly, because of the opportunity costs of labor.

### Credit

Credit programs may enable farmers to purchase inputs or acquire physical capital, thus contributing to technology adoption and increased capital and input intensity in agriculture (Feder et al. 1985). This may promote increased production and marketing of high-value crops or intensification of livestock production and permit reduction of subsistence production. If credit availability helps to relax credit constraints, this can reduce the extent to which households discount the future (Pender 1996; Holden et al. 1998), possibly leading to more investment in SWC (Pender and Kerr 1998). Credit may also facilitate labor hiring and thus promote labor intensification. However, credit availability may enable households to invest in nonfarm activities, and thus may contribute to less intensive management of land and other agricultural resources. In addition, by promoting intensification of capital and purchased inputs, credit may reduce labor-intensive land management practices that are substitutes for these (for example, fertilizer use may reduce the use of manure and compost). The net impacts of credit on land management, crop production, and land degradation are thus ambiguous. The impact of credit availability on income is likely to be positive, provided households have profitable uses for it (otherwise, the effect may be nil or even negative).

### Education

Education is likely to increase households' opportunities for salaried employment off farm, and may increase their ability to start up various nonfarm activities (Barrett et al. 2001; Deininger and Okidi 2001). Education may increase access to credit, as well as cash income, thus helping to finance purchases of physical capital and purchased inputs. This may help to promote high-value crop and intensive livestock production, as well as promoting greater use of such capital and inputs in producing traditional food crops. Education may also facilitate changes to income strategies and technologies, by increasing access to information about alternative market opportunities and technologies (Feder et al. 1985). However, more educated households may be less likely to invest in inputs or labor-intensive land investments and management practices, because the opportunity costs of their labor and capital may be increased by education. Thus, the net impacts of education on land management, crop production, and land degradation are ambiguous. The impact on household income is expected to be positive.

### Household Endowments

If factor markets (markets for land, labor, and capital) do not function efficiently, then there may be significant differences among households in their land management practices and agricultural productivity (de Janvry et al. 1991). In the context of imperfect labor and land markets, agricultural households with less land or a larger family-labor endowment per unit of land can be expected to use labor more intensively in agricultural production (Feder et al. 1985). Essentially, the impacts of smaller farm size—or larger family-labor endowment, controlling for farm size—are similar to the effects of population density, if imperfections in labor or land markets limit the extent to which differences in labor endowments can be overcome through labor or land transactions. Greater labor availability per unit of land may also induce households facing land constraints to pursue alternative off-farm income strategies, such as wage employment and various nonfarm activities. The impact of smaller farm size or larger family size on the value of crop production per hectare is likely to be positive if labor and land markets are imperfect, or zero, if these markets function well. The impact of labor availability on household income is expected to be positive (as long as the marginal product of labor is positive), although the impact on income per capita may not be (if there are diminishing returns to labor). As with population pressure, the impact of labor availability on land degradation is ambiguous.

If credit is constrained, farmers who own more livestock, equipment, or other physical assets may be better able to finance the purchase of inputs or investments, either by liquidating assets or through better access to credit. The impacts on crop choice, land management, and labor intensity are thus qualitatively similar to the impacts of access to credit discussed above, and are ambiguous for the same reasons.

The impact of livestock on land degradation may be mixed, and depends on the type of degradation, as well as interactions between crops and livestock. Livestock may contribute to soil compaction and erosion along animal walkways, and if draught animals are used for tillage, they may also contribute to erosion and compaction as a result of tillage operations. Livestock usually have a more positive role in nutrient cycling at the household level. Crop residues are fed to animals, and manure may be applied to farm plots or exported off-farm (Rocheleau et al. 1988; Young 1997; Rowlinson 1999). If farmers apply animal manure to their crop plots, then it is likely that farmers with more animals would have higher nutrient balances than those with fewer animals. However, farmers may fail to apply manure to many of their crop plots for various reasons. Farmers often keep animals close to the homestead, which implies greater availability of manure close to the homestead. This, together with the difficulty of transporting manure due to its bulkiness, implies that plots farther away from the homestead are less likely to receive manure and other bulky organic materials, such as household wastes. Thus, we expect plots farther away from the residence to have lower nutrient balances than those closer to it.

Farm equipment may also have mixed impacts on land degradation. Plows and other machinery may contribute to soil erosion by facilitating tillage, especially if used on sloping lands. However, equipment may be used to help construct SWC structures, and to apply fertilizer or other inputs that help to prevent soil erosion, nutrient depletion, or other forms of degradation.

The impact of livestock and other physical assets on household income is expected to be positive, to the extent that such assets are accumulated for the purposes of increasing income. However, there may be other reasons for accumulating assets. For example, livestock may be kept as a store of relatively liquid wealth and as an insurance substitute, where financial and insurance markets are poorly developed, due to problems of covariate risk (Binswanger and McIntire 1987). Livestock, jewelry, or other assets may also be accumulated for dowry or bequest purposes. Thus, the impacts of physical assets on income may be limited.

### Land Tenure

As mentioned previously, the form of tenure on a plot can affect land management and productivity for several reasons. If there is insecurity of tenure, the household operating the plot may have less incentive to invest in land improvement (Feder et al. 1988). This is not necessarily the case, however, if the household can increase tenure security by investing in the land (Besley 1995; Otsuka and Place 2001).

The extent to which there is insecurity of tenure among the different tenure systems in Uganda is debatable. Customary tenants have had access to their lands for a long time, although in some areas, the power of traditional authorities (clans and chiefs) has been undermined in the past by actions of the government (Place et al. 2001b), which may have contributed to land disputes and insecurity. The 1998 Land Act seeks to ensure tenure security and limit disputes on customary land by recognizing the jurisdiction of local authorities and customary laws over this land. *Mailo* tenants are, in most cases, long-term occupants who have legal protection against eviction and hence, may be quite secure in their tenure (Place et al.

2001b). *Mailo* occupants have long had uncontested rights over the land they occupy, including the right to bequeath occupancy, and the 1998 Land Act provides freehold status to long-term *mailo* occupants. Absentee *mailo* owners may face more insecurity than do occupants (Kisamba-Mugerwa 1989), due to fears of tenants who favor land tenure reform by the government. However, this insecurity may have limited impact on land management, because absentee *mailo* owners are not the land managers.[32] Holders of leasehold land generally have long-term leases of public land from the state. In some cases, however, such leases have been provided to elites without regard to other occupants of the land, contributing to the risks of insecurity and conflict (Kisamba-Mugerwa 1989). Thus, tenure security may be an important concern for occupants of leasehold or public lands.

Perhaps more important for land management than security of tenure is the set of rights associated with the different tenure systems. Owners of freehold land have complete rights to use, lease, sell, bequeath, and mortgage their land. Owners or occupants of lands under other tenure systems have more restricted rights, including restrictions on sales, leasing, and mortgaging. As mentioned in Chapter 2, customary owners can bequeath their land, but cannot sell it without consultation with clan leaders and family members, and *mailo* occupants have been subject to restrictions on subleasing. Under the 1998 Land Act, customary landholders also cannot mortgage or pledge the land unless they obtain a certificate of ownership from the district land board (ULA 2000). Due to poor enforcement of the 1998 Land Act, *mailo* land bona fide or lawful occupants are still affected by the old land laws, which had restrictions on tree marketing, planting perennial crops, and subletting. As is the case for the customary land, bona fide and lawful *mailo* land occupants who have not obtained certificate of ownership are also not allowed to mortgage the land.

These restrictions may reduce farmers' access to credit, where land is (or could be) used as collateral for credit (Feder et al. 1988; Place and Hazell 1993). If so, farmers having more complete property rights (such as ownership under freehold tenure) may be more prone to use cash inputs or make investments than would other farmers. The effects of this are similar to the effects of increased access to credit, discussed above. To the extent that land sales or lease rights enable households to recoup the value of land improvements, owners with more complete transfer rights may be more likely to make investments in land improvement (Pender and Kerr 1999).

Ownership of a formal title may amplify the impacts of greater tenure security and complete land rights associated with freehold, by providing proof of freehold status.[33] In particular, formal title may facilitate access to credit and help to prevent or resolve land disputes (Feder et al. 1988). Thus, we investigate the impacts of a title, per se, in addition to the land tenure status. We also investigate the impacts of the perception of tenure insecurity, as indicated by whether the

[32]For owners of *mailo* land occupied by long-term bona fide *mailo* tenants, this point is moot, because the occupants of the land have been provided freehold tenure under the 1998 Land Act. However, due to high cadastral costs involved in granting land titles, most *mailo* tenants do not have formal titles or certificates granting them freehold tenancy. For other absentee *mailo* owners, their insecurity, coupled with restrictions on *mailo* tenant rights (for example, restrictions on the right to cut trees) may affect land management. For example, absentee *mailo* owners may be reluctant to plant timber trees due to their insecurity, and the occupant may not plant due to the restriction on cutting.

[33]Not all freehold owners have an actual title to their freehold parcels. Among those who do not have title are long-term occupants of *mailo* land who have been granted freehold status as a result of the 1998 Land Act.

household expects to continue farming the same plot for the next 10 years.

In addition to tenure status and land title, the means of acquisition of land may also influence tenure security and incentives to invest in land management. For example, tenants on rented or borrowed land are unlikely to invest in SWC measures or in perennial crops if the lease or borrowing arrangement is relatively short term, regardless of the tenure system under which the landholder claims the land. Tenants on sharecropped plots may have less incentive to apply labor and other inputs than owner-operators or tenants using fixed rental (Shaban 1987; Otsuka and Hayami 1988).[34] By contrast, owners of purchased land and tenants using cash rental may have more incentive than owners of inherited land to produce cash crops and apply inputs, to facilitate recouping the costs of their investment and repaying any loans used to finance the investment. Land users who have encroached on public or communal lands may face substantial tenure insecurity; this may prevent them from undertaking investments or fallowing, unless such investments are perceived as increasing the land user's tenure security (Otsuka and Place 2001).

### Summary of Hypotheses

The hypotheses are summarized in Table 3.1. In general, most factors have theoretically ambiguous impacts on crop production, land management, and land degradation. Many factors have more predictable impacts on household incomes. These hypotheses suggest that the impacts of policy and program interventions on agricultural production and land degradation may be very context specific, and may often involve trade-offs among the objectives of increasing agricultural production, reducing land degradation, and increasing household incomes. Empirical research is essential for understanding these impacts and trade-offs, given the theoretically ambiguous nature of most of these relationships.

## Research Methods

In this section, we describe the research methods that were used to test the hypotheses discussed above. As noted in Chapter 1, our analysis in Chapter 4 investigates the determinants of income strategies and land management and their impacts on crop production, land degradation, and incomes. Our analysis in Chapter 5 focuses on a small sample of households in eastern Uganda to analyze the determinants of soil nutrient balances as the indicator of sustainability. Accordingly, this section first looks at the data sources and analysis of livelihoods and land management in general, and then presents the data sources and analysis methods for soil nutrient balances.

### Determinants and Impacts of Income Strategies and Land Management

*Data Sources.* Many of the above hypotheses are tested using econometric analysis of survey data collected in 107 communities during 1999–2001. The study region covered most of Uganda, including more densely populated and more secure areas in southwest, central, eastern, and parts of northern Uganda, representing seven of the nine major farming systems of the country (Figure 3.4).[35] In the study region, communities (LC1; the lowest administrative unit, usually a single village) were selected using a stratified random sample, with the stratification based on development domains

[34]Sharecropping is rare in Uganda, however, so this hypothesis will not be investigated.

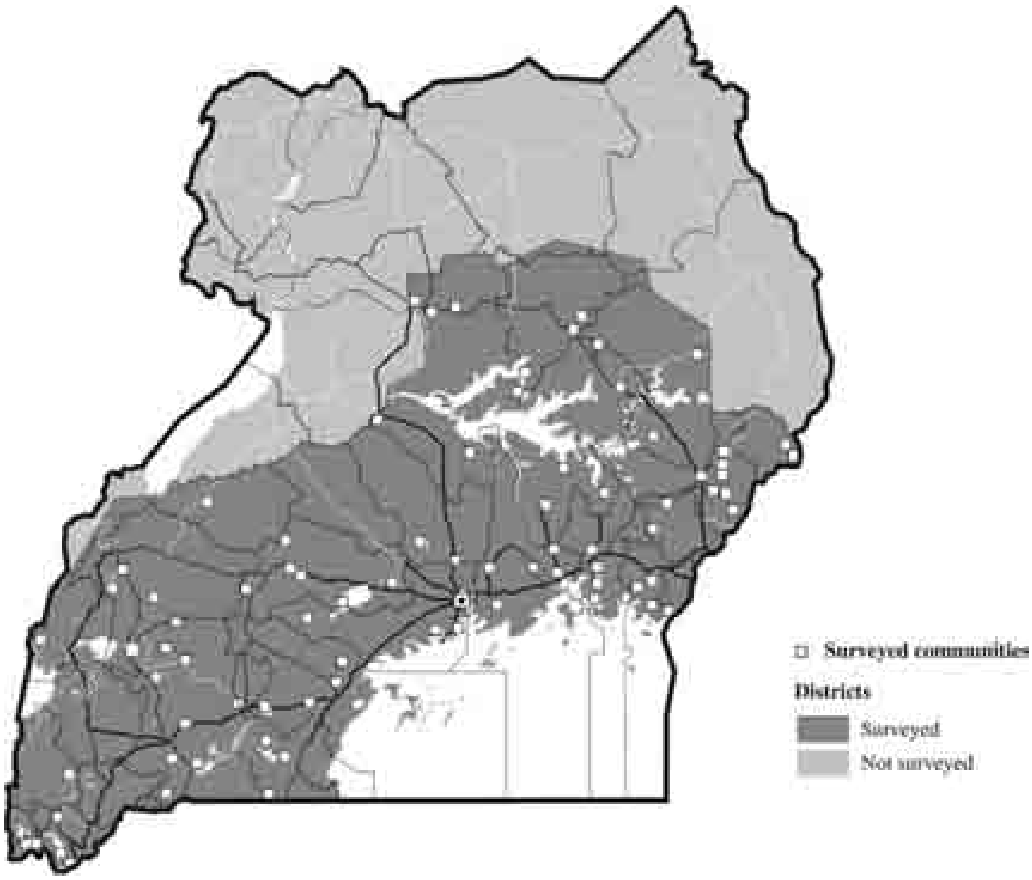
[35]The districts in the project study area include Apac, Bugiri, Bushenyi, Busia, Iganga, Jinja, Kabale, Kabarole, Kamuli, Kapchorwa, Kasese, Katakwi, Kibale, Kiboga, Kisoro, Kumi, Lira, Luwero, Masaka, Mbale, Mbarara, Mpigi, Mubende, Mukono, Nakasongola, Ntungamo, Pallisa, Rakai, Rukungiri, Sembabule, Soroti, and Tororo.

**Table 3.1 Summary of hypotheses**

| Impacts of: | Income strategy and crop choice | Labor intensity | Land management practices | Value of crop production | Land degradation | Income |
|---|---|---|---|---|---|---|
| Higher agricultural potential | + Higher value crops<br>– Lower value crops<br>– Extensive livestock<br>+/– Intensive livestock<br>+/– Nonfarm activities | + | + Labor or capital intensive practices<br>+ Agroforestry, vegetative methods<br>– Some SWC measures | + | +/– | + |
| Higher market/road access | + Perishable cash crops<br>– Storable crops<br>– Subsistence food crops<br>+ Intensive livestock<br>– Extensive livestock<br>+ Nonfarm activities | +/– | + Capital and input intensive practices<br>+/– Labor intensive practices | +/– | +/– | +/0 |
| Higher population density | + Labor intensive activities (food crops, horticulture, intensive livestock)<br>– Land intensive activities (extensive livestock, forestry)<br>+ Nonfarm activities | + | – Land intensive practices (fallow, slash-and-burn)<br>+ Labor intensive practices<br>+/– Capital and input intensive practices | +/0 | +/– | 0/– |
| Income strategy (cf. subsistence food crops) | NA | | | | | |
| – High value crops | | + | + Labor and capital intensive practices | + | +/– | + |
| – Livestock | | +/– | + Use of manure | +/– | +/– | + |
| – Nonfarm activities | | +/– | + Purchased inputs, hired labor | +/– | +/– | +/– |
| Irrigation | + Horticultural crops | + | + Practices complementary to irrigation and horticultural crops (e.g., fertilizer use) | + | +/– | + |
| Programs and organizations | ? Depends on focus | ? | ? | ? | ? | ? |
| Credit | + Capital and input intensive strategies (high value crops, intensive livestock, nonfarm)<br>– Subsistence food crops | +/– | + Purchased inputs and capital (if credit used for agriculture)<br>+/– Labor intensive practices | +/–<br>(depends whether used for crops) | +/– | +/0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Education | + Salary employment<br>+ Nonfarm activities<br>+/0 High value crops and intensive livestock | +/– | + New technologies<br>+ Capital and input intensive practices<br>+/– Labor-intensive practices | +/– | +/– | + |
| Larger household labor endowment or smaller farm size | +/0 Labor intensive activities (food crops, horticulture, intensive livestock)<br>–/0 Land intensive activities (extensive livestock, forestry)<br>+/0 Nonfarm activities | +/0 | –/0 Land intensive practices (fallow, slash-and-burn)<br>+/0 Labor intensive practices<br>+/– Capital and input intensive practices | +/0 | +/– | 0/+ (labor)<br>– (smaller farm size) |
| Livestock ownership | + Livestock activities<br>+ Complementary cropping activities (e.g., cereals) | +/– | + Capital intensive practices<br>+/– Labor intensive practices | +/– | +/– | +/0 |
| Farm equipment ownership | + Capital-intensive agricultural activities<br>+/– Labor intensive practices | +/– | + Capital intensive practices | +/– | +/– | + |
| Land tenure security/more complete land rights (freehold vs. others; titled vs. not; owner vs. not) | +/– Perennial crops<br>+/0 Capital and input intensive commodities | +/– | +/– Land investments<br>+/0 Capital and input intensive practices<br>+/– Labor intensive practices | +/– | +/– | +/– |

**Figure 3.4 Study region and sample communities**




Source: Ruecker et al. 2003.

defined by the different agro-ecological and market access zones (shown in Figures 3.2 and 3.3) and on differences in population density (Pender et al. 2001b). One hundred villages were selected in this way. Additional communities were purposely selected in southwest Uganda, where the African Highlands Initiative is conducting research, and in Iganga District, where the International Center for Tropical Agriculture is conducting research.

A community-level survey was conducted with a group of representative individuals from each selected community to collect information on access to infrastructure and services, local markets and prices, and other factors. A random sample of 451 households was selected (four households per community, in most cases). For each household selected, a household-level questionnaire was used to collect information about household endowments of assets, household composition, income and expenditures, and adoption of agricultural and land management technologies. A plot-level survey was also conducted to gather information on all of the plots owned or operated by the household, including information about land tenure, plot quality, land management practices, and uses of inputs and outputs from the plot in the year 2000. The survey information was supplemented by secondary information collected from the 1991 population census and available digitized map information incorporated into a geographic information system.

*Analysis.* We used econometric analysis of equations (1)–(8) and (12) to analyze the determinants and impacts of income strategies and land management practices on crop production, soil erosion, and income. Ideally, we would like to estimate this system using a linear systems approach, such as three-stage least squares, to deal with endogenous explanatory variables and account for correlation of error terms across the different equations, which would increase the efficiency of estimation. This is not feasible, however, due to the nature of many of the dependent variables. As measured by the survey and used in the analysis, several of the endogenous variables in this system are limited dependent variables (categorical or censored), for which a linear estimator is not appropriate. The variable $\mathbf{C_{hp}}$ represents area shares under different crops and thus, is a censored continuous variable (censored below at 0 and above at 1); we use a maximum likelihood Tobit estimator (with left and right censoring) for equation (2). The quantities $\mathbf{LM_{hp}}$ and $\mathbf{SC_h}$ are dichotomous-choice variables (whether certain land management practices are used, whether the household participates in different types of programs and organizations); we use probit models to estimate equations (4) and (6). The variable $\mathbf{IS_h}$ is a polychotomous-choice variable (primary income source); we use a multinomial logit model to estimate equation (5). The quantities $y_{hp}$, $L_{hp}$, $I_h$, and $e_{hp}$ are continuous uncensored variables (value of crop production, pre-harvest labor use, household income, and predicted erosion); thus, least-squares regression can be used for equations (1), (3), (7), (8), and (12).

Inclusion of endogenous explanatory variables in these equations could result in biased estimates, due to correlation of the error term with such variables. In standard linear models, instrumental variables (IV) estimation can be used to address the endogeneity problem, provided that valid instruments are available (Deaton 1997). In limited dependent-variable models, IV estimation cannot be used, but consistent estimates can be produced by a two-stage estimator substituting predicted values of the endogenous explanatory variables. As shown in equations (5) and (6), the ethnicity of the household is used as an instrumental variable to predict income strategies and participation in programs and organizations. These predicted income strategies and participation variables are used as instruments for actual strategies and participation in the IV or two-stage versions of the other equations.[36] In addition, predicted crop choice, labor use, and land management practices are used as instruments in estimating equation (1). Other instrumental variables are identified by hypothesis testing: exogenous variables that were jointly statistically insignificant in the full version of the models for equations (1), (3), (8), and (12) were dropped from the IV regression, but retained as instrumental variables. The variables thus dropped from the IV regressions are shown in Chapter 4 (Tables 4.8–4.10). In general, these instrumental variables included predetermined community- or household-level variables, such as population density, ownership of assets, and human capital variables, which, in many cases, affect income strategies, crop choice, and land management practices, but do not necessarily directly effect outcomes, such as crop production or household income, controlling for these decisions.

Identification of the effects of the endogenous variables in the IV models and two-stage models can be difficult, unless one has instrumental variables that strongly predict the endogenous explanatory variables. In finite samples, results of estimation with weak instruments can be more biased than ordinary least squares (OLS) (Deaton

[36]An early example of this approach (using predicted values of categorical variables as instruments in an IV estimation) is provided in Dubin and McFadden (1984).

1997). This is a potential concern for the regressions presented in this chapter. We address this concern by controlling for many exogenous explanatory factors in the regressions that could cause endogeneity or omitted variable bias if left out (such as many indicators of land quality and agro-ecological conditions) and by investigating the robustness of the regression results to estimation by OLS, IV, or two-stage approach, and reduced-form (RF) approach. In discussing our findings, we focus on results that are robust across at least two of these three specifications, unless noted otherwise. We also conduct Hausman (1978) tests comparing the OLS and IV models, and report the results.

For the least squares models with only positive values of the dependent variables—equations (1), (3), and (12)—we use a log-log specification (logarithm of the dependent variable and of all continuous uncensored explanatory variables). Because there are zero values for some household assets (land, livestock, and equipment) for some households, it is not possible to use a simple logarithmic transformation for these variables. Instead, we included a dummy variable for positive asset ownership, to allow for an intercept shift for households with zero values for some assets, as well as the logarithm of assets for households that have positive asset levels. These logarithmic transformations made the distributions of the continuous variables closer to a normal distribution, which improves the robustness of the regression results by reducing problems associated with nonlinearities, outliers, leverage points, and the like (Mukherjee et al. 1998). For the household income regression, we were not able to use this approach, because there were negative values of income for some households. Thus, the income regression was estimated in linear form. We also estimated the income model using robust regression (Berk 1990) as a further check on the robustness of the results. We used a linear specification for all limited dependent-variable regressions, because the dependent variables could not be transformed using logarithms in these cases.

In all models, we tested for multicollinearity, and found it not to be a serious problem (variance inflation factors less than 5) for almost all explanatory variables (except for some assets for which the logarithmic specification with the intercept-shift dummy variables were used) in the OLS and RF regressions. In the two-stage regressions, multicollinearity was more of a problem, as a result of the identification issue already discussed. Because stratified random sampling was used, all parameters were corrected for sampling stratification and sample weights. Estimated standard errors are robust to heteroskedasticity and clustering (nonindependence) of observations from different plots for the same household. Outliers were detected and errors corrected whenever possible. Two households were dropped from the analysis, because they own more than 300 acres of land and are thus not representative of the farmers in Uganda.[37]

*Explanatory Variables.* The village-level explanatory variables ($\mathbf{X}_v$) include the agro-ecological and market-access zones (shown in Figures 3.2 and 3.3) and the population density of the parish (the second-lowest administrative unit, consisting of several villages). Household-level factors include income strategy (primary income source of the household); ownership of natural and physical capital (area of land, value of livestock and farm equipment); human capital (education, age, and gender of household

[37]All remaining households owned less than 100 acres of land, and the average farm size for these was 8.2 acres.

head); the family labor endowment (size of household and proportion of dependents); social capital (participation in technical assistance programs [longer-term training and shorter-term extension programs] and in various types of organizations); and the ethnicity of the household. Plot-level factors include the size, tenure, and land rights status of the plot, whether the plot has a formal title, whether the household expects to have access to the plot in ten years, the altitude of the plot; the distance of the plot from the farmer's residence, roads, and markets; the investments that have been made on the plot (presence of irrigation, trenches, grass strips, live barriers, and planted trees; share of area planted to perennial crops), and various plot characteristics (slope, position on slope, soil depth, texture, color, and perceived fertility). For the income regression, plot-level factors were aggregated to the household level by computing the area-weighted characteristics (for example, share of land under different tenure categories, share of area on different slopes, area-weighted average altitude and distance of the plots to the residence).

*Predicted impacts of selected variables.* In a complex structural model, such as the one we are estimating in this study, a change in a particular causal factor may have impacts on outcomes of interest through many different channels, given the many intervening response variables that may be affected. For example, improvements in education may affect agricultural productivity and land degradation directly by affecting farmers' awareness or ability to use technologies that affect these outcomes. But it may also influence these outcomes indirectly by affecting opportunity costs of labor, thus affecting the labor intensity of production and willingness to adopt labor-intensive technologies, or by affecting access to cash or credit and the ability to adopt capital-intensive technologies. Education may affect these decisions directly, or indirectly by affecting choices of income strategies. Such indirect effects must be accounted for if we are to understand the full effect of causal factors on such outcomes as agricultural production, land degradation, and household income.

In studies in which the empirical relationships are linear and involve continuous variables, the predicted total impacts of changes in explanatory variables can be determined by calculating the total differentials of the system (Fan et al. 1999). In the present study, this approach is not practical, because of the nonlinear and limited dependent-variable models estimated, and because many of the causal variables of interest are measured as discrete variables (for example, education, participation in technical assistance programs). To overcome these problems, we simulate the predicted responses implied by the estimated econometric relationships under alternative assumptions about the values of the explanatory variables for the entire sample, and carry these predicted responses forward to determine their impact on subsequent relationships in the system.

For example, to predict the impacts of providing Universal Primary Education (UPE) to all household heads that do not have a primary education, we predict the probabilities of each income strategy and participation in programs and organizations using the results of estimating equations (5) and (6), assuming that all household heads that currently do not have primary education have it. Comparison of these values to those predicted by using the actual levels of education determines the predicted effect of UPE on income strategies and participation in programs and organizations. We then calculate the impact of UPE on crop choice, labor use, and land management by predicting these responses under three scenarios:

1. Using predicted values of income strategies and participation in programs and organizations (based on actual education levels and other explanatory variables), actual levels of education and other

explanatory variables for crop choice, labor use, and land management;[38]

2. Using the same predicted values of income strategies and participation as in scenario (1), but assuming UPE level of education in the explanatory factors for crop choice, labor use, and land management; and
3. Using the predicted values of income strategies and participation, assuming UPE level of education in the income strategy and participation regressions, as well as UPE education in the crop choice, labor use, and land management regressions.

The second scenario determines the direct effect of the change in education, controlling for income strategy and participation, whereas the third scenario determines the total effect, considering the effect of the change in education on income strategies and participation in programs and organizations, and the effect of those changes on responses, as well as the direct effect of the change in education on responses.

The indirect effects of UPE on crop production include the predicted impacts on crop choice, labor use, and land management practices, as well as impacts on income strategies and participation in programs and organizations. The indirect effects of UPE on household income and erosion are based only on impacts on income strategies and programs and organizations, because crop choice, labor use, and land management practices are not included in these regressions.

In Chapter 4, we report the impacts of various policy-related scenarios on the mean predicted value of crop production, erosion, and household income. In addition to UPE, the scenarios include the impacts of providing higher education to all household heads who have completed secondary education, higher population density, universal participation in agricultural training or extension programs, in agricultural/environment oriented NGOs, or in poverty-reduction oriented NGOs. These estimates are intended to provide a better sense of the quantitative (as opposed to statistical) significance of the regression results, which is not always obvious, and the importance of indirect effects. Although this is intended to be helpful to policymakers and others in interpreting the results, some caveats should be borne in mind. We were not able to assign confidence bounds on these predictions, although we report which impacts are based on statistically significant coefficients. Furthermore, the relationships underlying these predictions are based on cross-sectional regressions, and may not be representative of changes that occur over time as a result of policy changes. Nevertheless, we believe that the simulation results add significant value to the reported regression results, by increasing their interpretive meaning.

### Determinants of Soil Nutrient Balances

*Data and analysis.* The data used in this part of the study were obtained from the same survey described above. However, only 58 households were selected for an intensive soil fertility study aimed at determining the nutrient balances at household level for 1 year.

The 58 households that collaborated in the on-farm trial were selected from four villages: Nemba/Kasheshe, Agonyo II,

[38] These predictions differ from predictions using actual values of all explanatory variables only in that predicted rather than actual income strategies and participation in programs and organizations are used as explanatory factors. This is to control for errors caused by differences in predicted responses arising from using predicted income strategies and participation. In all cases, the differences in mean predicted values between these two sets of predictions were relatively small.

Odwarat, and Kongta in Sironko, Soroti, Kumi, and Kapchorwa districts, respectively. The sites are located in eastern Uganda along a transect that captures variability in soil productivity, land use intensity, and agricultural potential. Maize is the dominant crop in the farming systems studied in these sites. The altitudes range from 1,060 meters above sea level (masl) in Odwarat to 1,890 masl in Kongta. The mean annual rainfalls range from 2,000 millimeters in Kongta and 1,850 millimeters in Nemba/Kasheshe to about 1,300–1,350 millimeters in Agonyo II and Odwarat. Rainfall is higher and much more reliable and the soils more fertile at Kongta and Nemba/Kasheshe than at the other two sites (Kaizzi 2002). The fields were characterized using soil chemical and physical characteristics obtained from soil samples collected from the 0–20-centimeters depth. The pH, organic matter, N, extractable P, exchangeable K, calcium (Ca), and texture were measured using the routine soil-sample lab analytical methods according to Foster (1971).

Using the household- and plot-level survey, the data on soil nutrient flows that the farmer controls were collected. The data collected were farm management and SWC practices, crop-livestock interaction, crop diversity, and income strategies that affect nutrient flow. These data were used to get the following nutrient flows: (1) inflows: mineral fertilizers, organic inputs from outside the farm, animal feeds and concentrates, grazing outside the farm, purchased food, biological nitrogen fixation, and sedimentation; (2) outflows: harvested crop products, animal products, crop residue, and exported manure. Conversion factors and coefficients were used to quantify the soil nutrients from each of the sources of inflows and channels of outflows. The conversion factors and coefficients were derived from experiments conducted in Uganda and other countries with similar environment (Giller and Wilson 1991; Stoorvogel and Smaling 1990; Defoer et al. 2000; Kaizzi 2002). For example, 1,000 kilograms of manure is estimated to be about 2 percent nitrogen. Hence, it produces about 20 kilograms of nitrogen per year (Defoer et al. 2000).[39]

Similarly, the nutrient flows that the farmer does not control were computed based on empirical work done in Uganda or other areas with similar environments. Additional physical data (such as the slope of the plot, soil type, rainfall, and other climatic data) were collected to help determine these exogenous nutrient flows using transfer functions drawn from the literature on soils. These flows are atmospheric deposition, leaching, and gaseous losses. Erosion outflows were estimated using RUSLE, as in the erosion analysis discussed earlier. The nutrient flows were used to determine nutrient balances for the farm as a whole.

We used explorative analysis of the data to detect the distribution of the variables and violation of regression assumptions. Data that were skewed or had heavy tails were transformed to normality, avoiding as much as possible the dropping of any observations. Family labor, distance from residence to parcel, and farm size were positively skewed. A log-transformation normalized the distributions for these variables. Heteroskedasticity was also observed in all models; hence, the feasible generalized least squares (FGLS) method was used to estimate asymptotically efficient parameters.

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[39]For details on transfer functions and conversion factors for quantifying nutrient flows, see the cited references.

# CHAPTER 4

# Income Strategies and Land Management in Uganda

In this chapter, we investigate the determinants of households' income strategies, choice of crops, land management practices, and labor use in crop production, and the impacts of these decisions and other factors on agricultural productivity, land degradation, and household income. First we present the results of econometric analyses, which show partial effects of each variable on the response or outcome of interest, controlling for other factors. Then we present the total predicted impacts of selected changes in policies and other explanatory factors, considering the indirect as well as direct relationships between explanatory factors and outcome variables, as discussed in Chapter 3.

## Income Strategies

The primary sources of household income reported by the sample households include production and sale of agricultural products in general; production and sale of cereals (especially maize, sorghum, and millet), export crops (mainly coffee, but also including cotton, sugarcane, and tobacco), root crops (sweet potatoes, yams, Irish potatoes, and cassava), bananas, legumes, and horticultural crops (fruits and vegetables); livestock production; forestry and fishing activities; off-farm work for wages or salary; beer brewing; and various other nonfarm activities (for example, petty trade, masonry, carpentry, butchery; Table 4.1).

Data on sources of income of the sample households in 2000 are fairly consistent with reported primary income sources (Table 4.2). In most cases, the largest share of income is from the source stated as the primary income source. In some cases, another activity earned the highest share of income (for example, nonfarm activities for livestock producers and root crop producers, root crops for legume producers); the reported primary income source was the second highest source of income in all of these cases. Thus, there may be some misclassification of the primary income source, although respondents likely reported what they view as their usual primary source of income rather than the highest income source in the specific year of the study. We interpret the reported primary income source as an indicator of the usual primary activity, rather than the activity that necessarily earned the highest income in the study year.

In general, the data in Table 4.2 show that most households in rural Uganda have diversified income sources, regardless of their reported primary income source. Crop production as a whole is the largest source of income, followed by nonfarm activities, which are also quite important for most households. This finding is consistent with numerous other studies of rural livelihoods in Africa (Reardon 1997; Ellis 2000; Barrett et al. 2001; Ellis and Bahiigwa 2003; Ellis and Mdoe 2003; Ellis et al. 2003).

**Table 4.1 Descriptive statistics of variables used in econometric analyses**

| Variable | Mean | Standard error | Number of observations | Minimum | Maximum |
|---|---|---|---|---|---|
| **Household-level variables** | | | | | |
| Primary income source (proportion of households) | | | | | |
| General agricultural production | 0.351 | 0.035 | 446 | 0 | 1 |
| Gifts/donations | 0.005 | 0.003 | 446 | 0 | 1 |
| Wages/salary | 0.066 | 0.019 | 446 | 0 | 1 |
| Livestock | 0.066 | 0.020 | 446 | 0 | 1 |
| Nonfarm activities | 0.080 | 0.020 | 446 | 0 | 1 |
| Forestry/fishing | 0.015 | 0.007 | 446 | 0 | 1 |
| Brewing beer | 0.040 | 0.012 | 446 | 0 | 1 |
| Legumes | 0.035 | 0.009 | 446 | 0 | 1 |
| Horticultural crops | 0.011 | 0.005 | 446 | 0 | 1 |
| Bananas | 0.072 | 0.013 | 446 | 0 | 1 |
| Cereals | 0.121 | 0.020 | 446 | 0 | 1 |
| Root crops | 0.038 | 0.006 | 446 | 0 | 1 |
| Export crops | 0.101 | 0.020 | 446 | 0 | 1 |
| Household income (1,000 Ush) | 1,440.185 | 179.786 | 446 | –1,795.1 | 11,519.17 |
| Income per capita (1,000 Ush) | 147.272 | 17.128 | 446 | –212.6 | 1,570.136 |
| Ethnic group (proportion of households) | | | | | |
| Baganda | 0.267 | 0.031 | 451 | 0 | 1 |
| Western peoples | 0.177 | 0.015 | 451 | 0 | 1 |
| Northern people (Langi, Acholi) | 0.068 | 0.012 | 451 | 0 | 1 |
| Iteso and Kumam | 0.064 | 0.010 | 451 | 0 | 1 |
| Eastern lakeshore people | 0.417 | 0.032 | 451 | 0 | 1 |
| Other eastern people | 0.006 | 0.002 | 451 | 0 | 1 |
| Agro-ecological zone (proportion of households) | | | | | |
| Unimodal rainfall | 0.137 | 0.017 | 451 | 0 | 1 |
| Bimidal low rainfall | 0.091 | 0.007 | 451 | 0 | 1 |
| Bimodal medium rainfall | 0.189 | 0.012 | 451 | 0 | 1 |
| Bimodal high rainfall | 0.460 | 0.020 | 451 | 0 | 1 |
| Southwest highlands | 0.084 | 0.005 | 451 | 0 | 1 |
| Eastern highlands | 0.039 | 0.006 | 451 | 0 | 1 |
| Market access zone (proportion of households) | | | | | |
| Low market access | 0.256 | 0.014 | 451 | 0 | 1 |
| High market access | 0.744 | 0.014 | 451 | 0 | 1 |
| Population density (persons/km$^2$) | 219.518 | 7.145 | 451 | 10 | 962 |
| Physical capital | | | | | |
| Area owned (acres) | 10.400 | 2.117 | 451 | 0 | 640 |
| Value of livestock owned (10,000 Ush) | 5.646 | 0.631 | 451 | 0 | 267 |
| Value of equipment owned (10,000 Ush) | 1.612 | 0.233 | 451 | 0 | 80.55 |
| Human capital | | | | | |
| Age of household head (years) | 46.146 | 0.875 | 451 | 20 | 90 |
| Household size | 11.198 | 0.387 | 451 | 1 | 32 |
| Proportion of dependents | 0.540 | 0.012 | 451 | 0 | 1 |
| Highest education of household head (proportion of households) | | | | | |
| Not completed primary | 0.521 | 0.035 | 451 | 0 | 1 |
| Primary | 0.331 | 0.033 | 451 | 0 | 1 |
| Secondary | 0.071 | 0.018 | 451 | 0 | 1 |
| Higher | 0.077 | 0.020 | 451 | 0 | 1 |
| Sex of household head (proportion of households) | | | | | |
| Male | 0.895 | 0.026 | 451 | 0 | 1 |
| Female | 0.105 | 0.026 | 451 | 0 | 1 |

(*continued*)

## Table 4.1—Continued

| Variable | Mean | Standard error | Number of observations | Minimum | Maximum |
|---|---|---|---|---|---|
| Participation in organizations (proportion of households) | | | | | |
| Agriculture/environment | 0.241 | 0.032 | 451 | 0 | 1 |
| Credit | 0.356 | 0.032 | 451 | 0 | 1 |
| Poverty reduction | 0.107 | 0.021 | 451 | 0 | 1 |
| Community services | 0.464 | 0.033 | 451 | 0 | 1 |
| Participation in technical assistance (proportion of households) | | | | | |
| Training | 0.500 | 0.034 | 451 | 0 | 1 |
| Extension | 0.312 | 0.032 | 451 | 0 | 1 |
| Availability of credit in village (proportion of households) | | | | | |
| Formal credit | 0.260 | 0.023 | 451 | 0 | 1 |
| Informal credit | 0.698 | 0.024 | 451 | 0 | 1 |
| **Plot level variables** | | | | | |
| Crop choice (proportion of plot area) | | | | | |
| Cereals | 0.210 | 0.011 | 1,436 | 0 | 1 |
| Legumes | 0.129 | 0.008 | 1,436 | 0 | 1 |
| Root crops | 0.191 | 0.009 | 1,436 | 0 | 1 |
| Vegetables | 0.094 | 0.005 | 1,436 | 0 | 1 |
| Coffee | 0.115 | 0.010 | 1,436 | 0 | 1 |
| Bananas | 0.198 | 0.011 | 1,436 | 0 | 1 |
| Land management practices (proportion of plots) | | | | | |
| Slash-and-burn | 0.113 | 0.015 | 1,785 | 0 | 1 |
| Inorganic fertilizer | 0.017 | 0.003 | 1,786 | 0 | 1 |
| Manure/compost | 0.176 | 0.014 | 1,876 | 0 | 1 |
| Incorporation of crop residues | 0.251 | 0.025 | 1,786 | 0 | 1 |
| Crop rotation | 0.406 | 0.020 | 1,786 | 0 | 1 |
| Mulch | 0.079 | 0.010 | 1,788 | 0 | 1 |
| Household residues | 0.136 | 0.011 | 1,786 | 0 | 1 |
| Preharvest labor input (person-hours) | 366.549 | 19.141 | 1,874 | 0 | 10,344 |
| Value of crop production (Ush) | 188,146 | 18,606 | 1,876 | 0 | $2.61 \times 10^7$ |
| Soil loss (mt/ha/year) | 5.758 | 0.626 | 1,584 | 0.02002 | 127.0776 |
| Altitude (100 masl) | 13.224 | 0.383 | 1,572 | 10.12 | 42.09 |
| Area-weighted average distance (km) to: | | | | | |
| Residence | 0.538 | 0.062 | 1,854 | 0 | 32 |
| All-weather road | 2.505 | 0.195 | 1,854 | 0 | 77 |
| Market | 4.494 | 0.268 | 1,854 | 0 | 37 |
| Tenure of plot (proportion of plots) | | | | | |
| Freehold | 0.283 | 0.033 | 1,861 | 0 | 1 |
| Leasehold | 0.044 | 0.014 | 1,861 | 0 | 1 |
| *Mailo* | 0.185 | 0.027 | 1,861 | 0 | 1 |
| Customary | 0.488 | 0.031 | 1,861 | 0 | 1 |
| Formal title of plot held (proportion of plots) | 0.038 | 0.011 | 1,861 | 0 | 1 |
| How plot acquired (proportion of plots) | | | | | |
| Purchased | 0.507 | 0.032 | 1,665 | 0 | 1 |
| Leased in | 0.047 | 0.013 | 1,665 | 0 | 1 |
| Borrowed | 0.035 | 0.008 | 1,665 | 0 | 1 |
| Inherited | 0.404 | 0.029 | 1,665 | 0 | 1 |
| Encroached common land | 0.006 | 0.005 | 1,665 | 0 | 1 |
| Expect to operate plot in 10 years? (proportion of plots) | | | | | |
| No | 0.038 | 0.009 | 1,861 | 0 | 1 |
| Yes | 0.933 | 0.011 | 1,861 | 0 | 1 |
| Uncertain | 0.029 | 0.007 | 1,861 | 0 | 1 |
| Plot area (acres) | 2.352 | 0.635 | 1,604 | 0.1 | 636 |

[a] masl—Meters above sea level.

**Table 4.2 Sources of income of sample households in 2000**

| | Mean household income, 2000 (1,000 Ush)[a] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Primary income source | Cereals | Legumes | Root crops | Export crops[b] | Bananas | Livestock | Labor | Nonfarm activities | Total household income[c] |
| | 213 | 82 | 259 | 87 | 238 | 162 | 177 | **528** | 1,813 |
| All households | (37) | (14) | (140) | (16) | (28) | (48) | (51) | (152) | (266) |
| General agricultural production | 235 | 62 | **499** | 72 | 200 | 65 | 37 | 371 | 1,519 |
| | (71) | (9) | (388) | (13) | (45) | (49) | (18) | (57) | (421) |
| Wage/salary | 66 | 20 | 17 | 21 | 98 | 184 | **1,556** | 177 | 2,164 |
| | (21) | (8) | (18) | (11) | (36) | (129) | (607) | (76) | (758) |
| Livestock | 92 | 234 | 164 | 117 | 284 | 1,549 | 362 | **3,422** | 6,675 |
| | (25) | (151) | (107) | (38) | (149) | (605) | (220) | (1,632) | (2,027) |
| Nonfarm activities | 74 | 81 | 70 | 181 | 199 | –26 | 115 | **412** | 1,115 |
| | (27) | (31) | (28) | (138) | (94) | (51) | (62) | (159) | (263) |
| Brewing | 693 | 55 | 76 | 58 | 353 | 126 | 42 | **702** | 2,003 |
| | (634) | (11) | (36) | (35) | (152) | (127) | (25) | (157) | (643) |
| Legumes | 470 | 154 | **649** | 25 | 149 | 15 | 43 | 135 | 1,611 |
| | (220) | (59) | (586) | (12) | (62) | (33) | (29) | (32) | (782) |
| Bananas | 87 | 76 | 106 | 33 | **893** | 39 | 129 | 350 | 1,590 |
| | (29) | (19) | (33) | (14) | (159) | (43) | (81) | (108) | (248) |
| Cereals | **412** | 107 | 111 | 30 | 64 | 117 | 16 | 167 | 1,452 |
| | (92) | (36) | (27) | (13) | (20) | (58) | (6) | (50) | (478) |
| Root crops | 62 | 23 | 107 | 0.4 | 5 | 11 | 37 | **174** | 378 |
| | (22) | (7) | (32) | (1.3) | (3) | (39) | (15) | (52) | (87) |
| Export crops | 121 | 67 | 125 | **263** | 245 | 21 | 87 | 236 | 1,162 |
| | (58) | (14) | (22) | (67) | (85) | (33) | (75) | (81) | (177) |

Note: Standard errors in parentheses.

a Net income for crops computed assuming that the shares of costs for each crop type are equal to the shares of value of production for each crop type. Figures in **bold** are the largest mean sources of income for each primary income source type of household.

b Export crops include coffee, cotton, sugarcane, and tobacco.

c Total income also includes net income from production of fruits, vegetables, and other minor crops, and net rental of assets (land, equipment).

Households reporting general agricultural production as their primary income source had relatively diversified income sources compared with most other groups, with less than one-third of their income provided by the largest source of income (root crops). Cereals, bananas, and nonfarm activities are also important income sources for this group. Only two other groups had more diversified income sources: those reporting cereals or export crops as their primary income source. For cereal producers, legumes, root crops, livestock, and nonfarm activities are also important income sources. For export crop producers, bananas, cereals, root crops, and nonfarm activities are also important.

The diversity of household income sources in Uganda is also reflected in Table 4.3, which shows the types of crops grown by households reporting different primary income sources. The average number of crop

## Table 4.3 Crop diversity of sample households in 2000

| Primary income source | Number of crop types[a] | Proportion of households producing type of crop, by income source | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cereals | Legumes | Root crops | Coffee | Bananas | Cotton | Sugarcane | Tobacco | Vegetables | Fruits |
| All households | 3.94 (0.08) | 0.899 | 0.894 | 0.707 | 0.460 | 0.657 | 0.053 | 0.029 | 0.021 | 0.150 | 0.077 |
| General agricultural production | 3.94 (0.34) | 0.895 | 0.911 | 0.661 | 0.546 | 0.622 | 0.055 | 0.010 | 0.013 | 0.214 | 0.012 |
| Wage/salary | 3.94 (0.41) | 0.802 | 0.978 | 0.781 | 0.445 | 0.673 | 0.015 | 0.000 | 0.000 | 0.071 | 0.178 |
| Livestock | 3.95 (0.41) | 0.817 | 0.720 | 0.533 | 0.558 | 0.913 | 0.041 | 0.000 | 0.016 | 0.213 | 0.136 |
| Nonfarm activities | 3.86 (0.32) | 0.870 | 0.869 | 0.784 | 0.333 | 0.715 | 0.000 | 0.150 | 0.000 | 0.103 | 0.033 |
| Brewing | 3.90 (0.34) | 0.926 | 0.949 | 0.758 | 0.509 | 0.661 | 0.026 | 0.000 | 0.036 | 0.036 | 0.000 |
| Legumes | 3.53 (0.34) | 0.947 | 0.974 | 0.672 | 0.210 | 0.507 | 0.079 | 0.000 | 0.000 | 0.000 | 0.141 |
| Bananas | 4.16 (0.24) | 0.857 | 0.829 | 0.696 | 0.430 | 0.955 | 0.000 | 0.014 | 0.000 | 0.146 | 0.228 |
| Cereals | 3.43 (0.17) | 0.999 | 0.935 | 0.633 | 0.184 | 0.414 | 0.158 | 0.001 | 0.036 | 0.069 | 0.003 |
| Root crops | 2.56 (0.12) | 0.866 | 0.660 | 0.882 | 0.015 | 0.107 | 0.026 | 0.000 | 0.000 | 0.000 | 0.000 |
| Export crops | 4.86 (0.15) | 0.952 | 0.962 | 0.842 | 0.794 | 0.829 | 0.061 | 0.084 | 0.090 | 0.161 | 0.085 |

[a] Average number of types of crops produced by each type of household (standard error in parentheses). Crop types include those listed in the table: cereals, legumes (pulses and oilseeds), root crops, coffee, bananas, cotton, sugarcane, tobacco, vegetables, and fruits.

types grown is nearly four for all households, and this is similar across most primary income source categories. Production of cereals, legumes, and root crops is common for all types of households, indicating that all household types have a diversified crop mix, regardless of their reported primary income source. The different categories of income strategies are thus differentiated less by the number of crops that they produce, than by the extent to which they depend on particular crop types or other income sources, as shown in Table 4.2.

Export crop producers are the most diversified crop producers, growing nearly five crop types on average—with most of these households producing coffee, bananas, cereals, legumes, and root crops. This mix of crops is also relatively common for households reporting general agricultural production, wages/salary, livestock, beer brewing, or bananas as their primary income source. Coffee production is less common among the households reporting other income sources (that is, nonfarm activities other than brewing beer or producing legumes, cereals, and root crops), and banana production is uncommon for root crop producers, who are the least diversified crop producers (averaging less than three crop types).

As the preceding discussion demonstrates, the reported primary income source is an imperfect indicator of households' income strategies. Nevertheless, we feel that this indicator is useful for reflecting important aspects of income strategies: it may be less subject to variations in income in a particular year resulting from variations in weather or prices, and thus, is probably a more robust indicator of income strategies than the realized income. This indicator also has the advantage that respondents can readily recall changes in their primary income sources, which is not possible for changes in realized income, thus facilitating an understanding of the dynamics of income strategies (as discussed below). We attempted to use reported secondary or tertiary sources of income (data were also collected on these) in classifying income strategies, but this proved unworkable, as there were simply too many categories. We thus use the reported primary income source as an (imperfect) indicator of income strategies in the remainder of this report, but the caveats given here should be kept in mind.

There have been changes in the reported primary income source of many of the sample households since 1990 (Table 4.4). General production and sale of agricultural products has increased, whereas wage/salary employment has declined. In more than one-third of households dependent on wage/salary employment in 1990, general agricultural production had become the primary income source by 2000. This may reflect life-cycle effects, in which young households start out focusing on wage employment, but shift into agriculture as they accumulate some wealth. This trend contradicts the common perception that most people want to move out of agriculture. It may also have been a phenomenon particular to Uganda in the 1990s, when market liberalization and favorable world coffee prices were leading to higher farm incomes (Deininger and Okidi 2001, 2003; Dijkstra and van Donge 2001; Pender et al. 2001b; Morrissey et al. 2003). Agricultural production also became more important for a significant number of households reliant on other nonfarm income sources in 1990 (nonfarm trade, forestry, fishing, and gifts and donations). Other fairly common changes in income sources included households shifting from wage/salary employment to other nonfarm activities, from nonfarm activities to livestock or export crops, and from legumes and root crops to cereals. In most households, however, the primary income source did not change between 1990 and 2000.

## Determinants of Income Strategies

Table 4.5 presents the results of a multinomial logit estimation of the determinants of

**Table 4.4 Changes in primary income sources between 1990 and 2000**

| Primary income source in 1990 | Proportion of observations in 1990 | Primary income source in 1999/2000 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | General agricultural production | Gifts/ Donations | Wage/ Salary work | Livestock | Nonfarm activities | Forestry/ Fishing | Brewing beer | Legumes | Horticultural crops | Bananas | Cereal crops | Root crops | Export crops |
| General agricultural production | 0.282 | **0.824** | 0.000 | 0.016 | 0.042 | 0.058 | 0.016 | 0.011 | 0.000 | 0.000 | 0.033 | 0.000 | 0.000 | 0.000 |
| Gifts/ donations/ remittances | 0.017 | 0.256 | **0.221** | 0.092 | 0.000 | 0.100 | 0.000 | 0.050 | 0.000 | 0.000 | 0.080 | 0.000 | 0.201 | 0.000 |
| Wage/salary work | 0.153 | 0.371 | 0.000 | **0.318** | 0.077 | 0.150 | 0.000 | 0.006 | 0.013 | 0.000 | 0.053 | 0.002 | 0.010 | 0.000 |
| Livestock | 0.049 | 0.079 | 0.024 | 0.171 | **0.497** | 0.133 | 0.000 | 0.000 | 0.000 | 0.000 | 0.089 | 0.007 | 0.000 | 0.000 |
| Other nonfarm activities | 0.084 | 0.258 | 0.000 | 0.046 | 0.222 | **0.189** | 0.000 | 0.016 | 0.000 | 0.032 | 0.000 | 0.064 | 0.010 | 0.163 |
| Forestry/ fishing | 0.030 | 0.327 | 0.000 | 0.000 | 0.000 | 0.000 | **0.276** | 0.000 | 0.034 | 0.000 | 0.092 | 0.124 | 0.000 | 0.147 |
| Brewing beer | 0.042 | 0.034 | 0.000 | 0.080 | 0.000 | 0.000 | 0.000 | **0.715** | 0.092 | 0.000 | 0.079 | 0.000 | 0.000 | 0.000 |
| Legumes | 0.049 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.024 | **0.452** | 0.000 | 0.161 | 0.271 | 0.024 | 0.068 |
| Horticultural crops | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | **1.000** | 0.000 | 0.000 | 0.000 | 0.000 |
| Bananas | 0.051 | 0.000 | 0.000 | 0.000 | 0.000 | 0.056 | 0.000 | 0.000 | 0.061 | 0.000 | **0.656** | 0.094 | 0.000 | 0.132 |
| Cereals | 0.097 | 0.040 | 0.002 | 0.000 | 0.000 | 0.000 | 0.002 | 0.000 | 0.042 | 0.000 | 0.016 | **0.761** | 0.065 | 0.072 |
| Root crops | 0.043 | 0.000 | 0.000 | 0.000 | 0.101 | 0.000 | 0.000 | 0.000 | 0.000 | 0.036 | 0.077 | 0.252 | **0.535** | 0.000 |
| Export crops | 0.102 | 0.076 | 0.000 | 0.000 | 0.000 | 0.046 | 0.000 | 0.055 | 0.022 | 0.000 | 0.028 | 0.068 | 0.006 | **0.699** |
| Proportion of observations in 2000 | 1.000 | 0.341 | 0.005 | 0.070 | 0.071 | 0.071 | 0.013 | 0.043 | 0.038 | 0.008 | 0.078 | 0.119 | 0.037 | 0.106 |

Note: Figures are given as proportion of households having a given primary income source in 1990. Diagonal elements represent proportion of households that did not change their primary source of income between 1990/2000.

primary income sources.[40] Different income sources are associated with differences in agroclimatic conditions, access to markets and roads, human capital, and ethnicity.[41]

Wage/salary employment was not the primary income source of any household in the bimodal low-rainfall (BL) zone or the eastern highlands (EH). Wage/salary income was more important for households with higher education (beyond the "O" level).[42]

Beer brewing was less common in the BL zone, and more common further from a market. It was not a primary income source for any sample household whose head had higher education, or among the northern (Langi, Acholi) or other eastern (Sabiny, Sebei) ethnic groups. It was less important for eastern lakeshore people than for Baganda people.

Other nonfarm activities (for example, petty trade, masonry, carpentry, butchering) were less important in the BL and bimodal medium-rainfall (BM) zones than in the unimodal (U) zone. They were more important among more educated (post-secondary), younger, and larger households, and those headed by women. As with beer brewing, other nonfarm activities were not important among the northern or other eastern ethnic households sampled.

Livestock production was not a primary income source for any sample households in the EH, and was more important in all other zones outside of the U zone, controlling for other factors. It was not a primary income source for households whose head had completed secondary education, or for households of Iteso or Kumam ethnicity, but was much more common for Sabiny and Sebei ethnic groups.

Cereal production is least likely to be the primary income source in the EH in general, controlling for other factors. However, some eastern ethnic groups (Sabiny and Sebei) are much more likely than others to specialize in cereal production. Thus, cereal production in the EH is more closely associated with certain ethnic groups in the region than with residence in the region in general. Northern ethnic groups (Langi and Acholi) are also more likely to depend on cereal production than Baganda households. Household heads with higher education are less likely than uneducated heads to have cereal production as a primary income source.

Legume production was not a primary income source for any sample households in the EH, and was less important in the southwest highlands (SWH) than in the U zone. It is more important at higher elevations and in areas of good market access. Legumes are not a primary income source for any sample households whose head completed secondary education. They are more important for households with more dependents, and less important among the Baganda than among other ethnic groups.

Ethnicity appears largely to determine the importance of banana production. Banana production is most important for Baganda and western ethnic groups, for whom the cooking banana (*matooke*) is a

[40]The results in Table 4.5 are relative to general agricultural producers (the excluded livelihood category in the multinomial logit regression). Some income sources (primary income source as gifts or donations, forestry and fishing, or horticultural production) were excluded from the analysis reported in Table 4.5 due to the small number of observations.

[41]The ethnic groups found among the survey sample households were grouped into the following categories, based on consultation with Ugandan collaborators: Baganda people (the dominant ethnic group in central Uganda); western people (including Banyankore, Bakiga, Bafumbira, and other less common western ethnic groups); northern people (Langi and Acholi); Iteso and Kumam ethnic groups of the Teso region; eastern lakeshore people (Basoga, Bagisu, Banyole, Bagwere, and other less common eastern groups), and other eastern people (Sabiny and Sebei).

[42]The "O" level is achieved after completing seven years of primary school and four years of secondary school.

## Table 4.5 Determinants of primary income source in 1999/2000 (multinomial logit regression[a])

| Variable | Wages/ Salary | Livestock | Brewing beer | Other nonfarm activities | Cereals | Legumes | Bananas | Root crops | Export crops |
|---|---|---|---|---|---|---|---|---|---|
| Agroclimatic zone[b] | | | | | | | | | |
| Bimodal low rainfall (BL) | N | 21.344*** | –2.239** | –3.676** | 0.890 | –0.404 | –1.467 | N | N |
| Bimodal medium rainfall (BM) | –0.575 | 20.784*** | 0.414 | –4.428** | 1.558* | –0.904 | –2.043 | 2.073* | 0.637 |
| Bimodal high rainfall (BH) | 0.598 | 21.724*** | –0.811 | –2.655* | 0.835 | –2.844* | –1.328 | N | 0.258 |
| Southwest highlands (SWH) | 1.073 | 20.593*** | 1.189 | –1.820 | –0.086 | –9.761** | 0.567 | 2.415 | –0.270 |
| Eastern highlands (EH) | N | N | 2.555 | 2.088 | –20.008*** | N | 4.761** | –5.320** | 0.800 |
| Altitude (100 masl) | –0.086 | 0.014 | –0.208 | –0.180 | –0.647 | 0.873** | –0.298 | 1.018** | –0.078 |
| High market access | 0.631 | 1.020 | –0.777 | 2.188* | 0.880 | 4.074** | 0.583 | –1.044 | –0.650 |
| Distance to all weather road (km) | –0.021 | 0.070 | –0.062 | 0.049 | 0.001 | –0.296 | 0.009 | 0.225** | –0.069 |
| Distance to market (km) | 0.001 | –0.009 | 0.180*** | –0.028 | –0.034 | –0.153 | 0.029 | –0.166 | 0.099* |
| Population density (persons/km$^2$) | 0.000 | 0.000 | –0.001 | –0.006 | –0.002 | 0.005 | –0.003 | 0.002 | 0.000 |
| Education of household head[c] | | | | | | | | | |
| Completed primary | 1.044* | –0.188 | 1.106 | 0.413 | 0.471 | –0.708 | –0.780 | 2.167*** | –0.492 |
| Completed secondary (“O” level) | –2.199* | N | 0.833 | 1.342 | –0.919 | N | –0.290 | 0.854 | –0.572 |
| Higher education | 2.188*** | 2.123* | N | 2.989*** | –3.156*** | –1.358 | 0.664 | N | N |
| Age of household head (years) | –0.022 | –0.017 | 0.022 | –0.106*** | 0.013 | –0.046 | –0.023 | –0.012 | 0.031 |
| Female head of household | 0.331 | 1.955 | 0.877 | 1.752** | – 1.576 | 1.846 | –0.538 | –0.073 | –0.689 |
| Number of household members | –0.107 | 0.011 | 0.123 | 0.215*** | –0.096 | 0.111 | 0.079 | –0.117 | –0.005 |
| Dependents (proportion of households) | 5.127* | 3.495 | 0.874 | 0.206 | 2.368* | 5.648** | 0.847 | 1.064 | 4.583*** |
| Land area owned (acres) | –0.031 | 0.024 | –0.003 | –0.023 | 0.018 | 0.020 | 0.013 | –0.040 | 0.027 |
| Ethnicity of household head[d] | | | | | | | | | |
| Western people (Banyankore, Bakiga, Bafumbira, others) | 0.398 | 1.352 | –0.632 | 1.030 | 1.390 | 24.151*** | 1.658* | –8.012*** | 0.970 |
| Northern people (Langi, Acholi) | –0.338 | 2.823 | N | N | 2.177** | 25.767*** | N | 4.226** | N |
| Iteso and Kumam | 1.078 | N | –0.941 | –5.177 | 0.719 | 28.024*** | N | 3.721** | N |
| Eastern lakeshore people (Basoga, Bagisu, Banyole, Bagwere, others) | –1.249 | –1.547 | –2.195** | –1.217* | –0.439 | 18.192** | –3.687*** | N | –0.898 |
| Other eastern people (Sabiny, Sebei) | –1.359 | 122.9*** | N | N | 32.401*** | 21.267*** | N | N | N |
| Proportion of observations | 0.067 | 0.067 | 0.040 | 0.080 | 0.122 | 0.035 | 0.064 | 0.038 | 0.102 |
| Mean predicted probability | 0.069 | 0.068 | 0.043 | 0.083 | 0.125 | 0.037 | 0.067 | 0.041 | 0.104 |

Notes: *, **, *** = reported coefficient is statistically significant at 10 percent, 5 percent, or 1 percent level, respectively. N—there were no observations having this primary income source for all positive values of the particular explanatory variable; masl—meters above sea level.

[a] The omitted category is “production and sale of agricultural produce.” Intercept not reported. All coefficients and standard errors adjusted for sampling weights and stratification. Number of observations was 426. Livelihoods associated with gifts/donations, forestry/fishing, and horticulture as the primary income sources were excluded, due to the small number of observations.

[b] In contrast to the unimodal rainfall zone.

[c] In contrast to not completed primary education.

[d] In contrast to Baganda.

primary staple, controlling for other factors. It is less important for eastern lakeshore people than for Baganda people, and is not a primary income source for any sample households of the northern, Iteso, Kumam, or other eastern ethnic groups. Banana production is more important in the EH than in the U zone.

Root crop production (sweet potatoes, yams, Irish potatoes, or cassava) is less important in the EH than in the U zone, and is not the primary income source of any sample households in the BL and bimodal high-rainfall (BH) zones. Root crop production is more important at higher elevations, and further from an all-weather road. It is more important for household heads who have completed primary education than for less educated households, but is not a primary income source for any sample household heads with higher education. It is less important for western and eastern ethnic groups and more important for northern, Iteso, and Kumam ethnic groups than for Baganda households.

Export crops production (coffee, cotton, and other minor export crops) is not a primary income source for any sample households in the BL zone, or for any household heads with higher education. It is more important for households having more dependents. Export crops are not the primary income source for any sample households of the northern, Iteso, Kumam, or other eastern ethnic groups.

In summary, export crop production, nonfarm activities, and wage/salary income are least important in the low agricultural potential BL zone, where livestock production is relatively important. Livestock is also important and nonfarm activities limited in the BM zone, but cereal production is more important in this zone. Livestock and root crops are more important in the SWH, whereas bananas and beer brewing are relatively important in the EH, controlling for other factors. Other factors that influence income sources include altitude (higher altitudes favor legumes), market access (better access favors production of cereals and legumes), access to an all-weather road (better access predicts less beer brewing), higher education (favors wage and salary employment and other nonfarm activities over beer brewing or production of export crops or root crops), age and gender (nonfarm activities more important for younger households or those headed by women), household size (favors non-farm activities), greater numbers of dependents (favors production of legumes or export crops), and ethnicity (many significant impacts).

The negative impact of low agricultural potential on rural wage income and nonfarm activities emphasizes the important role of agriculture in stimulating rural off-farm and nonfarm activities, as emphasized in the rural "growth linkages" literature (Hazell and Roell 1983; Haggblade et al. 1989, 1991; Hazell and Hojjati 1995). The positive impact of higher education on off-farm employment and nonfarm activities is consistent with the findings of much of the literature on determinants of rural nonfarm income in Africa, which emphasizes barriers to entry (such as limited education) into higher-income occupations (for example, Barrett et al. 2001, 2002a). As in some of that literature, our results also suggest that "push factors" are contributing to nonfarm activities, such as constraints faced by younger or larger households, or those headed by women. However, we find that access to markets and roads has less impact on off-farm employment and nonfarm activities than expected or found in some of the literature. The impacts of ethnicity on income strategies is not well studied in research on rural livelihoods, diversification, and nonfarm income; however, the strong impacts of ethnicity that we found suggest that this is an important variable to consider in such analyses.

Many of our findings are consistent with our hypotheses about determinants of income sources. For example, agro-ecological potential is a primary determinant of livelihoods, with cash crops and nonfarm activities less important and livestock more important in low-rainfall areas, whereas cereal production is more important in medium-rainfall areas. Contrary to our expectations, legumes are more important in better market-access areas, where we expected more perishable crops to have comparative advantage. Interestingly, population density and land ownership were found to have insignificant impacts on the primary income source.[43] These factors may have more influence on the intensity of agricultural practices than on income sources (discussed below).

## Crop Choice

The most common crops grown in the study region of Uganda include cereals, legumes, root crops, vegetables, coffee, and bananas (see Table 4.1). As with the primary income source, the choice of which crops to plant on a particular plot is influenced by agro-climatic factors, access to markets and roads, and the human capital of the household (Table 4.6).[44] The choice is also influenced by population density and land ownership; the household's primary income source; its ownership of assets; participation in organizations, training, or extension programs; the size, tenure status, and quality of the plot; and the presence of land investments on the plot.[45]

Not surprisingly, the primary income source significantly influences a household's choice of crops on a given plot. Households with off-farm wages or salary as their primary income source are more likely to plant vegetables; perhaps because off-farm income enables them to purchase staple foods or cash inputs for vegetable production. Households for whom horticultural production is an important income source are more likely to plant vegetables or root crops on a given plot, and less likely to plant cereals. Households reliant on cereals for income are more likely to plant cereals on a given plot. Households reliant on root crop income are more likely to plant root crops and less likely to plant legumes. Households reliant on export crop income are more likely to plant vegetables and less likely to plant cereals. These findings are robust to the use of predicted rather than actual income sources in the regression specification.[46]

Crop choices differ across agro-climatic zones, controlling for income sources and other factors. Cereal crops are least common in the highland zones. Root crops are most common in the BM and SWH zones. Vegetables are most common in the bimodal rainfall areas (BL, BM, and BH), and are more common at higher elevations. These findings are robust in the reduced-form (RF)

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[43]Joint hypothesis tests for the significance of these variables were statistically insignificant (probability of false rejection of null hypothesis ($p$-value) was 0.46 for population density and 0.54 for area owned).

[44]As mentioned in Chapter 3, here we focus on determinants of annual crop choice. We regard current production of perennial crops as a predetermined decision in the year of the survey.

[45]As noted in Chapter 2, the extension programs we are referring to here do not include the National Agricultural Advisory Services, as this program was founded after our survey was completed.

[46]Other associations were found in the regressions reported in Table 4.6 but were not robust when predicted values of livelihoods and predicted participation in organizations and programs were used as explanatory variables to control for possible endogeneity bias. To predict livelihoods, a regression similar to that reported in Table 4.5 was used, but which also includes livelihoods in 1990 as explanatory factors (results available upon request). Multicollinearity is not much of a problem in the regressions using actual values of explanatory variables; the maximum variance inflation factor (VIF) is less than 5. However, multicollinearity is a problem for some variables—especially participation in organizations and training—in the regressions using predicted values of these variables (VIF is greater than 10 for several of these variables). This limits the ability to identify the effects of these variables using predicted values in the specification. Multicollinearity was not a major problem (VIF less than 5) for livelihoods and most other variables in the predicted values specification.

**Table 4.6 Determinants of annual crop choice in 1999/2000 (censored regressions)**

| Variable[a] | Cereals | Legumes | Root crops | Vegetables |
|---|---|---|---|---|
| Primary income source[b] | | | | |
| Gifts/donations | –0.304 | –0.047 | –0.135+++ | 0.068––– |
| Wages/salary | 0.066–– | 0.039 | 0.111+++ | 0.101**+++ |
| Livestock | –0.053 | –0.015––– | –0.018 | 0.027 |
| Nonfarm activities | –0.040 | –0.015– | 0.100 | 0.069 |
| Forestry/fishing | –0.028 | 0.042 | 0.020 | 0.010 |
| Brewing beer | –0.023 | –0.062– | 0.066 | 0.009 |
| Legumes | 0.103 | 0.019 | –0.004++ | 0.004 |
| Horticultural crops | –0.173**––– | 0.035 | 0.185**+ | 0.282***+++ |
| Bananas | –0.078– | –0.021 | –0.193*** | –0.036 |
| Cereals | 0.254***+++ | –0.034 | –0.007+ | –0.116*** |
| Root crops | 0.022––– | –0.108**– | 0.291***+++ | –0.020 |
| Export crops | –0.154***– | –0.058 | 0.046 | 0.093**+++ |
| Agro-ecological zone[c] | | | | |
| Bimodal low rainfall (BL) | –0.086 | 0.094–R | 0.046 | 0.144***+++R |
| Bimodal medium rainfall (BM) | –0.100 | –0.025–– | 0.251***+R | 0.164***++R |
| Bimodal high rainfall (BH) | –0.101R | –0.086––– | 0.122 | 0.118***R |
| Southwest highlands (SWH) | –0.223**R | 0.030–– | 0.269***R | 0.043R |
| Eastern highlands (EH) | –0.214*–––R | 0.051 | –0.052 | 0.082R |
| Altitude (100 masl) | 0.005+ | 0.004 | –0.005R | 0.009***+++R |
| Good market access | –0.086** | 0.002 | –0.110** | –0.004 |
| Area-weighted average distance to (km): | | | | |
| Residence | –0.009 | 0.023 | –0.083***––R | –0.049**– |
| All-weather road | 0.000 | 0.003+ | 0.002 | –0.003–– |
| Nearest market | 0.001 | 0.004*R | 0.003 | 0.003 |
| Population density (100 persons/km$^2$) | 0.003 | 0.003 | –0.015– | –0.032***–––R |
| Assets | | | | |
| Land owned (acres) | 0.000 | 0.000 | –0.001***R | 0.000** |
| Value of livestock owned (10,000 USh) | 0.000 | 0.001 | 0.000 | 0.000 |
| Value of equipment owned (10,000 USh) | –0.008 | 0.000 | 0.008* | 0.000 |
| Education of household head[d] | | | | |
| Primary | –0.070 | 0.030 | –0.059– | 0.075***R |
| Secondary | 0.022 | –0.044–– | –0.035 | –0.025 |
| Higher education | 0.015++ | 0.009– | –0.070 | –0.021 |
| Age of head (years) | 0.002 | 0.002 | –0.002R | 0.000 |
| Female head | 0.124**R | 0.043 | 0.003 | 0.043 |
| Size of household | –0.005R | –0.003 | –0.003 | 0.002 |
| Proportion of dependents | –0.121 | –0.162–R | –0.043 | –0.154** |
| Participation in organizations | | | | |
| Agriculture/environment | –0.122***–– | 0.029 | 0.000 | 0.014 |
| Credit | –0.008+ | 0.011 | 0.043––– | 0.027––– |
| Poverty reduction | –0.002+ | –0.038 | 0.044+ | 0.038+++ |
| Community services | 0.023 | –0.004 | 0.098***+++ | 0.022 |
| Participation in technical assistance programs | | | | |
| Longer-term training | 0.033 | 0.010++ | –0.094*** | –0.025 |
| Short-term extension | 0.036 | –0.023++ | 0.068 | 0.049** |
| Credit availability in village | | | | |
| Formal credit | –0.092R | –0.078 | 0.095 | 0.024 |
| Informal credit | 0.137**++ | –0.136***–––R | 0.101 | –0.025 |
| Tenure of plot[e] | | | | |
| Leasehold | 0.081 | 0.107 | –0.037 | –0.089 |
| *Mailo* | –0.210***–––R | –0.154***–––R | 0.091* | –0.036R |
| Customary | –0.023 | –0.040- | 0.003 | –0.029 |

(*continued*)

**Table 4.6—Continued**

| Variable[a] | Cereals | Legumes | Root crops | Vegetables |
|---|---|---|---|---|
| Formal title to plot | –0.160–R | –0.188***––R | –0.108– | –0.180*––R |
| How plot was acquired[f] | | | | |
| Leased in | 0.337**+++R | 0.041 | –0.059 | 0.170**R |
| Borrowed | 0.083 | 0.086 | 0.252**+R | 0.151** |
| Inherited | 0.033 | 0.035 | 0.047 | 0.051*+ |
| Encroached communal land | –0.682*–R | –0.050 | 0.677***+++R | 0.318**+R |
| Expect to operate plot in ten years?[g] | | | | |
| Yes | –0.183 | –0.061 | 0.175 | 0.029 |
| Uncertain | –0.248 | –0.019 | 0.219+ | –0.074 |
| Area of plot (acres) | 0.038***+++R | 0.019*+++ | 0.007 | –0.003 |
| Slope of plot (cf. flat) | | | | |
| Moderate | –0.046 | –0.029 | 0.018 | 0.055 |
| Steep | –0.115 | 0.007 | 0.062 | 0.090 |
| Mixed | –0.148 | –0.106– | 0.228**+++R | 0.160**+ |
| Investments on plot | | | | |
| Irrigation | 0.024 | –0.460**–– | 0.171 | 0.326***+++ |
| Trenches | –0.356***––– | –0.129**–– | –0.141**–– | –0.032 |
| Grass strips | 0.092 | –0.026 | –0.127– | –0.167**–– |
| Live barriers | –0.028 | 0.036 | –0.123 | –0.055 |
| Trees | –0.088*–– | 0.060 | –0.079 | –0.067* |
| Intercept | 0.273+ | –0.029 | –0.253– | –0.256*–– |
| Number of observations | 1,189 | 1,189 | 1,189 | 1,189 |
| Uncensored ($0 < y < 1$) | 519 | 510 | 532 | 417 |
| Left censored (=0) | 582 | 669 | 568 | 767 |
| Right censored (=1) | 88 | 10 | 89 | 5 |

Notes: Figures are percentages of plot area planted. Full regression results are available upon request. *, **, *** = reported coefficient is statistically significant at the 10 percent, 5 percent, or 1 percent level, respectively; +, ++, +++ (–,––,–––) = coefficient is positive (negative) and statistically significant at the 10 percent, 5 percent, or 1 percent level, respectively, in regressions using predicted value of livelihoods, participation in organizations, training or extension; R = coefficient is of the same sign and statistically significant at 10 percent level in reduced-form regression, excluding variables for livelihoods, participation in organizations, training, extension, and land investments, but including ethnic groups. masl—Meters above sea level.

[a] Coefficients of some plot quality variables (position on slope, soil depth, texture, color, and perceived fertility) not reported due to space limitations.

[b] In contrast to general agricultural production.

[c] In contrast to the unimodal rainfall zone.

[d] In contrast to not completed primary education.

[e] In contrast to freehold tenure.

[f] In contrast to purchased.

[g] In contrast to "No."

specification and most are robust to use of predicted income sources.

Root crops and vegetables are more common on plots closer to the household residence. This makes sense, given the difficulty of transporting such crops due to their bulkiness (especially root crops) and fragility (many vegetables). The risk of theft of high-value crops, such as vegetables, may also explain why these are less likely to be grown far from the homestead. Legumes are more common farther from the nearest market, consistent with our hypothesis that such storable crops have a comparative advantage away from markets. Also consistent with this, cereals and root crops are more common in areas of poor market access, although this result is not statistically robust in the instrumental variables (IV) or RF specifications.

Population pressure and land ownership affect planting of some crops. Vegetables are less common in more densely populated communities, perhaps because land constraints and demand for food staples limit vegetable production in such areas. Consistent with this explanation, vegetable production is more common (although this result not robust) and root crop production less common for farmers who own more land.

Household heads that have completed primary education are more likely to produce vegetables than are less educated heads. As hypothesized, education contributes to households' ability to produce such high-value crops.

Households headed by women are more likely to produce cereals. This may be due to a greater emphasis by women on food crop production in Uganda.

Participation in organizations is associated with different crop choices. Households that participate in agriculture or environment-oriented organizations are less likely to plant cereals. Perhaps such organizations promote other types of crops, or the technologies that are promoted (for example, mulching) are more suited to other crops (such as bananas), and thus indirectly contribute to reduced planting of cereals. Participants in community service organizations are more likely to plant root crops, although the reasons for this are not clear. Participation in technical assistance programs does not have statistically robust impacts on crop choice.

Availability of informal credit also appears to influence crop choice. In communities where informal credit is available, households are more likely to plant cereals but less likely to plant legumes. It may be that informal credit is more useful for cereal production, which may involve more use of purchased inputs, such as hybrid seeds or more hired labor (especially maize).

Land tenure influences crop choice as well. Cereals and legumes are less likely to be planted on *mailo* land than on land under other types of tenure. This may be because *mailo* occupants are more dependent on subsistence agriculture, and commonly produce *matooke* for their own consumption. Cereals, legumes, and vegetables are less likely to be planted on parcels for which the farmer has formal title; title ownership may favor perennial crop production by increasing tenure security. Leased plots are more likely to be planted in cereals or vegetables than are purchased plots, probably because leases tend to be short term, limiting the ability of tenants to benefit from perennial crop production. Root crops are more common on borrowed plots, probably for a similar reason. Plots acquired through encroachment on communal land are more likely to be planted in root crops or vegetables, possibly also due to tenure insecurity. However, cereals are less likely to be planted on encroached communal land than on purchased plots. This may reflect the greater land preparation required to cultivate cereals than some other crops on uncultivated communal land.

The investments that have been made on the plot also influence crop choice. Not surprisingly, vegetables are more likely and legumes less likely to be planted on irrigated plots than on rainfed plots. Several types of annual crops (cereals, legumes, and root crops) are less likely on plots with trenches, probably because trenches are used for perennials to accumulate organic matter and soil moisture around the plants. Plots with grass strips are less likely to be planted in vegetables, and the presence of trees reduces the likelihood of planting cereals (probably due to difficulties of tilling cereals where trees are present).

Plot size also influences crop choice. A larger share of area is planted to cereals and legumes on larger plots, suggesting that there are economies of size in producing these crops, or that transportation or other constraints limit the scale of production of other less readily stored crops. Other plot characteristics (slope, position on slope, soil depth, texture, color, and perceived fertility) influence crop choice as well. To focus the discussion on policy and socioeconomic factors, in this report, we do not focus on the impacts of such biophysical factors, although they are controlled for in the regressions.[47]

To summarize this section, annual crop choice on a given plot is influenced by many factors, including agro-ecological conditions, access to markets and to the plot, population density and farm size, the household's income strategy, education and participation in organizations, availability of credit, land tenure, prior investments on the plot, and the size and quality of the plot. These findings indicate that crop choice is determined by more than just biophysical factors at the plot level, which would occur in the idealized case of perfect markets with no transaction costs. In the presence of imperfect markets and transactions costs, crop choice also depends on community- and household-level socioeconomic factors that affect the local profitability, risks, and constraints of different crops for different households. Thus, for example, we find that smaller farms are more likely to grow root crops and less likely to grow vegetables, probably as a subsistence strategy, whereas more educated households are better able to grow high-value vegetable crops. Farmers are more likely to grow annuals, such as cereals and vegetables, than perennials on leased plots, given the lack of long-term tenure security on leased land and the need to earn cash in the near term to pay for the lease.

These findings suggest that public investments and development of commodity and factor markets can have a major impact on crop production choices in Uganda. For example, investments in education and irrigation will promote increased production of vegetable crops, whereas development of short-term credit markets could facilitate cereal production. Increased fragmentation of land may undermine production of bulky root crops and vegetables (given that these crops are more likely to be produced close to the homestead), whereas increased reliance on land leasing for access to land will favor production of such crops over perennials. The implications of such changes for agricultural productivity, income, and land degradation will be considered further below.

## Land Management Practices

The most common land management practices used by farmers in the study villages are crop rotation, incorporation of crop residues, application of household residues, application of manure or compost, use of slash-and-burn to prepare fields, and application of mulch (see Table 4.1).[48] We investigate determinants of these practices, as well as the use of inorganic fertilizer, which is much less common (used on less than 2 percent of plots).

Farmers' land management practices depend on many factors, including the presence of perennial crops on the plot (Table 4.7). Not surprisingly, slash-and-burn, fertilizer use, and crop rotation are less common on plots with a greater share of area in coffee or bananas, as such practices are associated more with annual crops. On the other hand, application of manure, compost, mulch, and household residues is more common on these perennials. This finding is consistent with findings from analysis of a community survey in the same villages showing that adoption of such land management practices is associated with perennial

[47]Full regression results are available from the authors upon request.

[48]Household residues include kitchen waste and other residues from the household. Compost includes vegetative wastes (usually from crop production) combined with manure.

**Table 4.7 Determinants of land management practices (probit regressions)**

| Variable[a] | Slash-and-burn | Fertilizer[b] | Manure and compost | Incorporate crop residues | Rotate crops | Mulch | Incorporate household residues |
|---|---|---|---|---|---|---|---|
| Primary income source[c] | | | | | | | |
| Gifts/donations | N | | N | 1.257 | –0.898 | 2.956*** | –0.355 |
| Wages/salary | –1.229*** | | –0.540 | 0.119– | –0.053 | –0.491 | –0.217 |
| Livestock | 0.307 | | 0.500 | 0.781* | 0.343 | 0.612+++ | 0.429 |
| Nonfarm activities | 0.454 | | 0.078 | –0.240 | –0.163 | 0.133 | 0.099 |
| Forestry/fishing | –0.052 | | 0.038 | 0.093 | 0.468 | 0.046 | 0.216 |
| Brewing beer | 0.131 | | –0.062 | –0.101 | 0.111 | –0.148––– | 0.437+ |
| Legumes | –0.727* | | 0.717** | 0.229– | –0.274––– | 0.894*+ | 0.337 |
| Horticultural crops | 0.024 | | 0.323 | 0.440 | 0.451+ | 2.512***+++ | 1.156*** |
| Bananas | –0.555 | | –0.297 | 0.047– | –0.267 | 0.679* | –0.235 |
| Cereals | –0.658**– | | –0.070 | –0.191 | –0.128 | –0.176 | 0.532** |
| Root crops | –0.143 | | 0.014 | 0.101 | –0.319 | 0.046 | –0.244 |
| Export crops | 0.226 | | –0.211– | –0.475–– | –0.311 | –0.491 | 0.146 |
| Agro-ecological zone[d] | | | | | | | |
| Bimodal low rainfall (BL) | 0.672* | 0.001 | –0.071––R | –0.349 | 0.267R | 2.206*** | –0.127R |
| Bimodal medium rainfall (BM) | 0.650**R | 0.542 | –0.165R | –0.263 | –0.033 | 1.027* | –0.551*R |
| Bimodal high rainfall (BH) | –0.035–– | 0.384––– | –0.086 | –0.230 | 0.149R | 1.358***+++ | –0.796***R |
| Southwest highlands (SWH) | –1.769***–––R | 2.240*** | 0.693* | 0.477R | –0.312–– | 2.143*** | 1.138***++ |
| Eastern highlands (EH) | –1.774***R | 3.859***+++R | 0.722*R | –0.161–– | –0.573––– | –0.522–– | –0.16R |
| Altitude | –0.009 | –0.012 | 0.049***+++R | 0.002 | 0.020++ | 0.039**+++R | 0.042***+++R |
| High market access | –0.774***–––R | –0.066 | 0.109R | 0.404* | –0.147––– | –0.706**– | –0.494*** |
| Area-weighted average distance to (km): | | | | | | | |
| Residence | 0.187*+++R | –0.499 | –0.198*––R | 0.033 | 0.188**+ | –0.806***–––R | –0.282*––R |
| All-weather road | 0.004 | 0.010 | 0.011 | –0.002 | –0.014 | –0.022 | –0.006 |
| Nearest market | 0.005 | –0.071**––– | 0.000 | 0.000 | –0.013 | 0.010 | –0.001 |
| Population density | 0.001** | 0.003*** | 0.000 | –0.001 | 0.000 | 0.000 | 0.002+++R |
| Assets | | | | | | | |
| Land owned | 0.003***++R | –0.111*R | –0.023*R | –0.001 | 0.000+++ | –0.001 | –0.002 |
| Value of livestock | 0.001 | 0.003 | 0.000 | –0.005 | –0.012 | 0.002 | 0.006 |
| Value of equipment | –0.080***––– | –0.208** | –0.035 | 0.017 | 0.029 | –0.116** | –0.030-R |
| Education of household head[e] | | | | | | | |
| Primary | 0.248 | 1.668***–R | –0.225 | –0.064 | –0.113–– | –0.694**R | –0.429***R |
| Secondary | 0.189R | –0.250 | 0.165 | 0.141 | –0.625***––– | 0.419 | 0.547**++ |
| Higher education | 0.726** | 0.261– | 0.542R | –0.112 | –0.161––– | –0.002 | –0.381R |
| Age of head | –0.011 | –0.023 | 0.005 | 0.006 | 0.011**R | 0.008++ | 0.000 |
| Female head | 0.054 | –1.576*–– | 0.082 | 0.519R | 0.797***R | –0.165–– | –0.849***R |
| Size of household | 0.000 | 0.002 | –0.025 | –0.009 | 0.016 | –0.021 | –0.002 |

(*continued*)

**Table 4.7—Continued**

| Variable[a] | Slash-and-burn | Fertilizer[b] | Manure and compost | Incorporate crop residues | Rotate crops | Mulch | Incorporate household residues |
|---|---|---|---|---|---|---|---|
| Proportion of dependents | –0.171 | –1.675**––– | –0.731*R | 0.350 | 0.096 | 1.138 | 0.153 |
| Participation in organizations | | | | | | | |
| Agriculture/environment | –0.173 | 0.082 | –0.158 | 0.023 | 0.069+++ | 0.751*** | –0.314*–– |
| Credit | 0.236–– | 0.011––– | –0.299++ | –0.081++ | –0.088+ | –0.047++ | –0.479*** |
| Poverty reduction | 0.992*** | –3.040***–– | –0.143 | –0.512**+++ | –0.055 | 0.118+++ | –0.474** |
| Community services | –0.262++ | –0.233+++ | 0.321* | –0.179 | –0.026 | –0.863*** | –0.006 |
| Participation in technical assistance programs | | | | | | | |
| Training | –0.139 | 1.213**+++ | 0.335** | 0.061 | 0.364***+++ | 0.269 | 0.141 |
| Extension | –0.186++ | 0.770*+++ | 0.200++ | –0.134 | 0.004–– | 0.513**–– | –0.048 |
| Credit availability in village | | | | | | | |
| Formal credit | –0.238 | –0.787 | –0.109 | –0.467 | 0.129 | –0.663–– | 1.008**++ |
| Informal credit | –0.384 | 0.307 | –0.204– | –0.207 | 0.407 | 0.124 | 1.258***+++R |
| Tenure of plot[f] | | | | | | | |
| Leasehold | –0.113 | N | 0.242 | 0.267 | –0.299 | –0.556R | –1.380***–––R |
| *Mailo* | 0.920*** | 0.058 | 0.495* | 0.323 | –0.448**R | –0.407 | 0.324R |
| Customary | 0.155 | –0.514 | 0.274 | 0.291 | –0.025 | –0.541** | 0.184 |
| Formal title to plot | –0.718R | 2.684***+++ | 0.503R | –0.207 | –0.547R | –0.144 | 0.718*+R |
| How plot acquired[g] | | | | | | | |
| Leased in | 1.418***+++R | –0.893 | 0.268 | –0.661 | 0.180 | 3.044***+++ | –0.353R |
| Borrowed | 0.540R | N | –0.190 | –0.268 | 0.142 | –0.849 | –0.542R |
| Inherited | –0.329*– | 0.126 | –0.271R | –0.210R | 0.590***+++R | –0.179 | –0.253* |
| Encroached | N | N | N | –0.332 | 1.036 | N | N |
| Expect to operate plot in ten years?[h] | | | | | | | |
| Yes | 1.602***+++R | –1.291 | 0.604 | 0.175 | 0.487 | 1.577*+++ | 0.085 |
| Uncertain | 1.010+ | N | –0.625 | 0.414 | 0.481 | 0.407+++ | 0.059 |
| Area of plot | 0.083 | 0.130 | 0.080+ | 0.033 | 0.052+ | 0.115*++ | –0.005 |
| Slope of plot (cf. flat) | | | | | | | |
| Moderate | –0.084 | 1.586***+++R | –0.134 | 0.124 | 0.248+R | 0.029 | 0.127 |
| Steep | 0.560 | –0.168 | –0.578** | 0.084 | 0.368R | 0.437+ | –0.298 |
| Mixed | 0.450 | –1.178*–– | –0.159 | –0.236 | –0.457*–– | –0.075 | 0.324R |
| Investments on plot | | | | | | | |
| Irrigation | N | 1.348 | 1.032* | –1.389**–– | 2.100***+++ | 6.193***+++ | N |
| Trenches | –0.502 | 1.054**+++ | 0.424**++ | 0.094 | 0.066 | 0.208 | 0.503**++ |
| Grass strips | –0.087 | 0.625 | 0.778***+++ | 0.386++ | 0.076 | –0.260 | –0.039 |
| Live barriers | –0.453 | 0.586 | 0.414* | 0.220 | –0.379 | 0.214+ | 0.375* |
| Trees | –0.143 | –0.083 | 0.367**+ | –0.120 | –0.044 | 1.082***+++ | 0.422***+++ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Perennial crops on plot (share of area) | | | | | | | |
| Coffee | –2.196***––– | –4.044***––– | 0.632***+++ | –0.317 | –2.393***––– | 0.934**+++ | 0.884***+++ |
| Bananas | –2.112***––– | –1.922***–– | 0.688***+++ | –0.256 | –1.372***––– | 2.978***+++ | 1.476***+++ |
| Number of observations | 1,161 | 755 | 1,177 | 1,183 | 1,183 | 1,177 | 1,168 |
| Mean proportion positive | 0.122 | 0.026 | 0.154 | 0.275 | 0.434 | 0.094 | 0.157 |
| Mean predicted probability | 0.123 | 0.026 | 0.153 | 0.274 | 0.435 | 0.095 | 0.157 |
| Pseudo $R^2$ | 0.410 | 0.792 | 0.320 | 0.171 | 0.300 | 0.616 | 0.390 |

Notes: Full regression results are available upon request.*, **, *** = reported coefficient is statistically significant at 10 percent, 5 percent, or 1 percent level, respectively. +, ++, +++ (–, ––, –––) mean coefficient is positive (negative) and statistically significant at 10 percent, 5 percent, or 1 percent level, respectively, in regressions using predicted value of livelihoods; participation in organizations, training, and extension. R means coefficient is of the same sign and statistically significant at 10 percent level in reduced form regression excluding variables for primary income source, participation in organizations, training, or extension, land investments and share of plot area under perennial crops, but including ethnic groups. N—the dependent variable was zero for all positive values of the particular explanatory variable. That variable was excluded and all observations with positive values of that variable were dropped from the regression.

[a] Coefficients of some plot quality variables (position on slope, soil depth, texture, color, and perceived fertility) and intercept not reported due to space limitations.

[b] Due to the small number of positive observations of fertilizer use, regression excludes primary income sources to limit the number of explanatory variables and problems due to overfitting the data.

[c] In contrast to general agricultural production.

[d] In contrast to the unimodal rainfall zone.

[e] In contrast to not completed primary education.

[f] In contrast to freehold tenure.

[g] In contrast to purchased.

[h] In contrast to “No.”

crop production (Pender et al. 2001b). Similar associations of perennial crop production with organic land management practices have been found in Ethiopia (Pender et al. 2001a) and Kenya (Freeman and Coe 2002). Barrett et al. (2002) also noted that perennial crop farmers are more apt to adopt tree planting, mulching, and terracing than are annual crop farmers.

Different income sources are associated with some differences in land management practices, controlling for other factors. Households for whom wage/salary income is important and specialized cereal producers are less likely to use slash-and-burn than are general agricultural producers. Horticultural producers are more likely to apply mulch or household residues. Cereal producers are also more likely to apply household residues. Few of these results are robust to use of predicted primary income sources in the regression specification, however.[49] Thus, we are not confident that the choice of income strategy has a significant influence on land management practices, as hypothesized in Chapter 3.

Controlling for other factors, there are significant and robust differences in land management practices across the different agro-climatic zones. Slash-and-burn is most common in the relatively sparsely populated BL and BM zones, and least common in the densely populated highland zones (SWH and EH). Use of fertilizer and manure/compost are more common in the EH than in other zones. Proximity to the Kenya market apparently contributes to a greater use of fertilizer in the EH, as expected. Use of mulch is most common in the SWH and the BL zone and least common in the EH and the U zone. Application of household residues is most common in the SWH and least in the BH zone.

Access to markets and to the household residence significantly affects land management practices. Use of slash-and-burn and application of mulch and household residues are less common in areas of better market access.[50] Higher wage rates in areas of better market access probably discourage the use of labor-intensive practices. Application of manure and compost, mulch, and household residues is more common closer to the residence, which is not surprising, given the high labor costs of transporting such bulky materials.[51] Slash-and-burn and crop rotation are more common farther from the residence. Fertilizer use is more common closer to a market, as one would expect.[52] Distance to an all-weather road and distance to the nearest market were not found to have statistically significant impacts on other land management practices.

Population density and farm size influence some land management practices. In more densely populated communities, farmers are more likely to apply household residues to their crops. Households who own more land are more likely to use slash-and-burn and less likely to apply fertilizer

[49]Lack of significance when using predicted values of income strategies and participation in organizations and programs is likely due in part to multicollinearity. The maximum VIF in this specification is greater than 28.

[50]Clay et al. (1998) found the opposite result in Rwanda—that households farther from market were more likely to adopt organic inputs. However, they found that households closer to a paved road were more likely to adopt such inputs.

[51]Clay et al. (1998) also found that use of organic inputs is less likely on plots farther from the residence.

[52]However, Clay et al. (1998) found that the use of chemical inputs was more likely in Rwanda farther from market, although more likely closer to a road. Deininger and Okidi (2001) also found that fertilizer use in Uganda was greater closer to a road. Freeman and Coe (2002) found insignificant effects of market access on fertilizer use and other nutrient management strategies in eastern Kenya.

or manure and compost to a given plot.[53] These findings are consistent with the Boserup (1965) hypothesis of population-induced intensification.

Ownership of other assets influences some aspects of land management. Greater ownership of farm equipment is associated with less use of slash-and-burn or household residues, which are practices associated with nonmechanized farming.

Human capital influences land management. Household heads who have completed primary education are more likely to use fertilizer and less likely to apply mulch or household residues than those who did not complete primary education. A positive impact of education on fertilizer use is a common finding in Africa.[54] Household heads that have completed secondary education are less likely to rotate crops, but more likely to apply household residues. Better educated households may be more aware of the benefits of fertilizer, better able to understand labels and directions for using modern inputs, and/or have better access to cash or credit, and thus less prone to use traditional soil fertility methods, such as crop rotation. Older and female household heads are also more likely to use crop rotation, possibly for similar reasons (especially cash or credit constraints).[55] Households headed by women are less likely to apply fertilizer or household residues, perhaps due to cash and labor constraints.[56] Households with a higher proportion of dependents are also less likely to use fertilizer, manure, or compost, probably for similar reasons.

Farmers' participation in organizations and technical assistance programs and access to credit affects their land management practices. Participants in agricultural training are more likely to use fertilizer and more likely to rotate crops. Participants in agricultural extension are also more likely to use fertilizer. The importance of technical assistance programs in promoting adoption of land management technologies is a common finding.[57] Participants in organizations focused on poverty reduction are less likely to use fertilizer, probably due to cash constraints. By contrast, availability of formal or informal credit in the village is associated with a greater likelihood of applying household residues. Informal credit apparently facilitates access to hired labor, thus promoting more labor-intensive land management (more on this in the section on labor intensity).

Differences in land tenure are associated with differences in some land management

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[53]Clay et al. (1998) also found that smaller farms were more likely to use organic inputs in Rwanda, and Place et al. (2001a) found that tobacco farmers in Malawi who have higher labor/land ratios use more cash inputs per hectare. However, Place et al. (2002a) found that smaller farms in western Kenya were less likely to adopt compost or improved fallows, and Deininger and Okidi (2001) found that larger farms in Uganda were more likely to use fertilizer (although these results are not for a specific plot, as are ours).

[54]Deininger and Okidi (2001) also found that education increases fertilizer use in Uganda, as did Place et al. (2002a) in western Kenya, Freeman and Coe (2002) in eastern Kenya, and Mekuria and Waddington (2002) in Zimbabwe and Malawi. Place et al. (2002a) found education to have a negative impact on compost use.

[55]Although we control for availability of credit sources at the village level, access to credit at the household level may vary across households, as may cash availability.

[56]Clay et al. (1998) and Place et al. (2002a) also found that households headed by women are less likely to use fertilizer, whereas Place et al. (2002a) found that these households are more likely to apply compost.

[57]For example, Deininger and Okidi (2001) also found a positive impact of extension programs on fertilizer use in Uganda, Mekuria and Waddington (2002) found that extension programs contribute to manure use, Place et al. (2002a) found that the presence of agroforestry programs increased adoption of improved fallows and biomass transfer, Adesina and Chianu (2002) found that research and technical assistance programs contributed to the adoption of alley cropping, and Clay et al. (1998) found that farmers' knowledge of conservation technologies contributes to the use of organic inputs.

practices. Household residues are less likely to be applied to leasehold than to freehold plots, and crop rotation is less common on *mailo* than on freehold plots.[58] These differences may be due to differences in tenure duration or security. For example, limited duration of leases on leasehold plots might reduce the incentive of the users of such land to apply household residues, whereas *mailo* occupants may be less prone to rotate crops, because of insecurity about future access to the land. However, we do control for an indicator of tenure duration and security in the regression (whether the household expects to operate the parcel in 10 years), and this is found to have a statistically insignificant impact on the use of crop rotation or household residues. Thus, other factors may be involved. For example, as noted in the previous subsection, *mailo* parcels are less likely to be planted in annual crops (such as cereals and legumes), for which crop rotation is a common practice. Leasehold plots tend to be farther from the household residence, and thus may be less likely to receive household residues (although we do control for distance to the residence in the regressions).[59] Thus, the impacts of tenure status per se on land management are not fully clear.

Ownership of a land title is associated with more intensive land management. Farmers are more likely to apply fertilizer and household residues on formally titled plots than on untitled plots. We also find that labor use is greater on titled plots (discussed in the next section). These findings suggest that land titling could contribute to the intensification of land management, and contrast with a significant body of literature that argues that land titling in African tenure systems does not encourage greater land investment or more intensive land use (Atwood 1990; Place and Hazell 1993; Platteau 1996). Titling may increase intensification by increasing farmers' access to credit, or promoting investment by increasing tenure security and land values (Feder et al. 1988; Place and Hazell 1993; Besley 1995; Pender and Kerr 1999). Data from our survey show no clear differences in the use of credit between households having titled plots and others, and we control for an indicator of tenure security in the regression. Thus, the effect of title on land management appears unrelated to its effect on credit access or tenure security, but may be related to its effect on land values (that is, by increasing land value, title may raise the incentive to invest in the land). Alternatively, titles may be associated with differences in land quality or market opportunities not adequately controlled for in the regressions.

The mode of acquisition of the plot is also important. Farmers are more likely to use slash-and-burn and mulch on leased than on purchased plots.[60] Leased plots may be less continuously cropped than purchased plots, and thus require more clearing and have more vegetative material available for mulching. Crop rotation is more likely to be used on inherited than on purchased plots. Perhaps farmers use more traditional practices, such as crop rotation, on inherited land, but seek to maximize profits on purchased

[58]However, Place et al. (2001b) found that farmers in central Uganda were more likely to fallow *mailo* plots than plots under customary tenure.

[59]If there is a nonlinear relationship between distance to the residence and probability of applying household residues, a dummy variable that is correlated with distance to the residence—such as leasehold tenure—could pick up the effect of the nonlinearity, even after controlling for the linear effect of distance on the probability of adoption.

[60]By contrast, Clay et al. (1998) found that Rwandan farmers are less likely to make conservation investments or apply organic inputs to leased land than to land they own.

plots by specializing their crop production to facilitate recouping the costs of their land investment.

Perceived tenure security also affects some land management practices. Farmers are more likely to use slash-and-burn and to apply mulch on plots that they expect to operate in 10 years than on plots perceived as short-term assets. The relationship with mulch is as expected, given that mulch helps to increase soil fertility in the future. The positive association of tenure security with slash-and-burn may be because slash-and-burn is used as part of a long-term fallow system (Place et al. 2001b).

Prior land investments influence current land management practices. Use of mulch and crop rotation are more common, whereas incorporation of crop residues is less common, on irrigated than on rainfed plots. Slash-and-burn and use of household residues were not found on any irrigated plots in the sample. The use of fertilizer, manure, compost, and household residues is more likely on plots with trenches. Grass strips are associated with greater use of manure and compost. Trees are associated with greater use of manure, compost, mulch, and household residues. The positive impacts of trees are consistent with the impacts of perennial crop production on the use of such practices noted earlier. These findings suggest that many land investments and annual soil fertility management practices are complementary, leading to greater benefits when such measures are used in combination. For example, according to representatives of the Africa 2000 Network (a nongovernmental organization promoting sustainable land management practices), the impact of compost is greater if placed in a strategically placed trench. By helping farmers to identify and exploit such synergies, technical assistance programs can multiply their impacts on sustainable land management.

To summarize this section, we find that many factors influence adoption of land management practices. Consistent with the nonseparable agricultural household model discussed in Chapter 3 and Appendix B, land management is affected not only by biophysical factors, such as agro-ecology and land quality, but also by the household's endowments of physical, human, social, and financial capital, and its access to markets. Thus, land management decisions are subject to many influences, and can be very household and site specific. Contrary to one of our hypotheses, the household's income strategy was not found to have a major influence on land management practices.[61] Among the most important factors influencing land management are prior investments made at the plot level, as reflected in the production of perennial crops and the presence of irrigation, trenches, or other land improvements. These investments tend to favor labor-intensive land management practices, such as the application of manure, compost, mulch, and household residues. Proximity of the plot to the household residence is also an important factor influencing such practices. Inorganic fertilizer use is promoted by proximity to markets, especially the Kenya market, participation in agricultural technical assistance programs, education, and ownership of titled land. The use of slash-and-burn is discouraged by many of the factors that favor more intensive land management practices, including access to markets, smaller farm sizes, proximity to plots, ownership of farm equipment, and production of perennial crops. Thus, policies and programs that promote improved access to markets, education, technical assistance, and land titling may have

[61]However, this is controlling for prior investment in planting perennial crops, which does have a strong influence on land management practices, and which is related to the perennials income strategies.

wide-ranging but complex impacts on land management in Uganda.

## Labor Intensity

The labor intensity of crop production is affected by many of the same factors affecting crop choice and use of land management practices (Table 4.8).[62] Pre-harvest labor use is lower where perennial crops are grown.[63] It is higher in the bimodal rainfall zones (BL, BM, and BH) than in the unimodal rainfall zone. It is higher closer to a road, possibly because of greater returns to labor in such areas. It is lower for household heads having higher (post-secondary) education, probably because of their higher opportunity cost of labor (and imperfect labor markets). The presence of informal credit is associated with higher labor intensity, suggesting that access to such credit helps farmers to hire labor. A formal title contributes to higher labor intensity, as noted earlier. Labor intensity is greater on leased plots than on purchased plots. This suggests that households must farm more intensively on leased plots to be able to pay the land rent (sharecropping is uncommon among the sample households). Labor use is also greater on plots acquired through encroachment on communal land; perhaps because more clearing is required, or because households invest more labor to be able to stake a claim to ownership of such land.[64] In some cases, tenure insecurity can encourage households to invest more effort in land clearing or other activities perceived to increase tenure security (Besley 1995; Otsuka and Place 2001).

Not surprisingly, labor use is greater on larger plots, although the elasticity of labor use with respect to plot size is only about 0.7, indicating that labor use per hectare is less on larger plots.[65] This is probably due to labor, management, credit, or other constraints that limit farmers' ability to use labor as intensively on larger plots. We do not find statistically robust impacts of land investments on labor intensity, controlling for other factors. We also find few significant differences in labor use among households pursuing different income strategies.[66]

In summary, pre-harvest labor intensity is most affected by rainfall (higher in bimodal rainfall regions), crop choice (lower on perennials), education (lower for highly educated households), access to informal credit (increases intensity), land title (increases intensity), and means of acquisition of the plot (more labor intensity on leased

[62]We discuss results that are statistically significant (at 10 percent significance level) in at least two of the three sets of regressions—ordinary least squares (OLS), IV, and RF regressions. In the IV regression, variables that were jointly statistically insignificant in the OLS regression were dropped ($p = 0.54$). Tests for nonlinearity in the model are statistically insignificant. Multicollinearity is not a problem (VIF < 5) for any explanatory variable except the equipment and livestock variables (maximum VIF = 21 for ln[equipment value] in the OLS regression). A Hausman test comparing the OLS and IV models was inconclusive (negative value of test statistic).

[63]The finding of lower pre-harvest labor intensity for coffee than for cereals is consistent with estimates of the labor used in coffee and maize production by the Uganda Agricultural Policy Secretariat (APSEC). For example, APSEC estimates traditional robusta coffee to require 106 labor-days of pre-harvest labor, compared with 112 labor-days of pre-harvest labor for local maize varieties (APSEC 2000). Quisumbing et al. (2001) found a similar result in Ghana; that is, labor intensity is lower on cocoa than on food crop fields.

[64]Place et al. (2001b) also found a positive relationship between encroached public land and labor intensity in central Uganda, although the result was statistically insignificant.

[65]Place et al. (2001b) also found lower labor use per hectare on larger plots in central Uganda, as did Quisumbing et al. (2001) in Ghana.

[66]The income strategy variables are jointly statistically insignificant in the OLS regression, and hence, were dropped from the IV regression.

**Table 4.8 Determinants of labor use and output value (least squares regressions)**

| | ln (preharvest labor use) (hours) | | | ln (output value) (USh) | | |
|---|---|---|---|---|---|---|
| Variable[a] | Ordinary least squares | Instrumental variables[b] | Reduced form | Ordinary least squares | Instrumental variables[b] | Reduced form |
| Crop Choice (share of area) | | | | | | |
| Legumes | | | | –0.068 | 0.752 | |
| Root crops | | | | –0.468* | 1.553 | |
| Vegetables | | | | 0.525 | 2.523 | |
| Coffee | –0.901*** | –0.865*** | | 0.098 | 1.097 | |
| Bananas | –0.592*** | –0.575*** | | 0.988*** | 2.090*** | |
| Land management practices | | | | | | |
| Slash-and-burn | | | | –0.048 | –0.140 | |
| Inorganic fertilizer | | | | 0.276 | 0.028 | |
| Manure and compost | | | | 0.103 | –1.384* | |
| Crop residues | | | | 0.043 | 0.483 | |
| Crop rotation | | | | –0.201* | –0.892** | |
| Mulch | | | | –0.171 | –0.152 | |
| Household residues | | | | –0.093 | 0.103 | |
| Pesticides | | | | 0.059 | 0.620 | |
| Integrated pest management | | | | 0.158 | –1.369 | |
| ln(preharvest labor use) | | | | 0.385*** | 0.563** | |
| Primary income source[c] | | | | | | |
| Gifts/donations | –0.194 | | | 0.230 | –1.026 | |
| Wages/salary | –0.029 | | | 0.169 | 0.348 | |
| Livestock | 0.041 | | | 0.626** | 0.457 | |
| Nonfarm activities | 0.119 | | | 0.549*** | 0.775*** | |
| Forestry/fishing | –0.264 | | | –0.732*** | –0.720** | |
| Brewing beer | –0.003 | | | 0.279 | 0.244 | |
| Legumes | –0.110 | | | 0.490** | 0.600* | |
| Horticultural crops | 0.248 | | | 1.676*** | 1.159*** | |
| Bananas | 0.083 | | | 0.164 | 0.105 | |
| Cereals | –0.237* | | | 0.484*** | 0.575** | |
| Root crops | –0.335** | | | 0.117 | –0.047 | |
| Export crops | –0.029 | | | 0.483*** | 0.197 | |
| Agro-ecological zone[d] | | | | | | |
| Bimodal low rainfall (BL) | 0.504** | 0.485** | 0.304 | 0.295 | 0.149 | –0.009 |
| Bimodal medium rainfall (BM) | 0.362** | 0.326** | 0.342** | 0.054 | –0.033 | –0.065 |
| Bimodal high rainfall (BH) | 0.591*** | 0.683*** | 0.381** | 0.291 | 0.031 | 0.303 |
| Southwest highlands (SWH) | 0.244 | 0.399* | 0.240 | 0.014 | –0.232 | –0.505* |
| Eastern highlands (EH) | 0.292 | 0.584*** | 0.271 | 0.672** | 0.661 | 1.008*** |
| Altitude | 0.185 | | 0.086 | –0.450** | 0.254 | –0.289 |
| Good market access | –0.104 | | –0.127 | 0.013 | | 0.122 |
| Area-weighted average distance to (km): | | | | | | |
| Residence | –0.058 | –0.085* | –0.054 | –0.093* | 0.002 | –0.056 |
| All weather road | –0.009* | –0.010* | –0.008 | 0.007 | 0.018* | –0.002 |
| Nearest market | 0.004 | 0.003 | 0.006 | –0.012 | –0.015 | –0.011 |
| ln(population density) | 0.067 | | –0.015 | 0.014 | | 0.001 |
| Assets | | | | | | |
| Own land | 0.302 | | 0.371 | 0.305 | 0.365 | 0.031 |
| ln(area owned) | –0.051 | | –0.063 | –0.097* | –0.260** | –0.133** |
| Own livestock | –0.338 | | –0.303 | –0.828* | –0.437 | –1.904*** |
| ln(value of livestock) | 0.018 | | 0.017 | 0.068* | 0.062 | 0.156*** |
| Own equipment | 0.285 | | 0.295 | 0.010 | | –0.747 |
| ln(value of equipment) | –0.018 | | –0.019 | 0.001 | | 0.060 |
| Education of household head[e] | | | | | | |
| Primary | –0.102 | –0.129 | –0.152* | –0.155 | –0.276* | –0.139 |
| Secondary | –0.112 | –0.150 | –0.079 | 0.129 | 0.071 | 0.095 |
| Higher education | –0.437*** | –0.393** | –0.406*** | 0.117 | 0.040 | –0.087 |

(*continued*)

## Table 4.8—Continued

| Variable[a] | ln (preharvest labor use) (hours): Ordinary least squares | Instrumental variables[b] | Reduced form | ln (output value) (USh): Ordinary least squares | Instrumental variables[b] | Reduced form |
|---|---|---|---|---|---|---|
| ln(age of head) | 0.039 | | 0.026 | –0.359** | –0.044 | –0.615*** |
| Female head | –0.109 | | –0.090 | –0.152 | | –0.176 |
| ln(size of household) | 0.083 | | 0.131 | 0.011 | | 0.043 |
| Proportion of dependents | 0.044 | | –0.100 | –0.266 | | 0.039 |
| Participation in organizations | | | | | | |
| Agriculture/environment | –0.075 | | | –0.168 | | |
| Credit | –0.092 | | | 0.129 | | |
| Poverty reduction | –0.081 | | | 0.229 | | |
| Community services | 0.052 | | | –0.038 | | |
| Participation in technical assistance programs | | | | | | |
| Training | –0.008 | 0.042 | | 0.271*** | 0.331 | |
| Extension | –0.122 | 0.023 | | 0.287*** | 0.629 | |
| Credit availability in village | | | | | | |
| Formal credit | 0.271 | 0.192 | 0.236 | 0.001 | | 0.248 |
| Informal credit | 0.473*** | 0.474*** | 0.459*** | 0.055 | | 0.175 |
| Tenure of plot (cf. freehold) | | | | | | |
| Leasehold | –0.373* | –0.278 | –0.405* | –0.436 | | –0.273 |
| *Mailo* | 0.156 | 0.100 | 0.103 | 0.217 | | 0.092 |
| Customary | –0.012 | –0.118 | –0.085 | 0.133 | | 0.271* |
| Formal title to plot | 0.357* | 0.339* | 0.276 | –0.306 | | 0.150 |
| How plot acquired[f] | | | | | | |
| Leased in | 0.499** | 0.470*** | 0.762*** | –0.138 | –0.403 | –0.525 |
| Borrowed | 0.412 | 0.242 | 0.597** | –0.414 | –0.663* | –0.620* |
| Inherited | –0.077 | –0.073 | –0.005 | –0.288*** | –0.253* | –0.371*** |
| Encroached | 1.093*** | 0.819** | 0.989** | –0.331 | –1.108** | 0.178 |
| Expect to operate plot in ten years?[g] | | | | | | |
| Yes | 0.046 | | 0.083 | –0.008 | | –0.454 |
| Uncertain | 0.273 | | 0.267 | 0.213 | | 0.040 |
| Area of plot | 0.690*** | 0.656*** | 0.686*** | 0.580*** | 0.648*** | 0.876*** |
| Slope of plot (cf. flat) | | | | | | |
| Moderate | 0.096 | 0.111 | 0.079 | –0.074 | –0.137 | –0.027 |
| Steep | –0.042 | –0.051 | –0.113 | –0.001 | –0.189 | –0.053 |
| Mixed | –0.187 | –0.230 | –0.209 | 0.145 | –0.157 | 0.120 |
| Investments on plot | | | | | | |
| Irrigation | 0.457 | 0.500** | | 0.790 | 2.426** | |
| Trenches | 0.084 | 0.061 | | –0.009 | 0.115 | |
| Grass strips | 0.191 | 0.213* | | 0.046 | 0.499 | |
| Live barriers | 0.025 | 0.072 | | –0.330 | –0.376 | |
| Trees | –0.143* | –0.108 | | 0.030 | 0.096 | |
| Intercept | 4.066*** | 5.208*** | 4.462*** | 11.461*** | 6.986*** | 15.905*** |
| Number of observations | 1,171 | 1,160 | 1,186 | 930 | 920 | 937 |
| $R^2$ | 0.524 | 0.505 | 0.457 | 0.565 | 0.308 | 0.456 |

Note: *, **, *** = reported coefficient is statistically significant at 10 percent, 5 percent, or 1 percent level, respectively.

[a] Coefficients of some plot quality variables (position on slope, soil depth, texture, color, and perceived fertility) and ethnic groups in reduced form not reported due to space limitations. Full regression results available upon request.

[b] Variables that were jointly statistically insignificant in the ordinary least squares (OLS) regression were excluded from the instrumental variables (IV) regression. A Hausman test failed to reject OLS model for value of crop production ($p$ = 1.000). The test statistic was negative for the labor use regressions, so unable to test hypothesis of exogeneity of explanatory variables in that regression.

[c] In contrast to general agricultural production.

[d] In contrast to the unimodal rainfall zone.

[e] In contrast to not completed primary education.

[f] In contrast to purchased.

[g] In contrast to "No."

and encroached land). As rural development proceeds in Uganda, with investments in education, increased annual crop production, and the development of credit and land markets, there may be mixed changes in the labor intensity used in crop production, with some of these changes promoting greater intensity and some promoting lower intensity. The net impact of such changes depends on the magnitude of each type of change.

## Value of Production

The value of crop production is substantially higher on plots where bananas are grown than where cereals and many other types of crops are grown,[67] controlling for labor use, land management, agro-ecological potential, and other factors (Table 4.8).[68] The coefficient of 0.988 for banana production in the OLS regression for ln(crop production value) implies that the average value of banana production per hectare is 2.7 times as high ($e^{0.988} = 2.7$) as the value of cereal production, other factors being equal. We do not find statistically significant differences in the value of production among other types of crops.

Crop rotation reduces the value of production significantly, at least in the short run. In the longer term, however, crop rotation may contribute to productivity by helping to restore soil fertility. We find no statistically significant and robust impacts of other land management practices on value of production, controlling for labor use and other factors. The insignificant impacts of fertilizer may be due to the small number of plots in our sample using fertilizer (less than 2 percent of plots), limiting the statistical power to discern the effect of fertilizer in a multiple regression with many explanatory variables. Analysis of descriptive statistics reveals significantly higher average maize yields on plots where inorganic fertilizer was used (1,688 kilograms per hectare on fertilized plots compared with 1,082 kilograms per hectare on unfertilized plots; the difference is statistically significant at the $p = 0.054$ level). Deininger and Okidi (2001), who had a larger sample of households, found a significant positive impact of fertilizer use on the value of agricultural production, resulting in more than a 100 percent return on outlays for fertilizer. Thus, our results should not be interpreted to mean that fertilizer has no impact on productivity or profits; we have simply too few observations of fertilizer use in our sample to have robust statistical results.

Not surprisingly, the value of crop production on a plot increases with both plot size and labor use.[69] The elasticities of production value with respect to plot size (0.580 in the OLS regression) and labor (0.385) imply that production shows approximately constant returns to scale (sum of elasticities = 0.965; standard error = 0.055;

[67]Place et al. (2001b) found higher profitability of plots with banana, coffee, or potato production in central Uganda.

[68]As in the regressions for labor intensity, we discuss results that are statistically significant in at least two of the OLS, IV, and RF regressions for output value. Also as in the labor regressions, variables that were jointly statistically insignificant in the OLS regression were dropped from the IV regression ($p = 0.57$), and multicollinearity is a problem only for the equipment and livestock variables in the OLS and RF regressions (maximum VIF = 20 for ln[equipment value]). A test for no nonlinearity was rejected at the 5 percent level in the OLS model (implying that nonlinearity exists), but not in the RF model. Additional explanatory variables beyond the full specification of the OLS model were not considered, however. A Hausman test of the OLS vs. IV models could not reject the hypothesis of no specification error in the OLS model ($p = 1.000$), which is thus preferred.

[69]Deininger and Okidi (2001) also found that the elasticities of production with respect to land and labor were positive and were the largest contributors to production, although their estimated elasticity for land was somewhat smaller than ours.

which is not statistically different from 1.000 [$p = 0.52$]).

Other factors that significantly affect the value of crop production include agro-ecological zone (highest in the high-potential EH), the primary income source of the household (higher for households with primary income from production of legumes, horticultural crops, cereals, export crops, livestock, or nonfarm activities than for general agricultural producers, and lowest for households with primary income from forestry or fishing), age of the household head (negative effect), amount of land owned (negative effect), value of livestock owned (positive effect), participation in agricultural extension or training programs (positive effect), and how the plot was acquired (lower for inherited than for purchased plots).[70]

The negative effect of farm size on the value of crop production appears consistent with much of the literature on the productivity effects of farm size (for example, Chayanov 1966; Sen 1975; Berry and Cline 1979; Carter 1984; Benjamin 1995; Barrett 1996; Heltberg 1998). However, because we find higher values of crop production even controlling for labor input, equipment availability, land quality, and other factors, our findings suggest that smaller farmers attain higher total-factor productivity, and not only higher land productivity; a finding that is less well established in the literature, although there is empirical support for this as well (Binswanger et al. 1993).

The literature suggests that the inverse relationship could be due to labor market dualism (Chayanov 1966; Sen 1966), decreasing returns to scale technology (Carter 1984), market failures (Bardhan 1973; Feder 1985; Binswanger and Rosenzweig 1986; Eswaran and Kotwal 1986; Barrett 1996), variations in land quality (Sen 1975; Bhalla 1988; Benjamin 1995); and errors in measuring farm size (Lamb 2003).[71] As mentioned earlier, our empirical results are consistent with constant returns to scale technology, as are the results of many other studies of developing country agriculture (for example, Bardhan 1973; Berry and Cline 1979; Carter 1984). Thus, decreasing returns to scale does not explain our result. Omitted land quality characteristics also seems unlikely to explain our result, as we have controlled for many aspects of land quality at the plot level (slope, position on slope, soil depth, texture, color, perceived fertility, and distance to the homestead), although it is impossible to completely rule out omitted-variable bias in a cross-sectional study. Explanations based on labor market failure are not consistent with our findings that farm size has an insignificant effect on labor use at the plot level. Other market failures could be involved; for example, Barrett (1996) shows how imperfections in insurance and land (or credit) markets can cause small farmholds that are net food buyers to exert more labor to reduce food risks than do larger farms that are net sellers. However, Barrett's theory also implies that small farms should use labor more intensively (as do the explanations based on labor market failures), which we do not find to be true. Measurement error will bias the coefficient of a variable toward zero (if measurement error occurs for only one variable) (Greene 1990), which can cause the coefficient of farm size to be less than 1 (indicating an inverse farm size–productivity relationship) in a farm-level regression of

[70]Deininger and Okidi (2001) also found that extension has a positive effect on production, although the result is only weakly statistically significant. Place et al. (2001a) found higher profits on leaseholds than on inherited plots in a least squares regression for profits from tobacco production in Malawi, although this result was not robust when using predicted leasehold to account for possible endogeneity of this variable.

[71]Note that if farmers are economically rational, labor market dualism requires market failures to exist. Thus, we consider labor market dualism as part of the broader class of explanations based on market failures.

production on farm size and other factors, as found by Lamb (2003). However, our regressions are estimated at the plot level, and the effect of farm size is calculated after controlling for plot size, labor use, and other factors. If errors in measurement were biasing the coefficient of farm size toward zero, such bias would reduce the likelihood of finding the negative relationship that we have, in fact, found. Thus, none of the explanations for an inverse farm size–productivity relationship discussed above suffice to explain our result.

One possible explanation for the inverse farm size–productivity result that we have found is that farmers' management and supervisory capabilities are limited and not marketable (Eswaran and Kotwal 1985; Pender and Fafchamps 2001). Small farms will have an advantage in crop production in management and supervision, causing them to use labor more productively, even if there are no differences between small and large farms in the amount of labor applied to a given plot. Regardless of the explanation, our finding implies that reallocation of land in favor of smaller farms, whether through land reform or the operation of land markets, would be expected to increase productivity in Ugandan agriculture.

The significant impact of income sources—controlling for land quality, land management, labor use, and many other factors—suggests that households pursuing different income strategies acquire skills or have access to information or markets that translate into higher value of production, and indicates the importance of considering income strategies to better understand how to increase agricultural production and incomes in Uganda. Several types of somewhat more specialized crop producers (that is, households dependent on horticultural crops, cereals, and legumes as their primary income source) and households dependent on livestock or nonfarm activities earn higher returns from crop production than do general agricultural producers or households more dependent on extractive activities (forestry and fishing). This observation suggests that there are gains from specialization in crop production, and also that there may be complementarities between livestock or nonfarm activities and crop production. However, specialization exposes farmers to increased production and price risks. For example, a recent study in eastern Uganda found that households with more crop diversity were more food secure (Nagujja 2002). Thus, many farmers may prefer to remain diversified in agricultural production, despite lower expected returns.

Participation in agricultural training and extension programs has a positive and statistically significant impact on value of production in the OLS regression, but the effects are not statistically significant in the IV regression. This could mean that these programs tend to work with people who are more productive anyway (because the IV regression controls for this selection issue). However, the coefficients in the IV regression are similar or larger in magnitude than those in the OLS calculation (which would not be the case if a selection bias were the only reason for the significant effect), and the regressions predicting participation in these programs do not show clear tendencies in this regard.[72] Insignificance of the coefficients of these variables in the IV regressions

[72]The only factors found to have a statistically significant impact on participation in extension programs are distance to a tarmac road (more participation farther from a road) and ethnicity (more participation by Baganda households than by other ethnic groups). The only factors having a statistically significant impact on participation in agricultural training programs are education (higher participation for more educated household heads). These findings do not clearly indicate that participants in technical assistance programs are households that would tend to be more productive in the absence of extension programs, because these factors do not have significant direct impacts on the value of crop production. Regression results are available on request.

may simply be a result of the difficulty of identifying these impacts, due to the limited number of suitable instrumental variables (that is, variables that can be excluded as predictors of value of production but that significantly predict participation in technical assistance programs). A Hausman (1978) test of the OLS vs. IV model failed to reject the OLS model ($p$ = 1.000), so OLS is preferred as the more efficient model. Thus, agricultural training and extension programs appear to have a positive impact on the value of crop production.[73] Participation in other organizations did not have a statistically significant impact on the value of crop production.

In summary, the regression results in this section suggest that promotion of several income strategies and the use of agricultural technical assistance programs can help to boost the value of crop production significantly. There appears to be potential for profitable expansion of banana production in the study region, and livestock and nonfarm development appear to be complementary to increased crop production. The potential impacts of improved land management on the value of crop production are less clear, however.

## Household Income

Households having livestock production as their primary income source earn substantially higher incomes than do general agricultural producers, controlling for other factors (Table 4.9; see also Table 4.2). Differences in household income among households pursuing other income strategies are statistically insignificant.

Higher education has a major impact on income. This is consistent with the findings of Deininger and Okidi (2001) and Appleton (2001b) for Uganda, and with many other studies of the impacts of education in developing countries. Households whose head has an education beyond the secondary level earn on average 3.7 million Ush. more than households whose heads lack primary education. Surprisingly, households that are farther from an all-weather road, those headed by women, and those with a higher share of dependents earn higher incomes, controlling for differences in wealth and other factors. We checked these findings using robust regression, to help address concerns about data outliers (Berk 1990): the positive impacts of distance to an all-weather road were also significant when using robust regression, but the effects of female head and proportion of dependents were not.[74] We do not have an explanation for the surprising positive association of income with distance from an all-weather road. This finding contradicts results of our earlier analysis of community-survey data from the same Ugandan communities where this study was conducted, in which we found that improvements in access to a paved road were associated with improvements in many welfare indicators (Pender et al. 2001b). Further research is needed to better understand the relationship between road access and household income in Uganda.

Participation in technical assistance programs and various types of organizations

[73]This contradicts Gautam and Anderson's (1999) findings on the impacts of the training and visit agricultural extension system in Kenya, which they find to have an insignificant impact.

[74]In Table 4.9, we also report the statistically significant results of the use of robust regression (for the OLS and RF models). Concerns about outliers are greater for the income regressions than for the labor or value of crop production regressions, because the dependent variable could not be transformed as in the labor and value of production regressions, due to negative values for income. Robust regression was used only as a check on the robustness of the results, and was not the preferred model, because this estimator (as implemented in Stata [StataCorp 2003]) does not account for the survey sampling method (sample weights, clustering, and stratification), and is not able to address the endogeneity issue, as can the IV estimation.

**Table 4.9 Determinants of household income (least squares regressions)**

| Variable[a] | Household income (1,000 USh) Ordinary least squares | Instrumental variables[b] | Reduced form |
|---|---|---|---|
| Primary income source[c] | | | |
| Wages/salary | –405.1 | –1,310.0 | |
| Livestock | 3,178.9*+ | 6,179.3* | |
| Nonfarm activities | –261.0 | –865.3 | |
| Brewing beer | 823.1 | 529.6 | |
| Legumes | 868.1 | 1,350.4 | |
| Bananas | –482.7 | –1,521.1 | |
| Cereals | 64.1 | 241.3 | |
| Root crops | –1,022.5 | –1,078.6 | |
| Export crops | –353.8 | 729.7 | |
| Agro-ecological zone[d] | | | |
| Bimodal low rainfall (BL) | 315.5+ | 55.4 | –37.4 |
| Bimodal medium rainfall (BM) | 678.1 | 546.8 | 664.7 |
| Bimodal high rainfall (BH) | 677.2 | 1,200.4 | 459.3 |
| Southwest highlands (SWH) | 1,520.4* | 1,789.1 | 110.9 |
| Eastern highlands (EH) | 1,107.3 | 579.7 | 531.9 |
| Altitude (area-weighted average of plots) | –56.41 | –56.79 | –21.85 |
| Good market access | –118.97++ | | –262.5+ |
| Area-weighted average distance to (km): | | | |
| Residence | 148.84 | –81.13 | 475.7* |
| All-weather road | 50.91**++ | 21.77 | 47.27***+++ |
| Nearest market | –6.46–– | –17.19 | –32.24– |
| Population density (persons/km$^2$) | 0.484 | | –0.381 |
| Assets owned | | | |
| Area owned (acres) | 74.49 | | 68.38 |
| Value of livestock (1,000 USh) | –0.022+++ | | 0.315+++ |
| Value of equipment (1,000 USh) | –0.002 | | 0.323 |
| Education of household head | | | |
| Primary | 911.7*++ | 1,750.2 | 950.5*++ |
| Secondary | 317.0 | 1,190.8 | 135.4 |
| Higher education | 3,712.0***+++ | 5,804.1* | 3,419.5***+++ |
| Age of head | 9.075 | 11.047 | 5.932 |
| Female head | 1,258.4** | 625.9 | 1,430.1* |
| Size of household | 4.85+++ | 92.9* | –11.97+++ |
| Proportion of dependents | 2,304.2** | 1,832.4 | 3,056.0*** |
| Participation in organizations | | | |
| Agriculture/environment | –636.4 | –2,529.7 | |
| Credit | 146.2 | 2,044.6 | |
| Poverty reduction | 52.8+ | 682.7 | |
| Community services | –1,332.6*** | –2,258.3 | |
| Participation in technical assistance programs | | | |
| Training | –54.7 | –1,817.7 | |
| Extension | 1,569.9*+ | –2,166.4 | |
| Access to credit in village | | | |
| Formal credit | 997.3 | | 1,446.4 |
| Informal credit | 862.0 | | 595.9 |
| Tenure of land (share of area)[e] | | | |
| Leasehold | 2,702.3**+++ | 5,578.8 | 2,026.6**++ |
| *Mailo* | 1,196.9 | 3,034.7 | 341.1 |
| Customary | 85.9 | 1,504.6 | 380.1 |

(*continued*)

**Table 4.9—Continued**

| Variable[a] | Household income (1,000 USh) Ordinary least squares | Instrumental variables[b] | Reduced form |
|---|---|---|---|
| Formal title to land – (share of area) | 234.3 | –480.5 | 402.1 |
| How land acquired (share of area)[f] | | | |
| Leased in | –1,924.8–– | –643.3 | –2,578.4**– |
| Borrowed | –1,730.8 | –2,261.5 | –1,797.9* |
| Inherited | –1,175.4** | –1,228.4 | –994.3** |
| Encroached | –1,032.9 | –272.4 | –1,403.1 |
| Expect to operate land in ten years? (share of area)[g] | | | |
| Yes | –447.8 | –727.3 | –1,504.2* |
| Uncertain | –505.6 | –1,563.0 | –1,548.7 |
| Slope of land (cf. flat) (share of area) | | | |
| Moderate | –366.1 | 134.9 | 77.7 |
| Steep | –11.5 | –844.7 | 450.7 |
| Mixed | –1,781.5* | –1,931.0* | –2,352.4* |
| Investments on land (share of area) | | | |
| Irrigation | –989.3 | | |
| Trenches | 95.5 | | |
| Grass strips | –789.7 | | |
| Live barriers | –1,100.7 | | |
| Trees | –568.1 | | |
| Intercept | 470.0 | 2,494.7 | 2,048.8 |
| Number of observations | 439 | 435 | 439 |
| $R^2$ | 0.357 | 0.058 | 0.278 |

Notes: Full regression results are available upon request. *, **, *** = reported coefficient is statistically significant at 10 percent, 5 percent, or 1 percent level, respectively. +, ++, +++ (–,––,–––) = coefficient is positive (negative) and statistically significant at 10 percent, 5 percent, or 1 percent level, respectively, in robust regression version of OLS and reduced-form RF models.

[a] Coefficients of some land quality variables (share of area by position on slope, soil depth, texture, color, and perceived fertility) and ethnic groups in reduced form regression not reported due to space limitations.

[b] Variables that were jointly statistically insignificant in the ordinary least squares (OLS) regression were excluded from the instrumental variables (IV) regression. A Hausman test failed to reject OLS model for income ($p = 1.000$).

[c] In contrast to general agricultural production.

[d] In contrast to the unimodal rainfall zone.

[e] In contrast to freehold tenure.

[f] In contrast to purchased.

[g] In contrast to "No."

does not have a statistically robust impact on income. The use of extension programs has a weakly significant positive association with income in the OLS model, but the coefficient is neither significant nor of opposite sign in the IV model.[75] Surprisingly,

[75]As with the regressions for crop production, a Hausman test failed to reject the OLS model ($p = 1.000$) for income, which is therefore the preferred specification.

participation in community service organizations is associated with lower incomes in the OLS regression, but this finding is not robust in the IV regression. It may be that poorer households tend to participate more in such organizations because of their greater needs, rather than such participation contributing to lower incomes. Consistent with this, households participating in such organizations have higher dependency ratios than do nonparticipants, although we do not find significant differences in the ownership of assets or education levels between participants and nonparticipants.

Some variables for land tenure and quality also have a significant impact on household income. Households with a higher share of leasehold land earn higher income than do households with more freehold land, whereas households with more inherited land earn lower incomes than those with more purchased land (consistent with the finding of lower crop productivity on inherited than on purchased land discussed earlier). Perhaps users of leasehold and purchased land feel more incentive to earn income to be able to pay for the use of the land than do owners of freehold and inherited land.

Overall, the regression results suggest that the most promising interventions for increasing household incomes in rural Uganda are investment in education and promotion of livestock development. No other policy-related factors were found to have significant and robust positive impacts on income.

## Erosion

The level of erosion varies across the development domains in Uganda. Erosion is highest in the intensively cultivated highlands (SWH and EH) and greater in areas of higher population density (although the impact of population density is significant only in the OLS regression; Table 4.10).[76] As shown in the next section, the positive impact of population density on erosion is found mainly in the steeply sloping and densely populated highlands. Consistent with the impact of population density, we find that erosion is greater for larger households, controlling for the amount of land owned by the household.

The positive effect of population density and household size on erosion supports neo-Malthusian concerns about population-induced land degradation, consistent with findings of recent studies in Ethiopia (Grepperud 1996; Pender et al. 2001a). This finding is not consistent with optimistic arguments about "more people, less erosion" cited by Tiffen et al. (1994) for the Machakos district of Kenya. In that study, the reduction in erosion was influenced by factors other than population growth, such as the presence of technical assistance programs promoting conservation and access to the Nairobi market, which favored production of high-value cash crops and thus increased the value of investment in land conservation. We believe that it is essential to control for such factors in a multivariate analysis, as we have done, to properly assess the impact of population pressure (or any other factor) on land degradation.

Participants in organizations focusing on agriculture and environment have lower levels of erosion on their plots than do other households, suggesting that such organizations are effective in helping to reduce land degradation.

Predicted erosion is lower on *mailo* land than on land under freehold tenure (in the OLS and IV regressions). This is likely due to a tendency of *mailo* land to be planted in perennial rather than annual crops, as noted

[76]A Hausman test failed to reject the OLS model ($p = 0.432$), which is therefore the preferred specification.

## Table 4.10 Determinants of predicted erosion (least squares regressions)

| | ln(erosion in mt/ha/year) | | |
|---|---|---|---|
| Variable[a] | Ordinary least squares | Instrumental variables[b] | Reduced form |
| Primary income source[c] | | | |
| Gifts/donations | –1.189 | | |
| Wages/salary | 0.007 | | |
| Livestock | –1.006 | | |
| Nonfarm activities | –0.184 | | |
| Forestry/fishing | 0.328 | | |
| Brewing beer | 0.061 | | |
| Legumes | 0.076 | | |
| Horticultural crops | –0.239 | | |
| Bananas | –0.299 | | |
| Cereals | 0.058 | | |
| Root crops | –0.030 | | |
| Export crops | 0.168 | | |
| Agro-ecological zone | | | |
| Bimodal low rainfall (BL) | 0.611 | 0.354 | 0.322 |
| Bimodal medium rainfall (BM) | 0.151 | 0.037 | 0.062 |
| Bimodal high rainfall (BH) | 0.084 | –0.187 | –0.162 |
| Southwest highlands (SWH) | 1.951*** | 2.114*** | 1.510*** |
| Eastern highlands (EH) | 1.160*** | 1.659*** | 0.940** |
| ln(altitude in (100 masl) | –2.380* | –2.774* | –2.612 |
| Good market access | –0.085 | | –0.109 |
| Area-weighted average distance to (km): | | | |
| Residence | 0.063 | | 0.067 |
| All-weather road | 0.016 | | 0.008 |
| Nearest market | 0.011 | | 0.023** |
| ln(population density) | 0.152** | 0.004 | 0.077 |
| Assets | | | |
| Own land | –0.341 | | –0.261 |
| ln(area owned) | –0.007 | | –0.001 |
| Own livestock | 0.355 | | 1.005 |
| ln(value of livestock) | –0.014 | | –0.075 |
| Own equipment | –0.097 | | 0.177 |
| ln(value of equipment) | –0.011 | | –0.028 |
| Education of household head | | | |
| Primary | 0.146 | 0.117 | 0.091 |
| Secondary | 0.441* | 0.661* | 0.357* |
| Higher education | 0.541* | 0.541* | 0.390 |
| Age of head | –0.271 | 0.243 | –0.200 |
| Female head | 0.469* | | 0.292 |
| Size of household | 0.291** | | 0.315** |
| Proportion of dependents | 0.088 | | –0.120 |
| Participation in organizations | | | |
| Agriculture/environment | –0.349** | –0.709*** | |
| Credit | –0.162 | –0.546* | |
| Poverty reduction | –0.219* | –0.733 | |
| Community services | –0.182 | 0.287 | |
| Participation in technical assistance | | | |
| Training | 0.047 | –0.300 | |
| Extension | 0.167 | 0.551** | |

(*continued*)

**Table 4.10—Continued**

| | ln(erosion in mt/ha/year) | | |
|---|---|---|---|
| Variable[a] | Ordinary least squares | Instrumental variables[b] | Reduced form |
| Credit availability in village | | | |
| Formal credit | –0.234 | | –0.460 |
| Informal credit | –0.097 | | –0.230 |
| Tenure of plot[d] | | | |
| Leasehold | 0.273 | 0.140 | 0.551 |
| *Mailo* | –0.424* | –0.535** | –0.334 |
| Customary | –0.108 | –0.133 | –0.003 |
| Formal title to plot | –0.157 | | –0.295 |
| How plot acquired[e] | | | |
| Leased in | –0.636 | | –0.605 |
| Borrowed | –0.327 | | –0.230 |
| Inherited | –0.088 | | –0.014 |
| Encroached | –0.061 | | –0.155 |
| Expect to operate plot in ten years?[f] | | | |
| Yes | –0.423 | | –0.267 |
| Uncertain | –0.052 | | 0.133 |
| ln(Area of plot) | –0.046 | –0.052 | –0.023 |
| Slope of plot[g] | | | |
| Moderate | 0.439*** | 0.304* | 0.455*** |
| Steep | 2.863*** | 2.673*** | 2.969*** |
| Mixed | 0.486** | 0.446* | 0.628*** |
| Intercept | 6.030 | 6.417* | 6.635 |
| Number of observations | 1,295 | 1,284 | 1,295 |
| $R^2$ | 0.563 | 0.493 | 0.541 |

Notes: Full regression results are available upon request. *, **, *** = reported coefficient is statistically significant at 10 percent, 5 percent, or 1 percent level, respectively.

[a] Coefficients of some plot quality variables (position on slope, soil depth, texture, color, and perceived fertility) and ethnic groups in reduced-form regressions not reported due to space limitations.

[b] Variables that were jointly statistically insignificant in the ordinary least squares (OLS) regression were excluded from the instrumental variables (IV) regression. A Hausman test failed to reject OLS model for erosion ($p = 0.432$).

[c] In contrast to general agricultural production.

[d] In contrast to freehold tenure.

[e] In contrast to purchased.

[f] In contrast to "No."

[g] In contrast to flat.

earlier, and may not be due to the tenure characteristics of *mailo* land per se.[77] That there is no statistically significant difference between erosion on *mailo* and freehold plots in the RF regression (in which ethnicity is included in the explanatory factors) suggests that the differences found in the other two models are due to cultural factors that lead to different cropping choices in *mailo* areas.

[77]Recall that crop choices are not included as explanatory variables in the erosion regressions, for reasons explained in Chapter 3. Thus, the land tenure variables may be associated with erosion as a result of their association with crop choices.

Most other factors considered—including income sources, household assets, education, participation in training or extension programs, access to markets, infrastructure and credit, land title, and tenure security—have a statistically insignificant impact on predicted erosion. Consequently, the evidence presented here does not support the use of policy interventions affecting these factors as a means of addressing this form of land degradation. It appears that efforts to reduce population pressure, and NGOs focusing on agriculture and environment concerns are likely to be more effective in reducing erosion than are interventions related to infrastructure, education, credit, or land titling. Of course, there may be indirect effects of some of these interventions on erosion; for example, if access to roads were to increase participation in agricultural and environmental organizations, it could indirectly contribute to reducing erosion.[78]

In the next section, we consider the potential impacts of selected interventions on erosion, as well as on agricultural production and household incomes in Uganda, considering the complex set of impacts of interventions on these outcomes via their impacts on participation in programs and organizations, income strategies, crop choice, land management, and decisions on labor allocation, as found in the econometric results.

## Potential Impacts of Selected Interventions

Several interventions may be considered as possible means of improving agricultural production, reducing land degradation, and increasing incomes. In this section, we focus on factors that are found to have statistically significant and robust impacts on at least one of the outcome variables (value of crop production, erosion, income). Among these factors are population growth, public investments in education, participation in agricultural technical assistance programs, and participation in NGOs. We explore the potential impacts of such interventions on crop production, erosion, and household incomes by using the predicted relationships from the econometric model, considering both the direct effects of such interventions based on the results reported in Tables 4.8–4.10, as well as indirect effects of such interventions, via their impacts on households' participation in programs and organizations, choice of income strategies, crops planted, land management practices, and labor use. In all cases, the total predicted effects turn out to be of the same sign and usually similar in magnitude to the direct effects (Table 4.11), indicating that the direct effects tend to dominate the total effect, partly because indirect effects are often opposite in trend and thus tend to cancel each other out, and because the magnitudes of such effects become attenuated, as they are less directly linked to the outcomes.

Population growth of 10 percent is predicted to have a small and statistically insignificant impact on the mean value of crop production and household incomes, and it would increase predicted erosion by 1.6 percent (Table 4.11). The impact of population growth on erosion takes place mainly in the highland zones (SWH and EH), with a small and statistically insignificant impact of population growth on predicted erosion and other outcomes in the lower-elevation zones (Table 4.12). This is not surprising, given the steep slopes and dense population in the highlands zones, creating substantial land degradation pressure in these areas. This suggests that priority should be given to reducing population pressure in the highlands to help reduce soil erosion.

Investments in education (both at the primary and higher levels) are predicted to

[78]This is only a hypothetical example: we did not find that access to roads had a statistically significant impact on participation in agricultural or environmental organizations.

**Table 4.11 Simulated impacts of changes in selected variables on outcomes**

| | | Mean of selected variable | | Value of crop production (plot level) (USh) | | Predicted soil erosion (mt/ha/year) | | Household income (1,000 USh) | |
|---|---|---|---|---|---|---|---|---|---|
| **Variable** | **Scenario** | **Before change** | **After change** | **Direct effects (%)** | **Total effects (%)** | **Direct effects (%)** | **Total effects (%)** | **Direct effects (%)** | **Total effects (%)** |
| Population density (persons/km$^2$) | 10 percent increase | 220 | 242 | +0.1 | +0.4 | +1.6** | +1.6 | +0.6 | +0.7 |
| Primary education (proportion of households) | Universal primary education | 0.480 | 1.000 | –8.2- | –7.7 | +8.1 | +8.2 | +26.9* | +24.5R |
| Postsecondary education (proportion of households) | Higher education for all heads with secondary education | 0.078 | 0.149 | –0.1 | –0.7 | +0.5* | +0.3 | +13.8***+ | +14.2R |
| Agricultural training (proportion of households) | All households receive training | 0.502 | 1.000 | +13.1*** | +12.2 | +2.5 | +2.5 | –1.5 | –1.5 |
| Extension (proportion of households) | All households receive extension | 0.311 | 1.000 | +18.5*** | +13.7 | +11.5 | +11.5 | +61.2* | +61.2 |
| Agricultural/environment organizations (proportion of households) | All households participate | 0.241 | 1.000 | –11.8 | –8.7 | –23.1**––– | –23.1 | –27.2 | –27.2 |
| Poverty reduction organizations (proportion of households) | All households participate | 0.107 | 1.000 | +23.4 | +19.4 | –16.8* | –16.8 | +2.7 | +2.7 |

Notes: Simulation results for direct effects based upon predictions from ordinary least squares (OLS) and full-model regressions reported in Tables 4.7–4.9. Results of regressions predicting choices of income sources, crops, land management practices, and labor use were used to predict indirect impacts. Percentages are change in mean predicted values. *, **, *** = direct effect is based on a coefficient that is statistically significant in the OLS regression at 10 percent, 5 percent, or 1 percent level, respectively. Statistical significance of indirect effects not computed. +, ++, +++ and –,––,––– = direct effect is of the sign shown and statistically significant in the instrumental variables (IV) regression at 10 percent, 5 percent, or 1 percent level respectively. R = the coefficient is of the same sign and statistically significant in the reduced form regression. Since participation in agricultural training, extension, and organizations were excluded from the reduced form regressions, the robustness of the total effects for these variables could not be shown.

**Table 4.12 Simulated impacts of changes in selected variables on outcomes, lowlands vs. highlands (all effects)**

| | | Lowlands (BL, BM, BH, and U zones) | | | | | Highlands (SWH and EH zones) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Scenario | Before | After | Value of crop production (%) | Soil erosion (%) | Household income (%) | Before | After | Value of of crop production (%) | Soil erosion (%) | Household income (%) |
| Population density (persons/km$^2$) | 10 percent increase | 207.9 | 228.7 | +1.1 | +0.6 | +0.5 | 308.6 | 339.5 | –5.0** | +2.8**R | +3.6*++ |
| Primary education (proportion of households) | Universal primary education | 0.483 | 1.000 | –11.1**––– | +6.7* | +20.5 | 0.462 | 1.000 | +42.1*++ | +12.5 | +35.9+R |
| Postsecondary education (proportion of households) | Higher education for all heads with secondary education | 0.077 | 0.155 | –0.7 | –0.5 | +16.8***+++R | 0.078 | 0.106 | +0.3 | +0.4R | +3.2R |
| Agricultural training (proportion of households) | All households receive training | 0.508 | 1.000 | +12.5***+++ | +1.9 | –1.4 | 0.457 | 1.000 | –16.9 | +13.3** | +39.0**+ |
| Extension (proportion of households) | All households receive extension | 0.321 | 1.000 | +10.8*** | +14.6 | +69.1* | 0.227 | 1.000 | +12.0 | +33.4*** | +21.1+++ |
| Agricultural/environment organizations (proportion of households) | All households participate | 0.254 | 1.000 | –10.7** | –19.5***––– | –34.7–– | 0.154 | 1.000 | +115.9** | –29.4*** | –44.5**–– |
| Poverty reduction organizations (proportion of households) | All households participate | 0.095 | 1.000 | –0.7 | +19.1 | –14.8 | 0.192 | 1.000 | +97.4*** | –16.6 | +48.4** |

Notes: Simulation results for direct effects based upon predictions from ordinary least squares (OLS) and full-model regressions reported in Tables 4.7–4.9. Results of regressions predicting choices of income sources, crops, land management practices, and labor use were used to predict indirect impacts. Percentages are change in mean predicted values. *, **, *** = direct effect is based on a coefficient that is statistically significant in the OLS regression at 10 percent, 5 percent, or 1 percent level, respectively. Statistical significance of indirect effects not computed. +, ++, +++ and –, ––, ––– = direct effect is of the sign shown and statistically significant in the IV regression at 10 percent, 5 percent, or 1 percent level respectively. R = the coefficient is of the same sign and statistically significant in the reduced form regression. Since participation in agricultural training, extension, and organizations were excluded from the reduced form regressions, the robustness of the total effects for these variables could not be shown.

have a major impact on household incomes. Universal primary education is predicted to increase average income by 25 percent, and providing post-secondary education to household heads that have completed secondary education is predicted to increase average income by about 14 percent. The predicted impact of primary education is larger in the highland zones, whereas higher education is predicted to have more impact on income in the lowland zones (Table 4.12). The greater response to higher education outside of the highlands is partly due to greater participation in secondary education in these zones (especially in the Lake Victoria region), which increases the number of households who can benefit from post-secondary education. It is also likely related to the proximity to large cities (especially Kampala and Jinja) in the Lake Victoria region, where opportunities for better educated people are greater.

Educational improvements may involve trade-offs between income and agricultural production or land degradation, however. Universal primary education is predicted to result in an average reduction in the value of crop production of about 8 percent and an increase in erosion of about 8 percent (although neither of these results is based on statistically robust regression results). By increasing opportunities off the farm, education may reduce small farmers' efforts to produce agricultural output or conserve soil. Such potential trade-offs do not mean that investments in improved education should not be pursued; but they do suggest that other measures will be needed to address low productivity and land degradation. Including the principles of sustainable agricultural production in educational curricula might help to minimize the negative impact of education, or may even have positive impacts on agricultural production and sustainable land management.

Agricultural technical assistance, whether through longer-term training programs or short-term extension visits, is predicted to increase crop production significantly. Universal participation in agricultural training programs is predicted to have a 12 percent increase in the value of crop production (considering indirect as well as direct impacts), and universal participation in extension programs increases predicted production by 14 percent. Extension programs are also predicted to increase household income significantly (although this result is based on regression results that are only weakly statistically significant and not robust in the IV specification). Such programs may achieve higher crop production and income at the expense of soil erosion, however: erosion is predicted to increase as a result of increased technical assistance—especially extension programs (although the effects are not statistically significant). This may be due to stepwise technology adoption (Byerlee and de Polanco 1986), whereby farmers may initially adopt a technology that leads to increased production (such as improved maize) but do not simultaneously adopt soil and water conservation technologies. However, the positive impacts of these programs on crop production are more significant in the lower elevation zones, whereas the positive impacts on soil erosion are more significant in the highlands (Table 4.12). Thus, agricultural technical assistance programs appear to be having differential impacts in different zones. Such differential impacts and potential trade-offs should be carefully considered by the new National Agricultural Advisory Service (NAADS) and other technical assistance programs.

Trade-offs between environmental and production objectives appear to result from participation in NGOs as well. Universal participation in NGOs focusing on agriculture and environmental issues is predicted to reduce soil erosion by 23 percent (see Table 4.11), with significant impacts in the highlands and other zones, although with larger impact in the highlands (see Table 4.12). However, such participation is predicted to reduce the value of crop production (mainly by reducing production in the lower-elevation zones) and to reduce household incomes (both in the highlands and other zones). By emphasizing labor-intensive technologies to conserve soils, such organizations are able to reduce soil erosion, but apparently at the expense of crop production and income in the near term. Although such near-term losses may be recouped in the longer term, they undoubtedly contribute to the low rate of adoption of conservation practices by most small farmers.

Increased participation in organizations focusing on poverty reduction appears to offer potential for "win-win-win" outcomes, including increased value of crop production, reduced erosion, and (slightly) higher incomes (see Table 4.11). However, none of these results is statistically robust, and we find different results across the zones. In the highlands, participation in poverty-reduction organizations is associated with higher crop production and income and lower levels of erosion. In the lower-elevation zones, participation in antipoverty organizations has less beneficial (and statistically insignificant) impacts. Apparently the antipoverty organizations operating in the highlands are more effective. However, none of the impacts of participation in such organizations is statistically robust in the IV regression specifications. More research on these types of programs is needed to draw robust conclusions about their impacts and the reasons for their differential impacts in different zones.

Other interventions that may contribute to one or more positive outcomes, based on the regression results reported above (see Tables 4.8–4.10), include promotion of livestock keeping as an income strategy (positive impacts on crop production and household income), promotion of nonfarm activities and more specialized and higher-value (especially bananas) crop production (which have positive impacts on the value of crop production), and investments in irrigation (higher value of crop production). Factors commonly thought to be important, but which were found to have insignificant impacts (or in some cases, unexpectedly negative impacts) on outcomes, include access to markets and roads (generally insignificant, except a surprisingly negative association of access to all-weather road with household income), amount of land owned (negative impact on value of crop production on a specific plot), and land tenure and ownership of a title (mostly statistically insignificant impacts). It appears that the development of land markets can contribute to more intensive land management and/or higher-value production (for example, higher labor use on leased than on purchased plots, or higher value of output on purchased than on inherited plots).

In general, these results imply that there are few "win-win-win" opportunities to simultaneously increase production, increase household income, and reduce land degradation. Different instruments are needed to achieve the different objectives, and trade-offs among these objectives must often be contemplated. Improving education is critical for increasing household incomes, but this is unlikely to solve problems of low agricultural productivity and land degradation. These issues will likely be more effectively addressed by investments in expanded agricultural technical assistance, NGO programs focusing on agricultural and environmental issues, investments in irrigation, and efforts to promote livestock production and other more remunerative livelihood activities.

Just as no single solution exists to improve all outcomes simultaneously, no single approach is appropriate for all locations. Thus, for example, control of population growth is more critical to reduce land degradation in the highlands, whereas technical assistance programs have been more effective in increasing crop production outside the highlands. There is no "one-size-fits-all" solution to the complex problems of small farmers in the diverse circumstances of Uganda.

# CHAPTER 5

# Sustainability of Land Management: The Case of Soil Nutrient Balances in Eastern Uganda

As noted previously, we examine sustainability of land management by analyzing the nutrient balance, which is the difference between inflows and outflows of the three most important macronutrients, nitrogen (N), phosphorus (P), and potassium (K). The largest estimated sources of N inflow for the sample households are sedimentation, symbiotic N-fixation, and atmospheric deposition (Table 5.1).

Sedimentation is an important source of N in areas with extensive rice cultivation in valley bottoms. However, the amount of nitrogen deposited via sedimentation is highly skewed, as about one-half of the 58 farmers under study received less than 10 kilograms N per hectare from sedimentation. This is due to noncultivation of rice in the highlands and the variation in the terrain on the mount Elgon sites (Nemba/Kasheshe and Kongta) and the Iteso plains (Odwarat and Agonyo), where the study was conducted.[79] On average, sedimentation contributes about 25 percent of the estimated soil N inflow for the sample farmers.

Symbiotic N-fixation contributed about 22 percent of the N input. The large contribution of symbiotic N-fixation is common for households who plant leguminous crops and do not apply inorganic fertilizer. This is the case for most farmers in the study area. Nitrogen fixation depends on soil conditions, climatic conditions, and some aspects of farm management, such as the planting of leguminous crops.[80]

Atmospheric deposition, over which the farmer has no control, is also an important source of nitrogen in the study area, as it contributed an estimated 16 kilograms N per hectare, which is about 22 percent of the N input. Atmospheric deposition is also a significant source of P and K inflows.

Inorganic fertilizers are the most important source of P for the sample farms, whereas organic fertilizers are not important sources of nutrient inflow for these farms. Organic fertilizers contributed only about 2 percent of the total N inflow. There is not much inflow of organic material through biomass transfer (for example, the collection of vegetative material from off-farm sources). However, inflows through the external grazing of farmers' livestock is the second

[79]Nemba/Kasheshe is in Mbale, Kongta in Kapchorwa district, Odwarat in Kumi, and Agonyo in Soroti district.

[80]Nitrogen fixation by tropical legumes may be limited by lack of nodules, which may be a result of soil acidity or deficiency of P. Drought can also be a problem, as less rainfall leads to less N-fixation (Giller et al. 1997; Wortman and Kaizzi 1998). Biological N-fixation can also be limited by altitude and cold temperatures (Kaizzi et al. 2002).

**Table 5.1 Sources of nutrient inflows**

| Source | Nitrogen | | Phosphorus | | Potassium | |
|---|---|---|---|---|---|---|
| | Mean kg/ha | Percentage of total N inflow | kg/ha | Percentage of total P inflow | kg/ha | Percentage of total K inflow |
| Mineral fertilizer | 7.84 | 11 | 3.85 | 61 | 0.92 | 6 |
| Organic fertilizer | 1.48 | 2 | 0.00 | 0 | 0 | 0 |
| External grazing | 8.36 | 12 | 0.88 | 14 | 8.43 | 53 |
| Purchased foods | 3.62 | 5 | 0.32 | 5 | 2.08 | 13 |
| Atmospheric deposition | 16.13 | 22 | 0.80 | 13 | 3.15 | 20 |
| Symbiotic N-fixation | 15.95 | 22 | 0.00 | 0 | 0 | 0 |
| Nonsymbiotic N-fixation | 0.99 | 1 | 0.00 | 0 | 0 | 0 |
| Sedimentation | 18.16 | 25 | 0.43 | 7 | 1.31 | 8 |

most important source of P and the most important source of K.

The sources of nutrient outflows are crop and animal products sold or given away; leaching of nutrients below the root zone; gaseous losses from the soil, and water and wind erosion. Crop products are the major outflow for N and K, accounting for more than 50 percent of outflows of these nutrients, and the second most important outflow for P (Table 5.2). Leaching is the second most important outflow for N. Soil erosion is the largest outflow for P and the second most important for K. Soil erosion is a major contributor to nutrient losses, because most soil nutrients in tropical agriculture are in the top 5–10 centimeters of the soil (Keeney 1982). Our findings on the contribution of soil erosion to nutrient loss are comparable to those of Wortman and Kaizzi (1998), who observed that in the maize farming systems in eastern Uganda, erosion contributes to about 14 percent of N outflows and 43 percent of P outflows.

The average annual total NPK balance is around 100 kilograms per hectare (Table 5.3), which is lower than corresponding estimates of 177 kilograms per hectare by Wortman and Kaizzi (1998) from the same region (eastern Uganda in the Pallisa, Iganga, and Kamuli districts) and the same maize-based farming system. However, our numbers are higher than those estimated by Stoorvogel and Smaling (1990) for sub-Saharan Africa (SSA) (70 kilograms NPK per hectare per year); these estimates are not surprising, given that Uganda has one of the lowest rates of inorganic fertilizer use in SSA. Only 5 percent of the sample households had positive total NPK balances, with N and K showing the lowest balances among the three macronutrients. The rest of the farmers used land management practices that appear to be unsustainable in terms of nutrient balances.

Ideally, studying sustainability of production systems should be temporal, because some of the nutrient flows take place over more than one year. Hence, a deficit in a single year may not imply unsustainable production practices. However, we did not have time series data, as this requires long-term experiments. We used experimental and survey data for the year 2000, which had typical levels of rainfall. We therefore assume that the cross-sectional data reported give a representative picture of nutrient flow over time.

Negative balances are possible over a number of years, because plants take nutrients from the available pool of soil nutrients. The nutrients in this pool are in equilibrium with labile and inert pools. When nutrient balances are negative, the supply from the available pools will decrease with time, which will affect the inert pool as well. The

**Table 5.2 Sources of nutrient outflows**

| | Nitrogen | | Phosphorus | | Potassium | |
|---|---|---|---|---|---|---|
| Outflow channel | Mean | Percentage of total | Mean | Percentage of total | Mean | Percentage of total |
| Crop products | 54.01 | 52 | 6.79 | 40 | 60.32 | 92 |
| Animal products | 0.74 | 1 | 0.26 | 2 | 0.27 | 1 |
| Crop residues | 1.18 | 1 | 0.1 | 0 | 0.96 | 0 |
| Manure | 8.33 | 8 | 0 | 0 | 0 | 0 |
| Leaching | 21.3 | 20 | 0 | 0 | 0.91 | 2 |
| Gaseous losses | 9.01 | 9 | 0 | 0 | 0 | 0 |
| Erosion | 10.04 | 11 | 9.87 | 58 | 3.18 | 5 |

**Table 5.3 Nutrient balances in farm plots, eastern Uganda**

| | Nitrogen | Phosphorus | Potassium | NPK |
|---|---|---|---|---|
| Percentage with positive balances | 12.07 | 39.66 | 34.48 | 5.17 |
| Mean nutrient balances (kg/ha) | –48.02 | –10.80 | –51.09 | –100.01 |
| Standard deviation (kg/ha) | 48.20 | 18.24 | 82.40 | 122.79 |
| NDVM (US$)[a] | 44.7 | 11.3 | 24.3 | 80.3 |
| Total NDVM (US$) for entire farm[b] | 85.00 | 21.40 | 46.2 | 152.6 |
| ENDR (%)[c] | 10.3 | 2.6 | 5.6 | 19.0 |

Notes: The cheapest available sources of nutrients in Kampala market are as follows: N = urea (46 percent N); P = triple super phosphate (45 percent P); and K = muriate of potash (60 percent K). Farmers are likely to pay higher fertilizer farmgate price due to transportation and other transaction costs, so our estimates are likely an underestimate of the costs of avoiding nutrient depletion.

[a] Nutrient deficit market value (NDMV) is the value of nutrients mined per hectare if such nutrients were to be replenished by applying purchased fertilizer (der Pol 1993).

[b] Each household had an average of 1.9 hectares.

[c] Economic nutrient depletion ratio (*ENDR*) is an index that shows the share of farmer's income from soil nutrient mining. $ENDR = \frac{NDMV}{GM} \times 100$,

where *GM* is the gross margin from agricultural activities per household. Note that de Pol (1993) computes ENDR at per hectare basis. However, this yields the same figure since the numerator and denominator are both multiplied by total crop area. *ENDR* is the value of mined nutrient for entire farm as a percentage of household income from agricultural activities, which is estimated to be US$823 per year.

decrease in the pools will eventually lead to decreases in crop yield, although the time for yield reductions to manifest will depend on the nutrient stock. Apparently, Ugandan soils had a large reserve of nutrients (Chenery 1960) that have sustained crop yields over many decades. However, the negative nutrient balances over many years are now being manifested as declining crop yields reported in the region (Wortmann and Kaizzi 1998; Deininger and Okidi 2001; Pender et al. 2001b). Decreases in crop yield tend to reduce the rate of nutrient depletion, because there is less outflow through harvests. Thus, in more degraded areas, the rate of nutrient depletion may be lower, and may eventually reach an equilibrium, but at very low crop yields.

Of the three macronutrients, the percentage of households having positive balances of N was the lowest. The highest percentage of farmers had positive balances and the smallest mean negative balances of P. About 35 percent of sampled households had negative K balances, although this does not raise as much concern, because in most SSA soils, K is the least limiting of the three macronutrients (Woodhouse and Rendle 1983; Smaling et al. 1992; Sanchez et al. 1997), except for the sandy savanna soils (Ssali et al. 1986). But K also can become limiting for land that has been continuously cultivated for some years (Singh and Goma 1995), and for land used to cultivate crops with high K off-take, such as root crops and banana (Sanchez et al. 1997).

If the cheapest available inorganic fertilizers were used to restore the mined nutrients, it would cost an equivalent of one-fifth of the household income from agricultural activities (farm income), which averages US$823 per household per year for the sampled farms. That is, the economic nutrient depletion ratio (ENDR in Table 5.3), which reflects the share of farm income that is derived from mining soil nutrients, is about one-fifth of farm income. This implies a farm income sustainability quotient of only about 80 percent. If farmers were to practice sustainable land management by producing at a nutrient balance of zero, their farm income would be reduced to about 80 percent of the income they realize when they use the current unsustainable land management practices.

To produce policy recommendations that address these unsustainable land management practices, we analyze the factors that determine the levels of nutrient inflows and outflows and nutrient balances. Human and financial capital, technical assistance, distance from plot to residence, agricultural potential, market access, crop diversity (biodiversity), farm size, and participation in off-farm activities are important determinants of nutrient flows and balances.

## Determinants of Soil Nutrient Inflows

Controlling for other factors, households with more family labor have smaller inflows of nutrients in the form of purchased food, animal fodder from grazing off the farm, or biological nitrogen fixation (BNF) (Table 5.4). Lower levels of food and fodder imports for such households may be due to greater poverty and the subsistence orientation of larger households (controlling for farm size). The lower level of BNF may be due to land constraints (relative to family size), because many technologies for restoring soil nitrogen through BNF require land and are thus more difficult for households to adopt when land availability is very limited relative to family size (Place et al. 2002a). An increase in the average distance from the farmer's residence to his or her parcels significantly reduces the inflow from purchased food and BNF. The negative impact of the distance to parcel on nutrient inflow from purchased food comes about as farmers with distant plots buy less food from the market, possibly because they are poorer than other farmers. The negative relationship between BNF and distance to parcel is due to the higher probability of planting N-fixing legumes near the homestead that we observe in this case study.[81]

The inflows from external grazing, purchased food, and BNF are lower in the low agricultural potential (unimodal rainfall) sites in Soroti and Kumi districts (Agonya II and Odwarat villages) than in the high-potential sites in Sironko and Kapchorwa districts

[81]A Probit model showed a significant negative relationship (at $p = 0.05$) between distance of plot from homestead and the probability of planting a legume crop on a plot for the 58 households used in this case study. We did not find a similar result for the entire sample (see Chapter 4). The 58 households included in the Uganda study were participating in an experiment with leguminous cover crops, which may have emphasized experiments on plots closer to the participating households' residence.

**Table 5.4 Full generalized least squares regression of determinants of soil nutrient inflows**

| | Coefficients of source of soil nutrient inflow | | | |
|---|---|---|---|---|
| **Determinant of soil nutrient inflow** | **Chemical fertilizer** | **External grazing** | **Purchased food** | **ln(biological N fixation)** |
| ln(family labor) | –0.601 | –0.506*** | –3.710*** | –0.158*** |
| ln(distance from residence to parcel) | 0.654* | –0.013 | –0.767** | –0.0866*** |
| Agricultural potential (low = 1, high = 0) | –2.472* | –2.518*** | –5.929*** | –0.886*** |
| Tropical livestock unit (TLU)[a] | –0.583 | –0.241*** | 4.475*** | –0.010 |
| Had extension contact? (yes = 1, no = 0) | 1.451 | 0.276* | 12.820*** | 0.236*** |
| Education of household head (secondary or higher education = 1, otherwise = 0) | 5.222* | –2.548*** | –5.313 | –0.352*** |
| Market access (high = 1, otherwise = 0) | –0.270 | –1.387*** | –11.261*** | 0.266*** |
| Crop biodiversity (number of crops grown) | 1.188** | –0.561*** | 0.219 | 0.035* |
| ln(farm size) | 0.620 | 0.662*** | 5.302*** | 0.149*** |
| Off-farm as primary activity of household head? (yes = 1, no = 0) | 65.573*** | –0.350 | 10.182*** | –0.500*** |
| Constant | –3.003* | 7.004*** | 0.379 | 3.396*** |
| Number of observations (households) | 54 | 54 | 54 | 54 |
| Probability > $\chi^2$ | 0.000 | 0.000 | 0.000 | 0.000 |

Notes: *, **, *** = coefficient is significant at 10 percent, 5 percent, and 1 percent, respectively.
[a] A standard animal with live weight of 250 kg is called TLU (Defoer et al. 2000). Average TLU for each livestock category: Cow = 0.9, oxen = 1.5, sheep or goat = 0.20, and calf = 0.25.

(Nemba/Kasheshe and Kongta).[82] The effect on grazing inflows is perhaps due to the low biomass potential in the unimodal rainfall zone that leads to low quality and quantity of pasture. Farmers living in the low-potential zone are more subsistence oriented, and buy less food from the market. The negative relationship between agricultural potential and BNF was as expected, because drier conditions and poorer soils limit BNF (Giller et al. 1997).

Ownership of livestock (as measured by tropical livestock units [TLU]) reduces the nutrient inflows from external grazing but increases inflows from purchased foods. It is not clear why livestock ownership is negatively associated with inflow from external grazing, as we expected that farmers with large herds of livestock would need supplemental grazing on communal or neighbors' grazing lands. The positive relationship between TLU and nutrient inflow from purchased food is consistent with theory, because farmers who own large herds of livestock are wealthier and hence have higher purchasing power and spend less time on subsistence crop production.

Access to extension services significantly influences inflows from purchased food and BNF. The positive association between extension contacts and purchased foods may be due to better extension services for farmers growing export crops (such as cotton and coffee). Export crop producers are more likely to buy food than are food crop producers, because they have more cash and may be less likely to produce enough food for their subsistence. The positive association

[82]The 58 households included in this study were in the following agricultural potential zones: unimodal rainfall (31), bimodal medium rainfall (12); bimodal high rainfall (1); and eastern highlands (14). To avoid losing degrees of freedom, we categorize the bimodal medium rainfall, bimodal high rainfall, and eastern highlands zones as the high-potential zone and the unimodal rainfall area as the low-potential zone.

between BNF and extension contact was expected, as one of the extension messages is planting leguminous crops to promote BNF.

The level of education of the household head shows a negative relationship with nutrient inflows from external grazing and BNF. The results of Chapter 4 also show that farmers who have completed primary education are less likely to apply household residues and mulch than are those who did not complete primary education. This is consistent with Nkonya et al. (2002), who noted that education increases farmers' opportunities to be engaged in nonfarm activities. Such options may reduce farmers' incentives to invest effort in BNF-enhancing technologies or grazing animals.

Better market access is associated with smaller inflows from external grazing and purchased foods. Due to land shortage in better market-access areas, farmers are less likely to feed their animals on other farmers' plots or common grazing areas. This may explain the negative effect of market access on nutrient inflow from external grazing. The likely explanation for the negative impact of market access on nutrient inflows from purchased food is that farmers with better access to markets produce enough crops for their subsistence and a marketable surplus. This explanation appears to be supported by the large positive effect of market access on nutrient outflows through crop harvest (Table 5.5). The nutrient inflow from BNF is higher in better market-access areas. This may be due to higher demand for leguminous crops in areas with better market access, which gives farmers an incentive to plant more legumes for sale. This argument is consistent with the finding in Chapter 4 that legume production is more likely to be a primary income strategy in areas of better market access.

Controlling for TLU, farm size, and other factors, crop biodiversity decreases soil nutrient inflows from external grazing. This is likely due to the limited space for external grazing in areas that plant a large number of crops, such as on farms that produce bananas

**Table 5.5 Full generalized least squares regression of determinants of soil nutrient outflows**

| | Coefficients for soil nutrient outflows | | | | |
|---|---|---|---|---|---|
| Determinants of soil nutrient outflows | Crop harvest | Animal grazing | Crop residues | Soil erosion | Animal manure exported |
| ln(family labor) | 10.171 | 0.066 | 2.123*** | 1.689*** | 1.271** |
| ln(distance from residence to parcel) | 1.484 | –0.020 | 0.419*** | 1.040*** | –0.359* |
| Agricultural potential (low = 1, high = 0) | 74.602*** | –0.113 | 3.863*** | 15.053*** | –18.289*** |
| Tropical livestock unit (TLU)[a] | –6.917*** | 0.074* | –0.271*** | –1.194*** | – 1.392*** |
| Had extension contact? (yes = 1, no = 0) | –5.175 | 0.209 | –1.189** | 2.804*** | 12.651*** |
| Education of household head (secondary or higher education = 1, otherwise = 0) | –20.313*** | –0.026 | –0.111 | –0.320 | –11.890*** |
| Market access (high = 1, otherwise = 0) | 131.321*** | 0.085 | 3.755*** | 28.971*** | –20.884*** |
| Crop biodiversity (number of crops grown) | 1.587 | 0.011 | –0.707*** | –1.193*** | –0.791*** |
| ln(farm size) | 25.201*** | 0.192 | 1.770*** | 0.810 | –0.768 |
| Off-farm as primary activity of household head? (yes = 1, no = 0) | 49.772*** | 0.635 | 0.422 | –8.105** | –1.169 |
| Constant | –41.406*** | –0.373 | –1.774*** | 1.590 | 31.566*** |
| Number of observations (households) | 54 | 54 | 54 | 54 | 54 |
| Probability > $\chi^2$ | 0.000 | 0.023 | 0.000 | 0.000 | 0.000 |

Notes: *, **, *** = coefficient is significant at 10 percent, 5 percent, and 1 percent, respectively.
[a] A standard animal with live weight of 250 kg is called TLU (Defoer et al. 2000). Average TLU for each livestock category: Cow = 0.9, oxen = 1.5, sheep or goat = 0.20, and calf = 0.25.

or coffee. It is interesting that crop biodiversity increases nutrient inflow from chemical fertilizer. In Uganda, production of a higher number of crops is probably associated with mixed perennial-annual crop systems that include maize. Producing more crops probably means that the farmer is more likely to produce maize and thus more likely to use fertilizer.

Contrary to our expectations, farm size increases nutrient inflows from external grazing (controlling for livestock ownership). Farm size also increases nutrient inflows from purchased food, probably because of its wealth effect, which is likely to increase purchased food. Larger farms also have more nutrient inflows per hectare from BNF. This is probably because some BNF technologies, such as crop rotation with legumes, leguminous cover crops, and improved fallows may reduce profits per hectare in the near term by using land for lower-return crops or fallows, and are thus less likely to be adopted by households with little land. This explanation is consistent with our results in Chapter 4, showing lower current returns on plots where crop rotation is used, and with the results of numerous studies on the constraints to adoption of leguminous cover crops and agroforestry technologies (for example, Adesina and Chianu 2002; Gladwin et al. 2002; Place et al. 2002a).

Controlling for market access and other factors, off-farm activities increase nutrient inflows from chemical fertilizer and purchased food but reduce BNF. Farmers engaged in off-farm activities are likely to have higher cash income for buying chemical fertilizer but they are likely to produce less food than their subsistence requirement, and hence, need to buy food.[83] The negative association between off-farm activities and BNF may be due to higher labor opportunity costs of households more dependent on off-farm income, as well as their greater ability to use chemical fertilizer.

## Determinants of Soil Nutrient Outflows

Households with more family labor have greater outflows of soil nutrients, via the use of crop residues, export of manure, and soil erosion (Table 5.5). This is likely due to the ability and necessity of households with more family labor relative to land area to use more intensive and erosive land management practices, such as higher frequency of tilling or weeding, which can deplete soil nutrients directly, as well as leaving soils more exposed to erosion. This is consistent with our finding in Chapter 4 for the broader sample that larger families experienced more erosion on their lands than did smaller households. Households with more labor per land area are also selling more of their crop residues and manure, probably because they are poorer and more desperate for income.

Average distance from the residence to the farmer's parcels increases nutrient outflows from crop residues and soil erosion. The positive association between distance to parcels and outflow through crop residues may be due to greater theft or grazing of residues by neighbors on distant parcels, because owners are too far away to have effective control on access to such parcels. More nutrient loss through erosion for distant parcels is due to the use of more erosive crops or practices on distant parcels.[84] For

[83]The positive impact of off-farm income on fertilizer use is consistent with results of Freeman and Coe (2002). However, other studies have found off-farm income to be associated with less use of fertilizer or other chemical inputs (Clay et al. 1998; Pender et al. 2001a; Holden et al. 2002).

[84]In Chapter 4, we found a positive but statistically insignificant effect of distance to residence on predicted soil erosion for the full Uganda sample. Clay et al. (1998) also found more erosive practices on plots more distant from the homestead in Rwanda, whereas Gebremedhin and Swinton (2002) found the opposite result in northern Ethiopia.

instance, the results reported in Chapter 4 show that farmers are less likely to apply manure, compost, mulch, or household residues on distant parcels, and are more likely to use slash-and-burn during land preparation.

Nutrient loss through crop and residue harvest and soil erosion is significantly higher in areas of lower agricultural potential, whereas losses through removal of animal manure are less in these areas. The negative association between agricultural potential and nutrient loss through crop harvest was contrary to our expectations, because higher yields and sales of crops are expected in the high-potential areas. The impact of agricultural potential on nutrient loss through soil erosion is likely due to less vegetation in the low-potential areas, which leaves the soils unprotected and hence, more susceptible to erosion. Farmers in areas of low agricultural potential are more likely to experience fuelwood shortages, which forces them to use crop residues for cooking. This may explain the negative relationship between agricultural potential and nutrient losses through crop residues. The positive association of agricultural potential and nutrient loss through animal manure may be explained by the higher probability of applying manure in the high altitude zones, which are of high potential, than in the low-altitude areas (see Chapter 4). This implies that farmers in zones of high agricultural potential have a market for manure and hence are more likely to export it than are those in the low-potential zones. Less removal of animal manure in low-potential areas may also be due to lower production of manure where fodder availability and quality is limited.[85]

Ownership of a significant number of livestock significantly reduces nutrient losses through crop harvest, crop residues, soil erosion, and exportation of animal manure. Farmers with more animals are likely to depend less on crop production, hence produce less crops and residues for sale. Less reliance on crop production by farmers with more livestock may also explain the negative impact of livestock on nutrient losses through soil erosion. This is because in the absence of overstocking—which is not a serious problem in the study villages—crop production is more likely than livestock rearing to cause soil erosion.[86] We do not have a good explanation for why increased livestock ownership leads to less exportation of animal manure.

Contact with extension agents reduces nutrient losses through crop residues, perhaps due to the extension messages that advise farmers to incorporate crop residues.[87] However, contact with extension agents increases nutrient losses through soil erosion and exportation of animal manure. The association between nutrient loss through soil erosion and contact with extension services may be due to the tendency of farmers to adopt one technology at a time (stepwise adoption), as observed by Byerlee and de Polanco (1986). In this case, farmers may adopt more erosive practices (such as a higher frequency of weeding in combination with the adoption of improved seeds), which increase soil vulnerability to erosion, without simultaneously adopting soil conservation measures.

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[85]Ndlovu and Mugabe (2002, p. 253) report that the quantity and quality of animal feed have a major impact on the quantity and quality of the animal manure produced.

[86]For instance, Tefera et al. (2002) observed that croplands are more vulnerable than pasture to soil erosion, because croplands are repeatedly tilled and left without adequate vegetative cover. Livestock ownership was insignificantly associated with erosion in the results of Chapter 4, also suggesting that overgrazing is not a serious cause of erosion in the study region.

[87]However, we did not find a significant relationship between participation in extension programs and incorporation of crop residues for the full Uganda sample in the analysis reported in Chapter 4.

The level of education of the household head is associated with lower nutrient losses through crop harvest and exportation of animal manure. The negative association of education with nutrient loss through crop harvest suggests that better educated farmers produce less crop harvest for sale. This is consistent with the results in Table 5.4 and those in Chapter 4, which show that better educated farmers use less labor-intensive land management practices, which in turn lead to lower yields. The higher labor opportunity costs of more educated households can also reduce their willingness to transport manure for sale.

Better market access increases nutrient loss through crop harvest, crop residues, and soil erosion. This was expected, because in areas with better market access, farmers are likely to produce more crops for sale, hence exporting more nutrients, whereas farmers in remote areas face high transactions costs that exclude them from participation in the market (Omamo 1998; Key et al. 2000). Farmers with better access to markets are also more likely to find a market for their crop residues, which leads to additional nutrient loss through exportation of crop residues and the consequent soil erosion. Controlling for TLU and other factors, the negative association between loss of nutrients through animal manure exportation and market access suggests that labor costs in the areas of good market access reduce the profitability of transporting animal manure for sale. Chapter 4 also shows that farmers with better market access use less household waste on their farms.

Greater crop biodiversity diminishes nutrient loss by reducing soil erosion, as expected,[88] and by reducing exports of crop residue and manure. In diversified perennial-annual crop systems, it is common for households to recycle such materials within the farm as mulch or compost (for example, Pender et al. 2001a,b,c).

Larger farms have greater soil nutrient loss (per hectare) through the export of crop harvest and residue, because larger farms produce larger surpluses for sale. Participation in off-farm activities leads to higher losses of nutrients through crop harvest but reduces nutrient losses through soil erosion. These results support our observations (see Table 5.4) that off-farm activities enhance the use of chemical fertilizer, which in turn increases crop yield and hence nutrient loss through crop harvest. The results also are consistent with some studies showing that off-farm activities are associated with more investment in soil and water conservation (for example, Pender and Kerr 1998; Gebremedhin and Swinton 2002; Pender et al. 2002; Wyatt 2002). This finding is not universal, however; several studies find off-farm activities associated with less conservation investment and greater erosion (Shiferaw and Holden 1998; Holden et al. 2002; Hagos 2003).[89]

## Determinants of Soil Nutrient Balances

We now turn to the net effects of the determinants of nutrient flows and analyze the determinants of nutrient balances of the three major nutrients (namely, N, P, K, and their total, NPK). This analysis helps to explain the overall effects of socioeconomic and physical factors on nutrient balances.

The impact of family labor on nutrient balances is mixed. It significantly increases

[88]Crop biodiversity increases soil cover; hence, it is likely to retard soil erosion.

[89]Some of these findings depend upon the type of off-farm employment and the type of investment, among other factors. For example, Hagos (2003) found that employment on food-for-work projects contributes to increased investment in stone terraces in northern Ethiopia, whereas other off-farm activities reduce such investment. Gebremedhin and Swinton (2002) found that food-for-work employment contributes to investment in stone terraces, but reduces investment in soil bunds.

**Table 5.6 Full generalized least squares regression of determinants of soil nutrient balances**

| | Coefficients | | | |
|---|---|---|---|---|
| **Determinant of nutrient balance** | **N balance** | **P balance** | **K balance** | **NPK balance** |
| ln(family labor) | 11.454*** | –1.283 | –13.456*** | –22.837*** |
| ln(distance from residence to parcel) | 3.980*** | 0.372 | –2.771*** | –0.320 |
| Agricultural potential (low = 1, high = 0) | 21.654*** | –15.805*** | –101.886*** | –50.356*** |
| Tropical livestock unit (TLU)[a] | 4.414*** | 0.838*** | 3.798*** | 16.184*** |
| Had extension contact? (yes = 1, no = 0) | –17.947*** | –1.081 | 23.733*** | –25.228** |
| Education of household head (secondary or higher education = 1, otherwise = 0) | 13.005 | 4.986 | –13.338 | 37.111** |
| Market access (high = 1, otherwise = 0) | –22.527*** | –22.192*** | –107.988*** | –125.400*** |
| Crop biodiversity (number of crops grown) | –0.163 | 1.572*** | –5.556*** | 8.825*** |
| ln(farm size) | 6.178** | –2.836*** | –9.376** | –28.820*** |
| Off-farm as primary activity of household head? (yes = 1, no = 0) | 50.443*** | 12.097*** | –8.547 | 28.715** |
| Constant | –74.954*** | 7.181 | 139.847*** | –31.838*** |
| Number of observations (households) | 53 | 39 | 40 | 54 |
| Probability > $\chi^2$ | 0.000 | 0.000 | 0.000 | 0.000 |

Notes: *, **, *** = coefficient is significant at 10 percent, 5 percent, and 1 percent, respectively.
[a] A standard animal with live weight of 250 kg is called TLU (Defoer et al. 2000). Average TLU for each livestock category: Cow = 0.9, oxen = 1.5, sheep or goat = 0.20, and calf = 0.25.

the nutrient balances for N but reduces those for K and NPK (Table 5.6). This is likely due to its negative effects on most nutrient inflows (external grazing, purchased foods, and BNF) and its positive effect on most outflows (soil erosion, and exportation of animal manure and crop residues). Distance from residence to parcel has a positive impact on N but a negative effect on K. This may be due to a higher level of chemical fertilizer application on distant parcels than on those near the residence (see Table 5.4). However, it is uncommon for farmers to apply K-rich chemical fertilizers, such as muriate of potash or potassium sulfate. Manure and household residues that are K-rich are more likely to be applied on parcels closer to the residence, because of the high cost involved in transporting such bulky materials to distant plots. Plots near the homestead benefit from household waste thrown on them regularly after cleaning the home or animal pens.

Households in areas of high agricultural potential have significantly higher nutrient balances than do those in low-potential areas, suggesting that crop production in the high-potential areas is more sustainable than in low-potential regions. This follows from the results reported in Table 5.4 and Chapter 4, where we noted that farmers in low-potential areas experience greater loss of nutrients through soil erosion and are less likely to apply chemical fertilizer or adopt BNF-enhancing technologies than those in the high-potential areas (see the results given in Chapter 4 for the comparison of the unimodal zones and the eastern highlands).

Livestock ownership is related to significant increases in the balances for N, P, K, and NPK. The results reported in Tables 5.4 and 5.5 suggest that farmers with more livestock are more likely to buy than to sell food and crop residues, and thus they increase importation and reduce exportation of nutrients.

We observe a significant negative impact of contact with extension agents on N and NPK balances. As noted earlier in this chapter, this is perhaps due to the stepwise adoption of technologies. To verify this, we ran a version of the regression analysis for nutrient balances that included a quadratic specification of extension contact hours (*ext* and $ext^2$) as explanatory variables.[90] We observed a U-shaped relationship of nutrient balances with extension. This relationship was significant for the two most limiting nutrients (N and P). For the case of few extension contact hours, as is the case now, farmers are likely to adopt improved crop varieties without implementing soil fertility technologies.[91] Hence initially, there is more soil depletion, which subsequently bottoms out; finally, nutrient balances start to go up with increasing extension contact hours, as the adoption of soil fertility management technologies increases. Farmers may follow the stepwise adoption and realize profits in the first few years. For example, Smale and Heisey (1994) observed that farmers planting hybrid maize in Malawi realized higher returns than did farmers growing unimproved varieties. However, as soil depletion is accelerated by the new, higher-yielding crop varieties, profits will likely decrease over time. Our research suggests that inadequate extension services are likely to contribute to unsustainable land management practices if farmers adopt improved crop varieties without adopting soil fertility management practices that would restore the additional nutrients utilized by high-yield crop varieties. This appears to be supported by some field observations. For instance, farmers often complained that productivity of plots previously planted with improved varieties decreased substantially.

Controlling for off-farm activities and other factors, farmers having secondary or higher education have higher nutrient balances than those having less education. Education increases fertilizer use and reduces external grazing (see Table 5.4). Education also reduces the exportation of manure and crop harvest (see Table 5.5). This suggests that better education is likely to contribute to more sustainable crop production.

Better market access significantly reduces balances of N, P, K, and NPK, suggesting that farmers closer to markets mine their soils more intensively than do those farther away from markets. As observed in Table 5.5, better market access increases nutrient outflow through the exportation of crop harvest and crop residue. Due to its positive impact on crop-residue harvesting, better market access also increases soil erosion significantly, further contributing to soil nutrient depletion. This observation is consistent with Woelcke et al. (2002), who found that commercially oriented farmers in eastern Uganda had worse soil nutrient depletion than did subsistence farmers. Omamo (1998) and Barrett et al. (2001b) also observed that farmers who are in remote areas tend to produce low-value food crops mainly for their subsistence needs. This autarkic behavior is likely to reduce nutrient depletion. Conversely, farmers with better market access tend to produce nonfood crops (Omamo 1998; Barrett et al. 2001b), which tends to increase soil nutrient depletion if inadequate fertilizers are applied. This implies that improved access to markets may induce farmers to practice unsustainable land management for the sake of short-term profit, as noted by Lipton (1987).

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[90]The results of this regression available upon request. To reduce number of independent variables and problems of multicollinearity, we did not include the quadratic function of extension in the reported set of regressions, but instead included a dummy variable for access to extension services.

[91]Among the 58 farmers considered in this chapter, 62 percent did not have extension contact in 2000. Among those who had extension contact, only 25 percent had more than 4 contact hours in the entire year. Undoubtedly, this is insufficient time for farmers to understand the rather complex technologies, such as soil fertility practices. MAAIF and MFPED (2000) also note the inadequate extension services in most districts of Uganda. Only 11.4 percent of households had access to extension services in 1998 (UBOS 2002b).

Our finding of more negative nutrient balances in areas with better market access is not a general result: evidence from other countries presents a different picture. For example, soil fertility levels are much higher in the tea farming areas of western Kenya than on the nearby farms of subsistence cereal producers. In general, fertilizer inputs are much greater on commercial crops than on subsistence crops, and studies reveal that most farmers in commercial areas perceive the fertility of their plots to have increased over time.[92] The case of Uganda smallholder farmers presents a unique picture, because the rate of fertilizer application in the country is lower than in all other SSA countries. Even farmers who are close to markets in Uganda still do not apply much fertilizer, unlike those in Kenya and other countries. Hence, as we observed in this research, the more the farmers sell their produce off the farm, the more severe the soil nutrient depletion becomes. These findings call into question the assumption of the Plan for Modernization of Agriculture that improvement in infrastructure and markets will solve unsustainable land management problems, at least in the near term.

As expected, crop biodiversity contributes to more positive (or less negative) nutrient balances, suggesting the need to encourage farmers to plant crops using intercrop systems. Intercropping may be more common in perennial-crop systems, which may have fewer nutrient depletion problems. Crop diversity appears to reduce soil erosion (see Table 5.5), the exportation of crop residues and manure, and the probability of external grazing; it increases the probability of the application of chemical fertilizers (Table 5.4). Crop diversity (including the planting of legumes) increases BNF, which is one of the major sources of nitrogen.

Farm size is negatively related to nutrient balances, implying that larger farms have higher levels of nutrient depletion. As pointed out earlier, this is likely due to the ability of larger farms to produce more marketable crop and residue surplus (see Table 5.5), which exports soil nutrients off the farm without adequate replenishment.

Households having a nonfarm primary activity have less negative nutrient balances than do those having agriculture as their primary activity. As observed earlier, this is likely due to their ability to buy fertilizer and food (see Tables 5.4 and 5.5), and to lower erosion. Barrett et al. (2001b) also observed that in Africa, farmers engaging in nonfarm activities have higher income and wealth. Hence, in addition to offering an important pathway out of poverty, our results show that nonfarm activities may contribute to the reduction of soil nutrient depletion.

Finally, we point out the weaknesses of the present chapter and recommend future research in this area. This chapter attempted to analyze the factors affecting nutrient balances using only 58 households in a largely maize-farming system. The sample of 58 households is small, although it generated quite interesting results. Future studies are needed that involve a larger sample of farmers from different systems of farming and land tenure in the country. This will allow better estimates of the status and causes of nutrient depletion in Uganda.

[92]We thank an anonymous reviewer for pointing this out to us.

## CHAPTER 6

# Summary of Findings, Conclusions, and Policy Implications

This study demonstrates the complexity of factors influencing the income strategies, crop choices, and land management decisions of households in Uganda, and their diverse implications for agricultural production, land degradation, and household income. Many of our hypotheses about the factors influencing these decisions and outcomes are confirmed by the results, but we also found some surprising results, and the impacts of many factors were found to be context-dependent (for example, differing between highland and lowland areas). Here we review key findings with regard to the factors hypothesized to affect these decisions and outcomes and then consider implications of the findings.

## Summary of Findings

This summary highlights the major findings discussed in Chapters 4 and 5, considering the factors hypothesized to influence livelihoods, land management, and outcomes in Chapter 3. Table 6.1 summarizes most of these results.[93]

### Agro-Ecological Zones

Our results show that income strategies, crop choice, and land management differ across agro-ecological zones. Livestock production was least likely to be the primary income source in the unimodal rainfall zone in the north, bananas were more important in the eastern highlands, and vegetable production was more important in the bimodal rainfall zones, whereas nonfarm activities were less important in these zones. Labor intensity was also higher in the bimodal rainfall zones than in the unimodal zone. As expected, the adoption of fertilizer was most common and the value of crop production highest in the high-potential eastern highlands. Despite these differences, we did not find statistically significant differences in household incomes across the agro-ecological zones. As expected, predicted soil erosion is greatest in the steeply sloping highlands. However, we find that soil nutrient balances are less negative in the high-potential eastern highlands than in lower-potential lowland sites in eastern Uganda.

### Market Access

Access to markets and roads does not have as much impact on income strategies, crop choices, land management, or outcomes as expected. Households with better market access were more

[93]Table 6.1 summarizes results in qualitative form. It does not report all of the results from Chapters 4 and 5, due to space limitations.

## Table 6.1 Determinants of labor use, land management, and outcomes in Uganda

| Variable | Labor use | Land management: Fertilizer | Land management: Manure/ Compost | Value of crop production | Income | Erosion | Soil nutrient balance |
|---|---|---|---|---|---|---|---|
| Agro-ecological zones | | | | | | | |
| Bimodal low rainfall | + | 0 | 0 | 0 | 0 | 0 | ne |
| Bimodal medium rainfall | + | 0 | 0 | 0 | 0 | 0 | ne |
| Bimodal high rainfall | + | 0 | 0 | 0 | 0 | 0 | ne |
| Southwestern highlands | 0 | 0 | 0 | 0 | 0 | + | ne |
| Eastern highlands | 0 | + | + | + | 0 | + | + |
| High market access | 0 | 0 | 0 | 0 | 0 | 0 | – |
| Distance to all-weather road | – | 0 | 0 | 0 | + | 0 | ne |
| Population density | 0 | + | 0 | 0 | 0 | + | ne |
| Primary income strategy[a] | | | | | | | |
| Wage/salary | 0 | ne | 0 | 0 | 0 | 0 | + |
| Nonfarm activities | 0 | ne | 0 | + | 0 | 0 | + |
| Livestock | 0 | ne | 0 | + | + | 0 | ne |
| Cereals | 0 | ne | 0 | + | 0 | 0 | ne |
| Root crops | – | ne | 0 | 0 | 0 | 0 | ne |
| Legumes | 0 | ne | + | + | 0 | 0 | ne |
| Horticulture | 0 | ne | 0 | + | 0 | 0 | ne |
| Coffee/export crops | 0 | ne | 0 | + | 0 | 0 | ne |
| Crop choice[b] | | | | | | | |
| Banana | – | – | + | + | ne | ne | ne |
| Coffee | – | – | + | 0 | ne | ne | ne |
| Irrigation | 0 | 0 | 0 | 0 | 0 | ne | ne |
| Technical assistance | | | | | | | |
| Training | 0 | + | 0 | + | 0 | 0 | ne |
| Extension | 0 | + | 0 | + | + | 0 | – |
| Agricultural/environment organizations | 0 | 0 | 0 | 0 | 0 | – | ne |
| Formal credit access | 0 | 0 | 0 | 0 | 0 | 0 | ne |
| Informal credit access | + | 0 | 0 | 0 | 0 | 0 | ne |
| Land tenure[c] | | | | | | | |
| Leasehold | 0 | 0 | 0 | 0 | + | 0 | ne |
| *Mailo* | 0 | 0 | 0 | 0 | 0 | – | ne |
| Customary | 0 | 0 | 0 | 0 | 0 | 0 | ne |
| Plot titled | + | + | 0 | 0 | 0 | 0 | ne |
| Education of household head[d] | | | | | | | |
| Primary | 0 | + | 0 | 0 | + | 0 | ne |
| Secondary | 0 | 0 | 0 | 0 | 0 | + | + |
| Higher | – | 0 | 0 | 0 | + | + | + |
| Household size | 0 | 0 | 0 | 0 | + | + | – |
| Farm size | 0 | – | – | – | 0 | 0 | – |
| Female head of household | 0 | – | 0 | 0 | + | 0 | ne |
| Livestock owned | 0 | 0 | 0 | + | 0 | 0 | + |
| Equipment owned | 0 | 0 | 0 | 0 | 0 | 0 | ne |

Notes: + (–) means coefficient is positive (negative), statistically significant at 10 percent level in the ordinary least squares (OLS) model, and robust in at least one other specification (instrumental variables or reduced form), unless OLS preferred by Hausman test. 0 = otherwise.

[a] In contrast to general agricultural production.

[b] In contrast to cereals.

[c] In contrast to freehold tenure.

[d] In contrast to no formal education.

likely to depend on nonfarm activities or legume production as an income strategy, and households closer to an all-weather road use labor more intensively in crop production than those in remote areas. Better access to markets was found to increase soil nutrient depletion in eastern Uganda by increasing the sales of produce without adequately increasing soil nutrient replenishment through the use of fertilizers or other land management practices. We find an unexpected negative association of road access with household income, which we are not able to explain. Further research is needed to establish whether this is a robust result, and the reasons for it if so.

### Population Density and Farm Size

We did not find significant effects of population density or farm size on the primary income strategy of households. However, crop choice was affected by population density. For example, vegetable production is less likely in more densely populated areas, and root crops are more likely to be cultivated on smaller farms, suggesting that land constraints may force farmers to focus on staple food crops. Consistent with Boserup's (1965) theory of population-induced intensification, application of household residues is more common in densely populated areas. Additionally, smaller farmholds are less likely to use slash-and-burn, more likely to use fertilizer and manure/compost and to obtain higher values of crop production on a given plot (controlling for plot size and other factors), also indicating that these farmholds farm more intensively and are more efficient. However, we do not find a significant association of population density or farm size with labor intensity and household income. This suggests that land constraints are being overcome through the operation of markets and/or greater efficiency of small farmers. Contrary to the optimistic "more people—less erosion" hypothesis (Tiffen et al. 1994), we find that population density has a positive impact on predicted erosion. However, smaller farms have less soil nutrient depletion per hectare, because they sell less of their production.

### Income Strategies

Households' income strategies are determined by relatively fixed factors, such as ethnicity and agro-ecology, as well as by their endowments of human capital. Access to markets and roads, population density, and farm size are less important determinants of income strategies.

As hypothesized, different income strategies were associated with different land management practices; for example, households whose primary income source was legume production were more likely to use manure and compost, whereas horticultural crop producers were more likely to apply mulch or household residues. Perennial crop production has a strong impact on land management practices, promoting the application of manure and compost, mulch, and household residues, and reducing the use of slash-and-burn, fertilizer, and crop rotation. Nevertheless, perennial crop production reduces labor intensity.

Income strategies had a strong impact on the value of crop production, with higher values of production associated with livestock production, nonfarm activities, and greater specialization in several specific crops, relative to the more generalized agricultural producers and households reliant on forestry or fishing activities. This result suggests that more specialized crop producers and households with more noncrop sources of income have advantages in crop production or marketing, perhaps because they are more market oriented. Among the crops, we find that banana production leads to higher values of production than do other crops. Despite such advantages of particular income strategies and crops in favoring higher-value crop production, we find insignificant differences among most income strategies in determining household income levels, except for livestock producers, who earn significantly higher income than do other households. We find no differences in predicted soil erosion among households pursuing different income strategies, but do find that households with off-farm or nonfarm primary sources of income have more favorable nutrient balances in eastern Uganda, because of their greater use of fertilizer and purchased foods.

### Irrigation

Irrigation favors the production of vegetables over other annuals, such as legumes, as expected. Irrigation also affects land management practices, being associated with a greater use of mulch and crop rotation, and less incorporation of crop residues. Irrigation has positive but not statistically robust impacts on labor intensity and the value of crop production, and insignificant impact on incomes. The mostly insignificant impacts of irrigation are probably due to the small number of irrigated plots in our sample.

### Programs and Organizations

The effects of programs and organizations depend on their focus and location. Agricultural extension and training programs appear to focus more on the use of inputs, such as improved seeds and fertilizer, whereas nongovernmental organizations (NGOs) focus more on other land management practices. Participation in extension programs increases crop production and household income significantly but also leads to more soil nutrient depletion, due to the increased production and sale of crop surplus and inadequate nutrient replenishment. Participation in agriculture/environment NGOs dealing with agriculture and/or the environment is associated with less predicted soil erosion, due to their emphasis on soil conservation, and with an increased value of crop production in the highlands but lower production in the lowlands. This result indicates that there are location-specific differences in the impacts of such organizations and trade-offs associated with the technologies promoted.

### Access to Credit

The availability of formal credit in a village has generally insignificant impacts on crop choice, most land management practices, and labor intensity. By contrast, informal credit availability is associated with more cereal but less legume production, and greater labor intensity in crop production. We also find statistically insignificant impacts of both formal and informal credit availability on the value of crop production, predicted soil erosion, and household income.

### Land Tenure

Land tenure and land title have some impacts on crop choice and land management practices. For example, cereals and legumes are less common on *mailo* plots, probably because *mailo* occupants tend to focus on *matooke* production for their own subsistence. There are few significant differences between customary and freehold plots in terms of land management practices, suggesting that tenure insecurity is not a serious concern for customary plots. Fertilizer use is more likely and labor intensity is higher on plots with formal title, possibly due to better credit access. Despite these differences, we find no statistically significant impacts of land tenure or title on the value of crop production, predicted soil erosion, or household income.

### Education

Education has a significant influence on households' income strategies, land management practices, and labor use in crop production. Higher education promotes off-farm salary employment, nonfarm activities, and livestock production, and reduces the likelihood of the household pursuing cereal production as its primary income strategy. Primary education favors the production of vegetables and the use of fertilizer, but is associated with diminished use of mulch and household residues. Higher education reduces labor intensity in crop production, but education does not have significant impacts on the value of crop production or on soil erosion. However, more educated household heads were found to have less negative nutrient balances in eastern Uganda. As expected, and consistent with results of numerous other studies, education contributes to significantly higher household income, especially when education beyond the secondary level is attained.

### Human and Physical Capital

Household endowments of labor influence income strategy. For example, larger households are more likely to pursue nonfarm activities. Household size has insignificant impacts on land management practices, labor intensity, and the value of crop production, suggesting that labor markets work relatively well. Larger households have higher predicted levels of erosion and more negative nutrient balances in eastern Uganda, however, due to intensive cropping and the reduced use of fertility-enhancing inputs.

Households headed by women are more likely than those headed by men to depend on nonfarm activities as their primary income strategy and to grow cereals relative to perennials on a particular plot. Consistent with this, households headed by women are more likely to practice crop rotation and less likely to apply crop residues. They are also less likely to apply fertilizer. Interestingly, households headed by women earn higher incomes than those households headed by men, suggesting that the extent of employment and/or labor productivity of women is greater than that of men. This supports a common view that men are underemployed relative to women in rural Uganda.

Ownership of livestock has a statistically insignificant impact on crop choice, land management practices, and labor intensity. However, farmers who own more livestock obtain higher values of crop production in the full sample, and less negative nutrient balances in eastern Uganda. Livestock ownership or dependence on livestock as an income strategy does not have a significant impact on predicted erosion. Ownership of farm equipment has statistically insignificant impacts on crop choice, most land management practices (except that it reduces the use of slash-and-burn), labor use, value of crop production, income, or soil erosion.

## Conclusions and Policy Implications

The findings of this study demonstrate the trade-offs that are taking place as rural development and agricultural modernization proceed in Uganda. Market liberalization and investments in roads, education, technical assistance, and other developments are providing new opportunities for rural households, contributing to increased commercialization and specialization, nonfarm employment, and increased rural incomes. However, many of these changes are also reducing households' interest in labor-intensive land management practices, and although some are promoting the increased use of fertilizer and other inputs, high costs and limited returns to such inputs are limiting their application, resulting in continued low productivity in agriculture and worsening land degradation.

The findings of this study support continued strong investment in education as a primary means of reducing poverty in rural Uganda. However, this will likely not solve the problems of low agricultural productivity and soil erosion, and may contribute to these problems, as education increases opportunities outside of agriculture. Including the principles of sustainable agricultural production in educational curricula could help to minimize negative impacts or even have positive impacts on agricultural production and sustainable land management. Hence, the Plan for Modernization of Agriculture (PMA)'s provisions to introduce an agricultural syllabus in primary and secondary education is a step in the right direction toward addressing this problem (MAAIF and MFPED 2000).

Agricultural training and extension programs appear to be contributing to improved agricultural productivity, but also to increased soil erosion in the highlands and to soil nutrient depletion. It is imperative that such programs be intensive enough to promote adoption not only of yield-enhancing technologies, such as improved seeds, but also of soil fertility-restoring and conservation technologies. The new National Agricultural Advisory Services (NAADS) and other extension and agricultural training programs should take into account these trade-offs and attempt to increase exposure to extension training to overcome the stepwise or partial adoption of technologies that are likely to lead to short-term gains only. It is also important that such programs recognize the context-dependent nature of the impacts of technologies. Ensuring that the approach is responsive to local demands and conditions, as the decentralized design of NAADS envisions, is an important step toward accomplishing this goal.

The impacts of NGO programs are also context-dependent, but also may involve trade-offs. For example, programs focusing on agriculture and environment in the lowlands are helping to reduce soil erosion but also appear to be reducing productivity, at least in the short term. Such programs appear to be more successful in improving production as well as reducing land degradation in the highlands, perhaps because soil and water conservation technologies can have more immediate impacts on production in steeply sloping highland areas, where soil moisture is more scarce (Shaxson 1988), or perhaps because the programs operating in the highlands are taking a more participatory and interactive approach than those operating elsewhere. More research is needed to better understand the reasons for the success or failure of such programs in different contexts and to achieve such "win-win" outcomes more broadly.

Given the ability of government training and extension programs to increase productivity and the ability of NGOs to reduce land degradation, "win-win" outcomes may be promoted by pursuing a greater degree of partnership between the different types of programs. There has often been limited collaboration between programs and organizations promoting productivity-enhancing technologies (such as fertilizers) and those promoting soil and water conservation, leading to mixed messages and lost opportunities to exploit complementarities between different approaches and technologies. The new NAADS approach, with its emphasis on involving NGOs as well as governments, offers an opportunity to bridge the gaps among these different types of organizations.

Government efforts to improve market access also involve trade-offs. Access to markets contributes to the diversification of income into nonfarm activities, but also contributes to negative soil nutrient balances, at least in the near term. This trade-off presents a serious challenge for policymakers. Farmers in remote areas are likely to be faced with high agricultural marketing transaction costs that make it unprofitable to produce surplus for the market. Such farmers are therefore likely to remain in a vicious cycle of poverty, which poses an enormous challenge to policymakers and development planners. Obviously, it is imperative to improve the market access for farmers in remote areas to facilitate their integration in the agricultural market, which is needed to reduce their poverty. Achieving this poses the second challenge: farmers who have better access to markets are more likely to sell more crops and consequently to experience worse nutrient depletion on their land. Hence, governmental efforts to commercialize agriculture and improve the road network must be matched by increased efforts to address the problem of land degradation.

Reducing the cost of soil fertility management technologies, improving agricultural markets, and reducing the input/output price ratio will help to address this challenge. Other steps may be taken to reduce the price of fertilizers, such as facilitating input traders by training and offering them credit, and waiving some of the taxes levied on input trading businesses. As noted by

IFDC (2001), there is also a need to increase trade between Ugandan and Kenyan input traders to benefit from the economies of scale of the Kenyan fertilizer market. Farmer associations may also help reduce the transaction costs of inputs and outputs.

Additionally, the expensive inorganic fertilizer option needs to be complemented with cultural practices that are affordable, feasible, and compatible with local farming systems. For instance, our research found that farmers with more livestock have higher soil nutrient balances. However, when using organic material to complement inorganic fertilizer, the benefits of biomass transfer must be weighed against the cost of nutrient depletion at the source of the organic materials (Palm et al. 1997). The option of recycling organic material produced on the plot is limited by the inadequate production of organic material and competition with other uses. Incorporating high-quality legumes (such as *Mucuna pruriens*) and rhizobial inoculation may greatly improve nitrogen balances at a much lower cost (Kaizzi et al. 2002; Ndakidemi et al. 2002), but adoption may be limited in lower-potential areas where such cover crops are less effective (Kaizzi et al. 2002), or in densely populated areas where farmers are unable to devote land to cover crops or leguminous trees, even for one season (Gladwin et al. 2002; Place et al. 2002a).

Our research also shows that use of different land management practices is influenced by several factors that are not likely to occur in many agricultural domains simultaneously. This suggests the need to design land management technologies that are specific to an agro-ecological zone, type of crop, market access, and other factors influencing the choice of land management practices. Most of the current agricultural production technologies are released with blanket recommendations covering diverse biophysical and socioeconomic environments, which render them irrelevant in some areas (Bekunda et al. 2002). We also noted that farmers tend to complement their agricultural investments with improved land management practices, which implies the need for extension agents to promote a package of complementary technologies. This will help to overcome the problem of stepwise adoption and hence increase technology uptake and returns for investments on plots.

One of the strategies used to address rural poverty is to promote the production of crops that have high returns to farmers. It was interesting to observe that plots planted in bananas had higher crop values than most other crops. This suggests the need to increase research efforts into banana production, addressing the soil fertility, disease, and pest problems that are facing the crop in the central region of Uganda. Research in banana marketing and value addition is also needed to identify policies and strategies for developing the banana sector.

The promotion of livestock production linked to crop production appears to be a "win-win-win" strategy, contributing to higher agricultural production, higher income, and less soil nutrient depletion. Such favorable outcomes result from synergies between crop and livestock production in mixed crop-livestock systems (McIntire et al. 1992; Staal et al. 2001). However, these findings are less relevant to the pastoral farming systems commonly found in the low-potential and fragile environments in the northeast and other parts of the cattle corridor.[94] Land degradation related to overgrazing is a serious concern in these areas (Muhereza and Otim 2002; NEMA 2001), and care needs to be exercised when promoting livestock development to ensure that it does not contribute to overgrazing and land degradation in such areas. To the extent

[94]These pastoral areas were not well covered by our survey sample, so our findings and implications are not necessarily applicable to them.

that households diversify to include livestock as well as crop production activities, this may also reduce their risk exposure. This has a bearing on the strategy of the Plan for Modernization of Agriculture (PMA) for commercializing agriculture, which is usually achieved by specialization. Even though specialization can increase crop value and income, it exposes farmers to production and price risks. These findings suggest that the PMA should encourage farmers to diversify their production portfolios to include livestock as well as crop production.

Participation in nonfarm activities also appears to lead to decreased nutrient depletion and higher values of crop production. Hence, promoting nonfarm development may be a "win-win" strategy, reducing land degradation while helping to reduce poverty. However, to increase the competitiveness of nonfarm products, farmers' skills in making them need to be increased through training in polytechnic and vocational schools based in rural areas.

Evidence from this study generally supports the Boserupian model of population-induced agricultural intensification, but does not support the optimistic "more people—less erosion" hypothesis (Tiffen et al. 1994). Population pressure contributes to soil erosion and lower crop production in the highlands. Efforts to reduce population pressure in the highlands may thus produce "win-win" outcomes, helping to both increase agricultural productivity and reduce land degradation. In addition to education and family-planning efforts to reduce birth rates, education and vocational training programs can help people in the highlands to develop skills to enable them to migrate and find remunerative employment elsewhere.

We do not find evidence that access to credit is a major factor influencing land management, agricultural production, and incomes at present. This is likely due to the limited adoption of inputs and limited commercialization, and is likely to change as markets develop and use of inputs becomes more profitable. To avoid credit becoming a serious constraint to agricultural modernization in the future, efforts to develop rural finance institutions should continue, recognizing that they are needed to serve multiple purposes beyond financing agricultural inputs (for example, the need for a secure place for savings, financing nonfarm activities, consumption credit). To the extent that such institutions can develop a broad range of services and be profitable in the present environment, they will be better able to handle the demands for agricultural credit that develops in the process of agricultural modernization.

We do not find evidence of a poverty–land degradation trap, given that erosion does not depend significantly on asset ownership. Poverty has mixed impacts on agricultural productivity, depending on the type of assets considered: smaller farms obtain higher values of crop production per hectare, as do households with more livestock. These findings suggest that development of factor markets (for example, for land and livestock) can improve agricultural efficiency. Development of land markets can also help to reduce problems associated with land fragmentation, which reduces the adoption of high-value crops and labor-intensive, sustainable land management practices. Implementation of the provisions of the 1998 Land Act providing for conversion of *mailo* and customary land to freehold status could help facilitate the functioning of the land market.

Land tenure and land title were found to have limited impacts on agricultural production, land degradation, and income. This is because the most common forms of tenure are relatively secure and transferable, and access to credit is not a critical factor affecting agricultural production, as noted above. As agriculture becomes more commercialized, the demand for formal titles to increase access to formal credit is likely to increase, however.

In general, these results imply that there are few "win-win-win" opportunities to simultaneously increase production, raise household income, and reduce land degradation. Different instruments are needed to achieve the different objectives, and tradeoffs among these objectives must often be contemplated. Addressing these issues will require appropriate demand-driven investments in education, training and extension programs, NGO programs, improvements in road infrastructure, agricultural input marketing, creation and facilitation of nonfarm opportunities in rural areas, and the promotion of livestock production and other more remunerative livelihood activities. Just as no single solution exists to improve all outcomes simultaneously, different approaches are needed in different locations. There is no "one-size-fits-all" solution to the complex problems of small farmers in the diverse circumstances of Uganda.

# APPENDIX A

## Descriptive Statistics and Selected Survey Results

**Table A.1 Household use of soil and water conservation technologies in 2000**

| | | Agricultural potential | | | | | | Market access | | Population density | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Technology | Average | Unimodal | Bimodal low | Bimodal medium | Bimodal high | Southwest highlands | Eastern highlands | Poor | Good | Low | High |
| Improved fallow | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) |
| Alley cropping | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | (0.0) | (0.0) | (0.0) | (0.2) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) |
| Planting leguminous trees | 3.8 | 7.0 | 2.3 | 0.0 | 3.7 | 10.6 | 0.0 | 0.3 | 4.9 | 0.9 | 5.0 |
| | (1.1) | (2.0) | (2.3) | (0.0) | (2.1) | (3.6) | (0.0) | (0.3) | (1.4) | (0.7) | (1.5) |
| Planting nonleguminous trees | 5.6 | 1.8 | 8.9 | 1.1 | 8.2 | 4.8 | 4.5 | 4.1 | 6.1 | 5.2 | 5.8 |
| | (1.7) | (1.1) | (4.4) | (0.8) | (3.5) | (3.6) | (4.1) | (2.7) | (2.1) | (2.9) | (2.1) |
| Crop rotation | 43.4 | 41.9 | 49.5 | 40.2 | 47.1 | 35.3 | 23.5 | 52.4 | 40.3 | 44.3 | 43.0 |
| | (3.7) | (9.6) | (9.9) | (4.3) | (6.8) | (6.9) | (10.0) | (5.3) | (4.6) | (5.0) | (4.8) |
| Mulching | 20.1 | 3.8 | 48.9 | 2.0 | 24.9 | 35.3 | 11.2 | 22.2 | 19.4 | 19.8 | 20.3 |
| | (2.6) | (1.8) | (9.7) | (1.2) | (5.0) | (8.0) | (8.7) | (4.1) | (3.2) | (4.0) | (3.3) |
| Composting | 10.0 | 0.4 | 5.7 | 1.5 | 15.4 | 19.9 | 9.4 | 0.0 | 13.4 | 0.0 | 14.4 |
| | (2.1) | (0.4) | (4.1) | (1.2) | (4.4) | (5.1) | (5.1) | (0.0) | (2.8) | (0.0) | (3.1) |
| Animal manure | 22.7 | 27.4 | 33.4 | 7.6 | 24.8 | 13.1 | 50.2 | 14.5 | 25.6 | 15.8 | 25.8 |
| | (2.8) | (9.9) | (8.6) | (1.2) | (4.9) | (4.0) | (10.5) | (2.6) | (3.7) | (2.3) | (3.9) |
| Crop residues | 17.7 | 40.5 | 17.3 | 19.5 | 10.4 | 20.2 | 12.7 | 24.9 | 15.3 | 21.0 | 16.3 |
| | (2.5) | (10.8) | (8.2) | (3.8) | (3.6) | (4.9) | (5.5) | (4.5) | (3.0) | (4.1) | (3.1) |
| Leguminous cover crops | 0.2 | 0.0 | 2.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.6 | 0.0 |
| | (0.2) | (0.0) | (2.1) | (0.0) | (0.0) | (0.0) | (0.0) | (0.0) | (0.3) | (0.6) | (0.0) |
| Grass strips | 7.9 | 2.3 | 2.3 | 0.5 | 8.5 | 24.6 | 35.7 | 5.5 | 8.8 | 3.3 | 10.0 |
| | (2.2) | (1.2) | (2.3) | (0.3) | (4.4) | (6.8) | (10.5) | (1.8) | (2.9) | (2.1) | (3.0) |
| Trash lines | 7.1 | 2.8 | 1.7 | 4.2 | 12.0 | 3.1 | 0.0 | 6.5 | 7.4 | 5.8 | 7.7 |
| | (1.4) | (1.7) | (1.7) | (1.9) | (2.9) | (3.1) | (0.0) | (3.0) | (1.6) | (2.6) | (1.7) |
| Tied ridges | 0.4 | 0.0 | 0.0 | 0.5 | 0.0 | 3.6 | 0.0 | 0.0 | 0.5 | 0.0 | 0.5 |
| | (0.2) | (0.0) | (0.0) | (0.5) | (0.0) | (2.1) | (0.0) | (0.0) | (0.3) | (0.0) | (0.3) |
| Infiltration ditches | 1.7 | 0.0 | 4.4 | 0.5 | 1.8 | 3.7 | 1.3 | 1.2 | 1.8 | 1.0 | 2.0 |
| | (0.8) | (0.0) | (4.4) | (0.5) | (1.3) | (3.7) | (1.3) | (1.2) | (1.0) | (1.0) | (1.1) |
| Minimum tillage | 3.3 | 3.9 | 7.1 | 0.0 | 1.3 | 16.9 | 4.2 | 1.1 | 4.1 | 3.8 | 3.1 |
| | (0.8) | (3.9) | (3.2) | (0.0) | (0.9) | (4.5) | (3.8) | (0.7) | (1.1) | (2.0) | (0.8) |
| Contour plowing | 1.5 | 4.5 | 1.7 | 0.3 | 0.0 | 5.3 | 6.4 | 2.4 | 1.2 | 2.1 | 1.2 |
| | (0.4) | (2.0) | (1.7) | (0.3) | (0.0) | (2.8) | (1.6) | (0.8) | (0.5) | (0.9) | (0.4) |
| Soil bunds | 1.6 | 0.0 | 4.6 | 1.5 | 1.9 | 0.0 | 1.7 | 0.5 | 2.0 | 0.3 | 2.2 |
| | (1.0) | (0.0) | (3.6) | (1.5) | (1.9) | (0.0) | (1.3) | (0.4) | (1.3) | (0.3) | (1.4) |

Notes: Means and errors are corrected for sampling stratification and sampling weights. Standard errors are given in parentheses. All figures are percentages; $N = 451$ for the household data.

**Table A.2 Change in household use of soil and water conservation technologies between 1990 and 2000**

| | | Agricultural potential | | | | | | Market access | | Population density | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Technology** | **Average** | **Unimodal** | **Bimodal low** | **Bimodal medium** | **Bimodal high** | **Southwest highlands** | **Eastern highlands** | **Poor** | **Good** | **Low** | **High** |
| Improved fallow | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Alley cropping | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Planting leguminous trees | 2.8 | 7.0 | 0.0 | 0.0 | 3.7 | 1.4 | 0.0 | 0.3 | 3.7 | 0.3 | 3.9 |
| Planting nonleguminous trees | 2.5 | 1.8 | 8.9 | 1.1 | 2.0 | 3.1 | 0.4 | 0.1 | 3.3 | 2.3 | 2.5 |
| Crop rotation | 9.5 | 14.3 | 12.3 | 8.7 | 8.3 | 8.3 | 6.4 | 11.5 | 8.8 | 6.2 | 11.0 |
| Mulching | 9.8 | 0.9 | 20.2 | 1.0 | 12.7 | 17.8 | 8.1 | 15.0 | 7.9 | 10.0 | 9.7 |
| Composting | 8.1 | 0.4 | 5.7 | 1.4 | 14.6 | 6.6 | 1.3 | 0.0 | 11.0 | 0.0 | 11.8 |
| Animal manure | 15.6 | 26.4 | 22.9 | 7.4 | 15.4 | 3.9 | 25.3 | 9.0 | 17.9 | 11.0 | 17.6 |
| Crop residues | 6.1 | 15.4 | 6.5 | 10.7 | 2.4 | 0.0 | 6.5 | 8.3 | 5.3 | 6.0 | 6.1 |
| Leguminous cover crops | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Grass strips | 4.9 | 1.9 | 2.3 | 0.2 | 5.4 | 12.2 | 23.4 | 4.2 | 5.1 | 2.9 | 5.8 |
| Trash lines | 5.4 | 2.8 | 0.0 | 1.5 | 9.7 | 3.1 | 0.0 | 3.4 | 6.0 | 2.9 | 6.5 |
| Tied ridges | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Infiltration ditches | 1.7 | 0.0 | 4.4 | 0.5 | 1.8 | 3.7 | 1.3 | 1.2 | 1.8 | 1.0 | 2.0 |
| Minimum tillage | 0.4 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 3.8 | 0.0 | 0.6 | 0.0 | 0.6 |
| Contour plowing | 0.4 | 1.0 | 0.9 | 0.3 | 0.0 | 0.0 | 4.3 | 1.2 | 0.2 | 0.7 | 0.3 |
| Soil bunds | 1.3 | 0.0 | 1.2 | 1.5 | 1.9 | 0.0 | 1.3 | 0.4 | 1.6 | 0.3 | 1.7 |

Notes: Means and errors are corrected for sampling stratification and sampling weights. All figures are percentage increase or decrease; $N = 451$ for the household data.

### Table A.3 Credit availability and savings for households in 2000

| | | Agricultural potential | | | | | | Market access | | Population density | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Credit and savings** | **Average** | **Unimodal** | **Bimodal low** | **Bimodal medium** | **Bimodal high** | **Southwest highlands** | **Eastern highlands** | **Poor** | **Good** | **Low** | **High** |
| Households with access to credit (%) | 95.8 | 97.6 | 100.0 | 91.6 | 98.0 | 92.7 | 80.0 | 92.0 | 97.1 | 94.0 | 96.6 |
| | (1.0) | (1.8) | (0.0) | (3.0) | (1.1) | (5.2) | (10.1) | (2.6) | (1.0) | (2.3) | (1.0) |
| Formal credit available in village (%) | 26.1 | 48.1 | 14.7 | 12.2 | 32.6 | 0.3 | 20.2 | 12.6 | 30.8 | 23.5 | 27.3 |
| | (1.8) | (5.2) | (3.5) | (2.9) | (3.2) | (0.3) | (4.2) | (1.8) | (2.3) | (2.5) | (2.3) |
| Informal credit available in village (%) | 69.7 | 49.6 | 85.3 | 79.4 | 65.4 | 92.4 | 59.8 | 79.4 | 66.3 | 70.6 | 69.3 |
| | (1.9) | (5.2) | (3.5) | (2.9) | (3.3) | (5.2) | (10.2) | (3.1) | (2.3) | (2.9) | (2.4) |
| Amount (1,000 Ush) of formal credit in cash | 178.6 | 298.33 | 47.75 | 140.48 | 305.62 | 99.29 | 126.71 | 195.81 | 133.21 | 175.43 | 190.05 |
| | (466.9) | (512.31) | (48.61) | (219.74) | (987.74) | (132.66) | (176.00) | (532.83) | (214.53) | (489.62) | (382.33) |
| Amount (1,000 Ush) of informal credit in cash | 129.28 | 102.11 | 102.06 | 78.13 | 234.26 | 154.68 | 144.06 | 143.85 | 100.14 | 136.64 | 114.06 |
| | (300.12) | (220.81) | (190.64) | (118.00) | (580.76) | (308.69) | (270.63) | (348.31) | (164.18) | (344.06) | (178.55) |
| Households saving for emergencies (%) | 92.6 | 88.9 | 96.7 | 88.8 | 94.8 | 90.7 | 90.6 | 88.6 | 93.9 | 86.0 | 95.5 |
| | (1.4) | (4.5) | (2.4) | (3.6) | (2.1) | (4.2) | (5.1) | (3.6) | (1.4) | (3.7) | (1.2) |

Notes: Means and errors are corrected for sampling stratification and sampling weights. Standard errors are given in parentheses. $N = 451$ for the household data.

## Table A.4 Change in availability of credit for households and household ability to save between 1990 and 2000

| | | Agricultural potential | | | | | | Market access | | Population density | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Credit and savings** | **Average** | **Unimodal** | **Bimodal low** | **Bimodal medium** | **Bimodal high** | **Southwest highlands** | **Eastern highlands** | **Poor** | **Good** | **Low** | **High** |
| Households with access to credit (%) | 34.2 | 41.9 | 37.5 | 28.2 | 37.7 | 19.0 | 19.4 | 36.1 | 33.6 | 42.0 | 30.8 |
| Formal credit available in village (%) | 20.4 | 36.7 | 13.3 | 6.3 | 27.6 | –3.5 | 13.0 | 6.5 | 25.2 | 18.6 | 21.2 |
| Informal credit available in village (%) | 14.1 | 5.6 | 26.9 | 21.9 | 10.1 | 22.5 | 6.4 | 30.7 | 8.4 | 24.2 | 9.6 |
| Households saving for emergencies (%) | 10.3 | 1.3 | 15.9 | 17.4 | 8.2 | 4.4 | 31.0 | 15.7 | 8.4 | 10.3 | 10.3 |

Notes: Means and errors are corrected for sampling stratification and sampling weights. $N = 451$ for the household data.

## Table A.5 Extension visits to households in 2000 and change in extension and training since 1990

| | | Agricultural potential | | | | | | Market access | | Population density | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Extension and training** | **Average** | **Unimodal** | **Bimodal low** | **Bimodal medium** | **Bimodal high** | **Southwest highlands** | **Eastern highlands** | **Poor** | **Good** | **Low** | **High** |
| Member of household participated in agricultural extension/training since 1990 (%) | 50.0<br>(3.5) | 39.4<br>(9.8) | 51.3<br>(7.3) | 40.1<br>(4.9) | 58.1<br>(6.4) | 50.5<br>(7.3) | 35.2<br>(11.2) | 40.4<br>(4.5) | 53.3<br>(4.5) | 44.5<br>(4.9) | 52.4<br>(4.6) |
| Contact between household members and extension agents in 2000 (%) | 31.4<br>(2.8) | 18.5<br>(3.6) | 39.9<br>(7.3) | 24.9<br>(4.0) | 38.2<br>(5.4) | 28.0<br>(5.8) | 13.8<br>(5.5) | 23.9<br>(3.9) | 33.9<br>(3.5) | 23.4<br>(3.6) | 34.9<br>(3.7) |
| Number of extension visits to household in 2000 | 2.28<br>(0.34) | 1.82<br>(0.59) | 1.90<br>(0.61) | 0.67<br>(0.10) | 3.40<br>(0.68) | 1.83<br>(0.93) | 0.32<br>(0.12) | 0.96<br>(0.40) | 2.74<br>(0.43) | 1.25<br>(0.51) | 2.74<br>(0.43) |
| Change in number of contacts with extension agents since 1990 (rank)[a] | 0.29<br>(0.03) | 0.18<br>(0.04) | 0.28<br>(0.07) | 0.18<br>(0.03) | 0.39<br>(0.05) | 0.31<br>(0.06) | 0.09<br>(0.05) | 0.13<br>(0.03) | 0.35<br>(0.04) | 0.17<br>(0.03) | 0.35<br>(0.04) |

Notes: Means and errors are corrected for sampling stratification and sampling weights. Standard errors are given in parentheses. $N = 451$ for the household data.

[a] Values represent the average of rank data, where 0 = no significant change; +1 = minor increase; +2 = major increase; –1 = minor decrease; –2 = major decrease.

## Table A.6 Household involvement in programs and organizations by type, 1990-2000

| | | Agricultural potential | | | | | | Market access | | Population density | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Program or organization** | **Average** | **Unimodal** | **Bimodal low** | **Bimodal medium** | **Bimodal high** | **Southwest highlands** | **Eastern highlands** | **Poor** | **Good** | **Low** | **High** |
| Government program | 0.71 | 0.00 | 0.00 | 0.00 | 1.2 | 1.7 | 0.00 | 0.00 | 1.0 | 0.00 | 1.1 |
| | (0.41) | (0.00) | (0.00) | (0.00) | (0.1) | (1.7) | (0.00) | (0.00) | (1.0) | (0.00) | (1.0) |
| NGO | 14.9 | 20.3 | 3.4 | 6.2 | 21.1 | 3.1 | 17.0 | 8.8 | 17.0 | 6.9 | 18.5 |
| | (2.6) | (9.5) | (3.4) | (2.4) | (4.6) | (1.9) | (9.7) | (2.9) | (3.3) | (2.7) | (3.5) |
| CBO | 81.8 | 74.2 | 75.1 | 76.1 | 86.2 | 96.6 | 2.5 | 70.7 | 85.7 | 76.9 | 84.0 |
| | (2.2) | (9.6) | (6.7) | (4.0) | (3.1) | (2.4) | (11.0) | (4.2) | (2.6) | (3.1) | (2.9) |

Notes: Means and errors are corrected for sampling stratification and sampling weights. Values in parentheses represent standard errors. $N = 451$ for the household data.

## Table A.7 Household involvement in programs and organizations by main focus, 1990-2000

| | | Agricultural potential | | | | | | Market access | | Population density | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Main focus of program or organization** | **Average** | **Unimodal** | **Bimodal low** | **Bimodal medium** | **Bimodal high** | **Southwest highlands** | **Eastern highlands** | **Poor** | **Good** | **Low** | **High** |
| Agriculture/Environment | 29.8 | 41.5 | 11.0 | 23.1 | 34.2 | 25.0 | 27.4 | 19.7 | 33.4 | 26.6 | 31.3 |
| | (3.4) | (9.6) | (6.5) | (4.8) | (6.2) | (6.3) | (10.7) | (4.5) | (4.3) | (3.6) | (4.7) |
| Infrastructure and services | 14.9 | 28.9 | 8.9 | 12.1 | 12.0 | 23.9 | 13.6 | 12.2 | 15.9 | 11.3 | 16.6 |
| | (2.3) | (10.1) | (4.4) | (3.8) | (3.4) | (5.8) | (9.0) | (3.9) | (2.8) | (3.7) | (2.9) |
| Credit | 41.8 | 23.2 | 62.3 | 34.4 | 37.9 | 82.1 | 22.6 | 35.9 | 43.9 | 41.2 | 42.1 |
| | (3.1) | (5.8) | (8.0) | (4.9) | (5.7) | (5.3) | (11.3) | (5.0) | (3.7) | (4.9) | (3.8) |
| Poverty | 14.0 | 9.9 | 13.6 | 11.6 | 13.5 | 23.5 | 27.6 | 10.8 | 15.2 | 12.5 | 14.7 |
| | (2.6) | (5.0) | (7.0) | (3.8) | (4.6) | (7.3) | (11.3) | (3.7) | (3.2) | (4.1) | (3.2) |
| Community service | 48.6 | 27.7 | 49.1 | 34.4 | 56.2 | 83.4 | 23.4 | 42.5 | 50.8 | 38.1 | 53.4 |
| | (2.8) | (9.6) | (9.1) | (5.0) | (4.3) | (6.1) | (9.9) | (5.3) | (3.2) | (4.8) | (3.4) |
| Labor exchange | 12.8 | 8.2 | 15.8 | 14.7 | 11.2 | 25.9 | 1.3 | 14.4 | 4.0 | 17.8 | 10.5 |
| | (2.1) | (4.8) | (7.1) | (4.5) | (3.4) | (6.8) | (1.3) | (12.2) | (2.4) | (4.3) | (2.3) |
| Miscellaneous | 12.2 | 11.1 | 4.7 | 8.7 | 16.5 | 9.6 | 4.2 | 9.5 | 13.2 | 9.9 | 13.3 |
| | (2.6) | (9.1) | (4.7) | (3.6) | (4.6) | (3.4) | (3.8) | (3.4) | (3.3) | (3.4) | (3.4) |

Notes: Means and errors are corrected for sampling stratification and sampling weights. Values in parentheses represent standard errors. $N = 451$ for the household data.

# APPENDIX B

# Theoretical Dynamic Household Model

In this appendix, we develop a theoretical household model of livelihood strategies and land management, drawing upon the conceptual framework presented in Chapter 3. The model incorporates household investment decisions—with investments broadly defined to include investments in physical, human, natural, social, and financial capital—as well as annual decisions regarding crop choice, labor allocation, and adoption of land management practices.

Consider a household that seeks to maximize its lifetime welfare:

$$Max \quad E_0\left[\sum_{t=0}^{T} u_t(c_t)\right], \tag{1}$$

where $c_t$ is the value of consumption in year $t$, $u_t(c_t)$ is the single period consumption utility[95] and the expectation ($E_0$) is taken with respect to uncertain factors influencing future income at the beginning of the year ($t$ = 0). Consumption in year t is given by:

$$c_t = I_{ci} + I_h + I_{wt} + I_{nt} + p_{Wt}INV_{Wt}, \tag{2}$$

where $I_{ct}$ is gross crop income, $I_{lt}$ is gross livestock income, $I_{wt}$ is net wage income, and $I_{nt}$ is income from nonfarm activities in year $t$.[96] $INV_{Wt}$ is a vector of investments (or disinvestments) in assets during year $t$, including investments in physical capital ($PC_t$) (livestock, equipment), human capital ($HC_t$) (education, experience, training), "natural capital" ($NC_t$) (assets embodied in natural resources, including land quantity and quality, land rights and tenure, land improving investments), "social capital" ($SC_t$) (assets embodied in social relationships, such as participation in organizations or networks), and financial capital ($FC_t$) (cash and other liquid assets, access to credit). The variable $p_{wt}$ is the price of marketed assets, or in the case of nonmarketed assets (for example, experience or social capital), we interpret $p_{wt}$ as the cost of acquiring an additional unit of these assets.

Household gross crop income is the sum of the value of crop production from each plot operated by the household:

[95]This is a generalization of the commonly used discounted utility formulation $u_t(c_t) = \beta^t u(c_t)$ (for example, see Stokey and Lucas 1989).

[96]The value of hired labor used in crop and livestock production is subtracted from net wage income. Costs of other purchased inputs used in agricultural production can be treated in exactly the same way. For simplicity of exposition, we treat labor as the only variable input in agricultural production (it is by far the most important for small farmers in Uganda).

$$I_{ct} = \sum_p y_{pt}(C_{pt}, p_{ct}, L_{pt}, LM_{pt}, NC_{pt}, PC_t, HC_t, SC_t, BP_t), \quad (3)$$

where $C_{pt}$ represents the vector of area shares of different annual crops grown on the plot,[97] $p_{ct}$ is the vector of farm level prices of the different crops, $L_{pt}$ is the amount of preharvest labor applied to the plot, $LM_{pt}$ is a vector of land management practices (for example, use of mulch, manure) used on the plot, $NC_{pt}$ is a subvector of $NC_t$ representing the quality, tenure characteristics[98] and prior land investments on the plot, and $BP_t$ accounts for other biophysical factors affecting the quantity of crop production (for example, rainfall, temperature).[99] The physical, human, and social capital of the household are included as possible determinants of crop production, because these assets may affect agricultural productivity if there are imperfect factor markets (de Janvry et al. 1991).

The farm-level prices may vary as a result of variations across communities in access to markets and roads (affecting transport costs to markets), agro-ecological conditions (affecting local supply), and population density (affecting local demand and supply). In the presence of transaction costs, prices may also vary across households as a function of household-level factors that may affect these transaction costs. For example, households with more experience in producing cash crops (part of $HC_t$) or who participate in agricultural organizations (part of $SC_t$) may have access to better information about buyers than do other farmers, and thus obtain higher prices for their products. Because we are interested in the impacts of such underlying factors on production and land management, and because prices for many commodities are not observed for many households, we model prices as a function of these underlying factors:

$$p_{ct} = p(X_{vt}, HC_t, SC_t, u_{ct}), \quad (4)$$

where $X_{vt}$ is a vector including observable agro-ecological characteristics, market access, and population density of the village, and $u_{ct}$ represents unobserved random factors affecting prices.

We also model biophysical conditions in a given year as dependent on observable agro-ecological conditions (a subcomponent of $X_{vt}$) and random factors:

$$BP_t = BP(X_{vt}, u_{bt}), \quad (5)$$

Substituting equations (4) and (5) into equation (3), we redefine the value of crop production function:

$$\begin{aligned} &y'_{pt}(C_{pt}, L_{pt}, LM_{pt}, NC_{pt}, PC_t, HC_t, SC_t, X_{vt}, u_{ct}, u_{bt}) \\ &\quad \equiv y_{pt}(C_{pt}, p(X_{vt}, HC_t, SC_t, u_{ct}), L_{pt}, LM_{pt}, NC_{pt}, PC_t, HC_t, SC_t, BP(X_{vt}, u_{bt})) \quad (6) \end{aligned}$$

In a similar way, livestock income is determined by labor allocated to livestock activities ($L_{lt}$); ownership of land, livestock, and other physical assets; the human and social capital of the household; biophysical conditions; access to markets and infrastructure; and population density:

$$I_{lt} = I_l(L_{lt}, PC_t, NC_t, HC_t, SC_t, X_{vt}, u_{lt}). \quad (7)$$

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[97]Perennial crops available for harvest in the current year are the result of investment in prior years, and are taken as part of the land investments on the plot (included in $NC_{pt}$).

[98]Tenure characteristics are taken as part of $NC_{pt}$ for notational convenience. In Chapter 3, tenure characteristics are represented by a separate variable ($T_{pt}$), to emphasize their presence in the empirical model.

[99]The function $y_{pt}$ is not strictly a production function, because it depends on prices as well as the quantity of production. This form is used because of the widespread use of intercropping and multiple cropping in Uganda, and because of the difficulty of determining the allocation of labor and land management practices to specific crops.

Net wage income is given by:

$$I_{wt} = w_{ot}(X_{vt}, HC_t, SC_t, u_{wot})L_{ot} - w_{it}(X_{vt}, HC_t, SC_t, u_{wit})L_{it}, \quad (8)$$

where $L_{ot}$ and $L_{it}$ are the amounts of labor hired out and in by the household, respectively, and $w_{ot}$ and $w_{it}$ are the wage rates paid for hired labor. As with commodity prices, we assume that wages may be affected by village-level factors, such as agro-ecological conditions, market access, and population density ($X_{vt}$) that influence the local supply and demand for labor, by household-level human and social capital ($HC_t$ and $SC_t$, respctively) that influence transactions costs of monitoring and enforcing labor contracts, and other random factors ($u_{wot}$, $u_{wit}$).

Nonfarm income is determined by the labor allocated to nonfarm activities, the human and social capital of the household, the local demand for nonfarm activities as determined by $X_{vt}$, and random factors:

$$I_{nt} = I_n(L_{nt}, HC_t, SC_t, X_{vt}, u_{nt}). \quad (9)$$

Labor demand by the household must be no greater than labor supply:

$$\sum_p L_{pt} + L_{lt} + L_{ot} + L_{nt} \leq L_{ft} + L_{it}, \quad (10)$$

where $L_{ft}$ is the supply of household family labor.

Most forms of capital must be nonnegative:

$$PC_t \geq 0, \quad HC_t \geq 0, \quad NC_t \geq 0, \quad SC_t \geq 0. \quad (11)$$

Financial capital may be negative, however, if borrowing occurs. We assume that the household's access to credit is determined by its stocks of nonfinancial capital (which determine the household's collateral, potential for profitable investments, and transaction costs of monitoring and enforcing credit contracts):

$$FC_{t+1} \geq -B(PC_t, HC_t, NC_t, SC_t), \quad (12)$$

where $B$ is the maximum credit obtainable. Financial assets (or liabilities) grow at the household-specific rate of interest $r$, which may be affected by the same factors affecting prices and wages, as well as factors affecting the borrowing constraint:

$$FC_{t+1} = (1 + r(X_{vt}, PC_t, HC_t, NC_t, SC_t))FC_t + INV_{FCt}, \quad (13)$$

where $INV_{FCt}$ is investment (or disinvestment) in financial capital in year $t$ (a subvector of $INV_{Wt}$ in equation (2)).

Physical capital also may grow or depreciate over time, in addition to changes in stocks resulting from investments:

$$FC_{t+1} = (1 + g)PC_t + INV_{PCt}, \quad (14)$$

where $g$ is a vector of asset-specific growth (or depreciation, if negative) rates and $INV_{PCt}$ is investment in physical capital in year $t$.

Natural capital may depreciate (degrade) over time as a result of unsustainable resource management practices, or it may appreciate as a result of investment. For example, if we think of soil depth as one component of natural capital, this may be depleted by soil erosion or restored by investments in soil conservation:

$$NC_{pt+1} = (1 - e(C_{pt}, LM_{pt}, L_t, NC_{pt}, X_{vt}, u_{et}))NC_{pt} + INV_{NCt}, \quad (15)$$

where $NC_{pt}$ is taken here to represent soil depth on plot $p$, $e$ is the rate of erosion (net of the rate of soil formation), $u_{et}$ represents random factors affecting erosion, and $INV_{NCt}$ is investment in increasing soil depth in year $t$.

We assume that human and social capital do not depreciate or grow without investment. Because these are also nonmarketed assets, they are subject to irreversibility constraints:

$$HC_{t+1} \geq HC_t, \quad SC_{t+1} \geq SC_t. \tag{16}$$

Maximization of equation (1) subject to the constraints defined by equations (2), (3), and (6)–(16) defines the household optimization problem. If we define the optimized value of equation (1) (the value function) as $V_0$ and notice that this is determined by the value of the state variables at the beginning of year $t = 0$ ($PC_0, HC_0, NC_0, SC_0, FC_0$) and by the other exogenous variables in this system that are determined at the beginning of year $t = 0$ ($X_{v0}, L_{f0}$), then we have:

$$V_0(PC_0, HC_0, NC_0, SC_0, FC_0, X_{v0}, L_{f0}) \equiv \max \quad E_0\left[\sum_{t=0}^{T} u_t(c_t)\right] \text{ subject to equations (2), (3), (6)–(16).} \tag{17}$$

Defining $W_t \equiv (PC_t, HC_t, NC_t, SC_t, FC_t)$ and defining $V_1$ as the value function for the same problem as in equation (1), but beginning in year $t = 1$, we can write the Bellman equation determining the solution in the first period:

$$V_0(W_0, X_{v0}, L_{f0}) = \max_{L_0, C_0, LM_0, INV_{W0}} E_0[u(c_0)] + E_0 V_1(W_1, X_{v1}, L_{f1}), \tag{18}$$

where $L_0$ is a vector of all labor allocation decisions, $C_0$ is a vector of crop area shares on each plot, $LM_0$ is a vector of land management choices on all plots in year $t = 0$, and $INV_{W0}$ is the vector of investments in different forms of capital in year $t = 0$.

Solution of the maximization in equation (18) implicitly defines the optimal choices of $L_0$, $C_0$, $LM_0$, and $INV_{W0}$:

$$C_0^* = C_0(W_0, X_{v0}, L_{f0}), \tag{19}$$

$$L_0^* = L_0(W_0, X_{v0}, L_{f0}), \tag{20}$$

$$LM_0^* = LM_0(W_0, X_{v0}, L_{f0}), \tag{21}$$

$$INV_{W0}^* = INV_0(W_0, X_{v0}, L_{f0}). \tag{22}$$

The optimal solutions for crop choice, labor allocation, and land management determine the optimized value of production, land degradation, and household income. Substituting equations (19)–(21) into equation (6), we obtain the optimal value of crop production:[100]

$$y_{p0}^* = y'_{p0}(C_{p0}(W_0, X_{v0}, L_{f0}), L_{p0}(W_0, X_{v0}, L_{f0}), LM_{p0}(W_0, X_{v0}, L_{f0}), NC_{p0}, PC_0, HC_0, SC_0, X_{v0}, u_0) \tag{23}$$

Equation (23) forms the basis for empirical estimation of the determinants of the value of crop production. It is estimated in structural form, including the impacts of the endogenous variables ($C_{p0}, L_{p0}, LM_{p0}$). To address potential endogeneity bias, the model is estimated using instrumental variables as well as ordinary least squares. The model is also estimated in reduced form:

$$y_{p0}^* = y''_{p0}(W_0, X_{v0}, L_{f0}, u_0). \tag{24}$$

Similarly, the reduced form erosion function can be derived by substituting equations (19)–(21) into the function determining erosion in equation (15):

$$e_{p0}^* = e(C_{p0}(W_0, X_{v0}, L_{f0}), L_{p0}(W_0, X_{v0}, L_{f0}), LM_{p0}(W_0, X_{v0}, L_{f0}), NC_{p0}, X_{v0}, u_0) = e'(W_0, X_{v0}, L_{f0}, u_{e0}) \tag{25}$$

[100]The terms related to random variations in prices ($u_c0$) and in biophysical factors ($u_{v0}$) have been combined into a single random variable reflecting random fluctuations in value of crop production ($u_0$) in equation (22).

Finally, the reduced-form income function is derived by substituting the crop value of production function from equation (24) into the crop income equation (3), the labor allocation functions in equation (20) into the other income equations (7)–(9), and then summing up total household income:[101]

$$\begin{aligned}
I_0^* = \sum_p y''_{p0}(W_0, X_{v0}, L_{f0}, u_0) \\
+ I_l(L_{l0}(W_0, X_{v0}, L_{f0}), PC_0, \\
NC_0, HC_0, SC_0, X_{v0}, u_{l0}) \\
+ w_{o0}(X_{v0}, HC_0, SC_0, \\
u_{wo0})L_{o0}(W_0, X_{v0}, L_{f0}) \\
- w_{i0}(X_{v0}, HC_0, SC_0, \\
u_{wi0})L_{i0}(W_0, X_{v0}, L_{f0}) \\
+ I_n(L_{n0}, HC_0, SC_0, X_{v0}, u_{n0}) \\
= I_0(W_0, X_{v0}, L_{f0}, u_{I0}) \quad (26)
\end{aligned}$$

Equations (19)–(26) are the basis of the empirical work.

[101]In the last part of equation (25), $u_{I0}$ combines the effects of the different random factors included in the middle expression ($u_0$, $u_{l0}$, $u_{wo0}$, $u_{wi0}$, $u_{n0}$).

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