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POLICY OPTIONS FOR INCREASING CROP PRODUCTIVITY AND REDUCING SOIL NUTRIENT DEPLETION AND POVERTY IN UGANDA

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ABSTRACT

This study was conducted with the main objective of determining the linkages between poverty and land management practices in Uganda. The study used the 2002/03 Uganda National Household Survey (UNHS) and more focused data collected from a sub-sample of 851 households of the 2002/03 UNHS sample households. We found that farmers in Uganda deplete about 1.2 percent of the nutrient stock stored in the topsoil per year, which leads to a predicted 0.31 percent reduction in crop productivity. The value of replacing the depleted nutrients using the cheapest inorganic fertilizers is equivalent to about 20 percent of household income obtained from agricultural production.

Econometric analysis of the survey results provides evidence of linkages between poverty and land management practices. Land investments increase agricultural productivity and income and conserve natural resources. Many inputs and land management practices increase crop production per acre. We observed an inverse farm size – crop productivity relationship but a negative association of farm size and per capita income. Education of female household members has generally a limited impact on land management, while male education is associated with greater use of inorganic fertilizer. Both female post-secondary and male primary and secondary education are associated with higher crop productivity. Larger families use more erosive practices but realize higher value of crop production per acre but have lower per capita income.

Access to financial capital, markets and roads has limited effect on land management. However, access to financial capital and non-farm opportunities increase crop productivity and per capita household income and access to roads contributes to higher per capita household income and less soil nutrient depletion. These results support the Uganda government poverty reduction strategy through building rural roads, and increasing access to financial capital and non-farm opportunities. Both the traditional and the new agricultural extension program increase use of fertilizer and crop productivity, suggesting that investment in extension services could significantly contribute to agricultural modernization and poverty reduction. The results suggest the need to give incentives for technical assistance programs to operate in remote areas, where access to extension services is limited.

Perennial crop producers deplete soil nutrients more rapidly, implying the need to promote measures to restore soil nutrients in perennial (especially banana) production areas. We find no significant differences in crop productivity or income per capita associated with differences in land tenure systems. Our findings suggest that customary land tenure, which is the most common form of tenure, is not a constraint to improvements in land productivity or use of sustainable land management.

Overall, our results provide general support for the hypothesis that promotion of poverty reduction and agricultural modernization through technical assistance programs and investments in infrastructure and education can improve agricultural productivity and help reduce poverty. However, they also show that some of these investments do not necessarily reduce land degradation, and may contribute to worsening land degradation in the near term. Thus, investing in poverty reduction and agricultural modernization is not sufficient to address the problem of land degradation in Uganda, and must be complemented by greater efforts to address this problem.

Keywords: Uganda, land degradation, soil nutrient depletion, poverty, crop productivity, natural resource management

TABLE OF CONTENTS

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Ephraim Nkonya,* John Pender,* Crammer Kaizzi, **
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1. INTRODUCTION

The world celebrated the beginning of the new millennium with more than one billion people living on less than one US$ a day. This has posed an enormous challenge to poor countries and their development partners. At a global scale, the United Nations has set millennium development goals (MDG) to halve the proportion of people living on less than one US$ a day by 2015. Most poor countries, including Uganda, have ratified the MDG's and committed to achieve them. Even though Uganda has reduced absolute poverty from 56 percent of the population in 1992 to 35 percent in 1999/00 (Appleton 2001), poverty reduction remains the primary goal of the country's policies and strategies. To achieve this goal, the government has laid out an ambitious strategy for addressing poverty through the Poverty Eradication Action Plan (PEAP), which sets a target of reducing the proportion of the population living in absolute poverty to below 10 percent by 2017 (MFPED 2001). However, there is concern over whether this goal can be achieved and whether poverty reduction statistics reflect an improvement in the living standards of the majority of the people, particularly in rural areas, where 96 percent of the poor live. Agricultural productivity in general has stagnated or declined for most farmers

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(Deininger and Okidi 2001). Recent data also show an increase in the incidence of poverty to 38 percent (8.9 million people) in 2002/03 (UBOS 2003).

Since poor households depend on natural resources more than wealthier households, one of PEAP's objectives is to ensure that poverty reduction efforts do not compromise natural resources (NEMA 2002; MFPED 2001). There is concern in Uganda, as elsewhere in Africa, that poor households in Africa face a downward spiral of land degradation and poverty (NEMA 2002; Cleaver and Schreiber 1994). Most communities in Uganda perceive that natural resources are degrading and that food insecurity is worsening (Pender, et al. 2001; APSEC 2001). However, scientific studies to verify these perceptions and to quantify land degradation in Uganda are limited. Available estimates indicate that the rate of soil fertility depletion in Uganda is among the highest in sub-Saharan Africa (Stoorvogel and Smaling 1990; Wortmann and Kaizzi 1998). A recent study of maize producing households in eastern Uganda estimated that the average value of soil nutrient depletion is equal to about one-fifth of average household income (Nkonya, et al. 2004b). Soil fertility depletion thus represents a substantial loss in Uganda's natural capital, as well as reducing agricultural productivity and income. Soil erosion is also a serious problem in the highlands (Ibid.; Magunda and Tenywa 1999; NEAP 1992). Soil nutrient depletion and erosion pose a serious concern since they contribute to declining agricultural production (Bekunda 1999; Deininger and Okidi 2001; Pender, et al. 2001), which in turn contributes to food and nutrition insecurity. Soil nutrient depletion and erosion could also lead to deforestation and loss of biodiversity since farmers are forced to abandon nutrient-starved soils and cultivate more marginal areas such as hillsides and rainforests. The overall implication of these impacts is increased poverty, which pose an enormous development challenge in SSA.

Poverty may also contribute to land degradation, if poor people lack the ability or incentive to invest in conserving and improving their land. However, little empirical evidence is available concerning the relationships between land degradation and poverty in Uganda and other African countries, or about the policy, institutional or technological responses that could most effectively address these problems. This study seeks to address this information gap, using analysis of data from a survey conducted in 2003 at the community, household and plot level by the International Food Policy Research Institute (IFPRI), in collaboration with the Uganda Bureau of Statistics (UBOS), the National Agricultural Research Organization (NARO) and Makerere University - hereafter referred to as IFPRI/UBOS survey. These data were collected from a sub-sample of households participating in the 2002/2003 Uganda National Household Survey (UNHS), and some of the 2002/2003 data were also used in the analysis.

There is a strong desire by the government to understand the nature of poverty and what can be done to address it. Particularly policy makers and other stakeholders would like to know the policies and strategies that effectively alleviate poverty and conserve the environment and natural resources. For example, one of the deficiencies of the PEAP is a weak framework on strategies for conserving the environment and natural resources (NEMA 2004). The PEAP is being revised to address this and other deficiencies. This paper contributes to better understanding of policies and strategies that would increase agricultural productivity and conserve the environment. The main focus of this study is on investigating how poverty, broadly defined to include limitations in physical, human, natural and financial capital as well as limited access to infrastructure and services, influences farmers' land management practices, land degradation in the form of soil erosion and depletion of soil nutrients, crop productivity, and household incomes in Uganda.

CONTRIBUTIONS OF THIS STUDY

This paper is the fourth in a series of papers produced by the IFPRI-UBOS-NARO-Makerere University Project "Poverty and Natural Resource Management in Uganda", which was supported by the World Bank Trust Fund for Environmentally and Socially Sustainable Development (Pender, et al. 2004; Nkonya, et al. 2004a; Kaizzi, et al. 2004). It builds on that work (especially the studies by Pender, et al. 2004 and Kaizzi, et al. 2004) and on earlier research in Uganda (Nkonya, et al. 2004b) to identify the impacts of poverty—broadly defined to include limitations in communities' and households' endowments of physical, human, natural, and financial capital, as well as access to infrastructure and key services, such as agricultural technical assistance—on their land management decisions and land degradation; and to identify the impacts of land management and land degradation on agricultural productivity and poverty.

The study by Nkonya, et al. (2004a) sought to understand the determinants of natural resource management (NRM) at the community level. The results showed that greater awareness of regulations contributes to more sustainable NRM. Awareness is greater in areas closer to all-weather roads, probably due to better access to information in such areas. Development of roads and communication can thus facilitate better community NRM. Other low cost options to increase awareness could include use of radio programs, environmental education in schools, resource user seminars, brochures, and district level training workshops. Nkonya, et al. (2004a) also found that compliance with bylaws that influence NRM is greater for bylaws enacted by local LC1 councils than for bylaws enacted at a higher level. These results suggest that involvement of locally accountable and representative authorities in enacting and enforcing NRM requirements appears critical for the legitimacy and success of such regulation. The results also showed that involvement of external programs and organizations focusing on agriculture and environment issues can help to promote local enactment of such bylaws (Ibid.). Several dimensions of poverty, including greater income poverty, poor education, and poor access to credit were found to be associated with lower compliance with NRM requirements (Ibid.). This supports the hypothesis of a poverty-natural resource degradation trap, and suggests that measures to reduce poverty can have “win-win” benefits helping to improve NRM as well. Land tenure had mixed relationships with enactment and compliance with NRM requirements (Ibid.).

The study by Pender, et al. (2004) assessed the household-level linkages between poverty and land management to the extent possible by analyzing available survey data from the 1999/2000 UNHS, which collected information on use of inputs in crop production (e.g., use of seeds, inorganic and organic fertilizer) and crop production and income at the household level. This analysis provided mixed support for the hypothesis that poverty causes poor land management and low productivity. For example, the results showed that smaller (land poor) farms compensate for land constraints by using some inputs more intensively, and thus obtain higher land productivity. However, smaller farmers’ incomes are lower as they are unable to fully compensate for land constraints. Households with lower value land use less of most inputs and obtain lower land productivity and income. To the extent that land degradation contributes to future declines in land quality and value, these results support the land degradation – poverty spiral hypothesis, though longitudinal data are needed to verify this. Lack of ownership of physical assets such as livestock and equipment was found to be associated with less use of fertilizer (inorganic or organic) and other inputs, and for some assets, lower productivity and income. These results also support the poverty spiral hypothesis, though the role of land degradation in reducing productivity and income is not clear. Lack of human capital was found to have mixed impacts on land management, with male education associated with adoption of fertilizer and some other land management practices, while female education had less impact on land management. Limited access to markets and roads was found to reduce adoption of fertilizer and some other inputs, though impacts on productivity and incomes were more region-specific. Limited access to credit, agricultural extension and market information were also associated with less use of fertilizer and, in the case of credit, lower productivity. Lower wage rates were associated with lower adoption of fertilizer and some other inputs, as well as lower productivity and incomes. This study also found low marginal returns to investments in inorganic or organic fertilizer, suggesting that it will be difficult for farmers to increase investment in these inputs in the present market environment.

Many, but not all, of the results in Pender, et al. (2004) support the idea that poverty, broadly defined, contributes to less intensive land management and lower productivity and income. However, several limitations of that study limited its ability to draw definitive conclusions about the linkages between poverty and land degradation. No land quality indicators were measured in the 1999/2000 UNHS, so estimated land value was used as a proxy; but land values may be poorly estimated and may reflect many factors other than land quality. The level of use of inputs and crop production were measured only at the household level, limiting the ability to take into account plot-specific characteristics that affect these responses. More importantly, no indicators of land degradation were measured, so that the relationships of poverty with land degradation could not be directly assessed. Assessing some of the linkages between poverty and land degradation requires longitudinal data on both poverty and land degradation, as well as on intervening factors such as land management decisions.

The present study addresses most of these shortcomings. Information on land quality indicators, land management and land degradation were collected at the plot level so that plot specific characteristics and responses could be taken into account. Soil samples were taken and use to quantify measures of soil fertility and as an input into estimation of soil erosion and soil nutrient losses based on the survey data. These soil analyses were led by a soil scientist from NARO, and the methodological approach and results are reported in Kaizzi, et al. (2004). We present the main conclusions of Kaizzi, et al. (2004) in this study. The assessment of determinants of soil nutrient losses in this study builds on an approach pioneered in a small study of determinants of household soil nutrient balances in eastern Uganda reported in Nkonya, et al. (2004b). In this study, the assessment of nutrient depletion is at the plot rather than the household level (which is the more relevant level to consider land degradation impacts), and has broader coverage with a much larger sample size, so that more robust conclusions are possible. Although the present study is still limited by the cross-sectional nature of the results, it has laid the foundation for future longitudinal studies of poverty-land degradation relationships by being linked to the 2002/2003 UNHS sample.

The remainder of the paper is organized as follows: In the next section, we discuss the theory of poverty-NRM linkages, followed by discussion of the empirical approach, key variables, hypotheses and data sources. The empirical results are presented in the fourth section, and conclusions and implications are discussed in the last section.

2. THEORY ON LINKAGES BETWEEN POVERTY AND NATURAL RESOURCE MANAGEMENT

Interest in research on poverty and its linkage with natural resource management has grown enormously in the past few decades (Grepperud 1997). There is yet no consensus on the impact of poverty on natural resource management (NRM). One view posits that in a perfect market setting, there is no linkage between poverty and NRM since households (and firms) would allocate natural resources such that they yield the highest returns to investment (Singh, et al., 1986). Under this unrealistic perfect market assumption, household endowments would therefore not determine allocation and management of natural resources since such decisions are dictated by local biophysical factors and market prices that determine the returns to investment. An alternative view assumes that poor households have high discount rate, hence have short-term planning horizons (Griffin and Stoll, 1984; Rausser, 1980; Hammer, 1986). Many studies have argued that lack of resources and alternative opportunities and their short-term perspective force poor farmers to degrade natural capital in order to meet their short-term needs (WCED, 1987; Leonard, 1989; Cleaver and Schreiber 1994).

Empirical evidence has shown that poverty-NRM linkages are more complex than these simplified views. The first view rests on an unrealistic assumption of perfect markets that is not easy to observe in real life. Imperfect markets of different types are a rule rather than an exception in most areas – especially in low income countries like Uganda - and contribute to failure of farmers to efficiently use their scarce resources. As will be discussed later, market imperfections greatly influence NRM. Some studies have also challenged the second view on both theoretical and empirical grounds. For example, Pender (1998) noted that farmers optimally choose to invest in higher-return investments in order to obtain higher income and better welfare, but such decisions may lead to natural resource degradation in the near term if the returns to investment in natural capital are lower than returns to investing in other forms of capital (until returns are relatively equalized across different investments). This suggests that natural resource degradation in the near term may be part of the process of poverty reduction, rather than a cause of increasing poverty. Neither does poverty necessarily lead to natural resource degradation. Poor households may invest more than wealthier ones in labor-intensive NRM practices because they depend more on natural resources for their livelihood or because they have lower labor opportunity costs.

A large number of factors may influence the direction and severity of impact of poverty on NRM. Empirical evidence suggests that market failure is one of the most important factors that give credence to the poverty-NRM linkage view. The impact of market failure on the linkage of poverty-NRM depends upon the nature of the market failure, the nature of poverty, and the type of resource management and resource degradation considered. For example, if there is no land or credit market, but all other markets function perfectly, households with less wealth or income will be less able to invest in soil and water conservation measures than wealthier households, other factors being equal, and thus may suffer greater land degradation (Pender and Kerr 1998). On the other hand, wealthier households are more able to invest in livestock, mechanical equipment, or other assets that may contribute to soil erosion or other forms of land degradation. Furthermore, the land management practices pursued by wealthier households may increase some forms of resource degradation (e.g., more soil erosion due to use of mechanical equipment, or more damage to water resources and biodiversity due to greater use of agro-chemicals), while reducing other forms of resource degradation (e.g., less soil nutrient depletion as a result of greater ability to purchase fertilizers or greater ownership of livestock and recycling of manure) (Swinton, et al. 2003).

If there are imperfect labor and land markets, households with access to more family labor relative to their land are likely to use more labor-intensive and less land-intensive farming practices, such as shorter fallow periods or no fallowing, farming on steep slopes, and tilling more frequently, all of which could contribute to land degradation. On the other hand, households with surplus labor (relative to land) may adopt labor intensive practices that lead to better NRM. Example of these practices are applying manure or mulch, investing in soil and water conservation measures, etc. (Scherr and Hazell 1994; Tiffen, et al. 1994). Thus, the effects of the labor/land ratio on the sustainability of land management are ambiguous (Pender 2001).

In an imperfect market setting, the nature of poverty is also important in determining its impact on natural resource management and degradation. Households that are not poor by welfare criteria such as minimum levels of consumption may still face "investment poverty" that prevents them from making profitable investments in resource conservation and improvement (Reardon and Vosti 1995). Households that lack access to roads and markets, or that own little land may deplete soil nutrients less rapidly since they are subsistence-oriented and thus export less soil nutrients in the form of crop harvest and sales. On the other hand, households that are livestock poor may deplete soil nutrients more rapidly because they lack access to manure. A recent study of determinants of soil nutrient depletion in eastern Uganda found support for these hypotheses of divergent effects of different types of assets (Nkonya, et al. 2004b).

In this research, we investigate the linkages between poverty and NRM by examining the impact of various types of poverty on private land management, soil erosion and soil nutrient depletion, agricultural productivity, and income. We focus on private land management because private land is the most important natural resource to most rural households in Uganda, the problem of land degradation on private land in Uganda is severe, and the linkages between poverty and private land management may be very direct. This is not to say that linkages between poverty and management of other natural resources are not important; some of these linkages are analyzed by Nkonya, et al. (2004a), who investigated the impacts of poverty on community level natural resource management decisions, and found some support for the hypothesis that poverty contributes to poor NRM at the community level.

Poverty can be defined in many ways, and has many dimensions. Typically, economists study income or consumption poverty, but poverty may also be measured by lack of assets, lack of access to infrastructure and services, lack of education, or other factors that determine a household's livelihood status. Among the poor, the meaning of poverty also differs widely, depending on their livelihoods and endowments of physical, human, natural and financial capital. The Uganda Participatory Poverty Assessment Process (MFPED 2002) defines poverty as lack of basic needs and services (food, clothing, and shelter), basic health care, education and productive assets. Poverty may also include lack of democracy or power to make decisions that affect the livelihoods of the poor, and social exclusion. For the case of farmers in northern Uganda, poverty also includes insecurity and internal displacement. In this study, we consider a broad definition of poverty, focusing on the impacts of limited endowments of physical, natural, human and financial capital, as well as poor access to infrastructure and services. Investigation of the impacts of other more political or social components of poverty such as lack of democracy and power, social exclusion, insecurity and internal displacement, was beyond the scope of the study.

3. EMPIRICAL MODELS AND DATA

Our main objective is to analyze the impacts of different aspects of poverty on land management practices, crop productivity, household income, and measures of land degradation. We do this by using an empirical model based on the sustainable livelihoods framework (Carney 1998) and literature on agricultural household models (Singh, et al. 1986; de Janvry, et al. 1991). In our theoretical framework, we assume that rural households make choices about labor allocation, land management, input use, and savings and investment to maximize their discounted expected lifetime welfare, subject to the factors that determine their income opportunities, constraints and risks, including their endowments of physical, human, natural, and financial capital, land tenure, agro-climatic potential, population pressure, commodity and factor prices, and access to markets, extension and other services. Under standard assumptions used in the dynamic programming literature (e.g., Stokey and Lucas 1989), this life-cycle decision problem reduces to a series of decision problems in each year, in which the household decides what is best to do in the current year based upon the endowments and information that it has at the beginning of the year and its expectations about how the decisions it makes will affect current consumption and the value of endowments that it will carry over to the next year.[1] These decision problems imply that current decisions about labor allocation, land management, input use and investments will depend upon the endowments of different types of capital that the household has at the beginning of the year, and other factors influencing the household's income potentials and risks in the present and future. The empirical models that we estimate in this paper are based upon such a dynamic household model.[2]

RESPONSE AND OUTCOME VARIABLES

We are particularly interested to know how different types of capital and access constraints (as measures of different types of poverty) influence household decisions on labor use, land management practices and use of agricultural inputs and implications for productivity, income and land degradation. The major land management practices and inputs that we analyze are those that are sufficiently common among survey respondents to be investigated empirically. These include application of organic matter (plant residues and animal manure) and inorganic fertilizer, use of short term soil and

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[1] This is a verbal statement of the Bellman principle of dynamic programming (Stokey and Lucas, 1989).

[2] See Appendix 1 for the specification of the theoretical dynamic household model and derivation of the empirical models used in this paper.

water conservation (SWC) practices, crop rotation, slash and burn, fallow, and use of purchased seeds. The short-term SWC practices include trash lines, deep tillage, zero tillage, and plowing and planting along contour lines.

We investigate the impacts of land management decisions on the value of crop production per acre (and hence indirectly on income), thus quantifying some of the linkages from land management to poverty. Total value of crop production was measured by multiplying the quantity produced per acre times the village level price, which was aggregated over the two seasons. Area cultivated was derived as the weighted average for both seasons. We also investigate the impacts of endowments on crop production per acre and household income per capita in reduced form, through which the total effects of asset holdings on income poverty (via impacts on labor use, land management and input use) can be assessed.

As indicators of land degradation, we focus on soil erosion and soil nutrient depletion, which are among the most severe forms of land degradation in Uganda. We analyze the severity of estimated soil erosion using the revised universal soil loss equation (RUSLE) (Renard, et al. 1991), and soil nutrient depletion by computing the soil nutrient inflows, outflows and balances (Smaling, et al. 1993). We define soil nutrient flow as the amount of plant nutrients that flow in and out of a system or area during a specified time period (one year in this case). The difference between soil nutrient inflow and outflow is referred to as “nutrient balance.” Nutrient flows and balances may be measured at different scales, such as at the plant, plot, household, water catchment, village, district, national, or higher level (Ibid.). Our study measures soil nutrient flows and balances at the plot level since there are wide variations across plots in soil nutrient balances, and it is at this level that actual impacts on sustainability of land use will be most evident.[3]

DETERMINANTS OF RESPONSES AND OUTCOMES

Our analysis is centered on land management since land is the major resource for the livelihoods of the poor. A large body of past research shows that the major determinants of land management include households' endowments of different types of capital, land tenure, and the biophysical and socio-economic environment in which rural households live (e.g., see Reardon and Vosti 1995; Barrett, et al. 2002; Nkonya, et al. 2004b). The capital endowments are the constraints in the welfare maximization model presented in Appendix 1. As noted earlier, due to imperfect or missing markets of these capital goods and services, household land management decisions may differ depending on the levels of their capital endowments. For instance, holding all else constant, households with abundant labor but with land scarcity are likely to invest more labor on their small land parcel than the case of households with large farms if land and labor markets do not function perfectly (e.g. see Feder 1985).

Specifically, the capital endowments that may influence land management practices (depending also on nature of markets) include:

1. *Natural capital*: The natural capital endowment that we consider in this research is mainly land, which includes the amount of land owned, the quality of the land – measured as topsoil depth, the stock of macronutrients (nitrogen, phosphorus, and potassium) and average slope, and the presence of prior land investments on plot. Most past studies consider land endowment as only farm size since it is difficult and expensive to measure

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[3] For details on estimation of household and plot level soil nutrient flow and balances, see Kaizzi et al. 2004.

quality of land. As noted earlier, one way in which this study contributes to the literature is its use of better data on land quality indicators. The topsoil is a storehouse of plant nutrients (Sanchez, et al. 1997). Hence, in farming systems where farmers apply a limited amount of inorganic fertilizer as is the case in Uganda, topsoil depth largely determines soil quality (Ssali 2002). We enrich the measure of land quality by including the stock of macronutrients, which is a more specific measure of soil fertility. We also include the slope of plot since it measures the potential for soil erosion, which accounts for a large share of nutrient loss (Wortmann and Kaizzi 1998). Land investments – such as soil and water conservation structures, agroforestry, etc -- also can improve soil moisture holding capacity and fertility (Sanchez, et al. 1997), hence can increase land quality.

2. The impacts of natural capital on land management decisions may be mixed. As noted earlier, farmers who own more land may farm the land that they own less intensively if factor markets are imperfect, and hence be less prone to invest in labor and input intensive land management practices. On the other hand, greater land ownership may increase households' ability to hire labor or purchase inputs by increasing their access to credit (Pender and Kerr 1998). The need to invest in intensive SWC practices will be greater on steeper soils, but the costs of such investments may be higher or the returns lower if slopes are very steep. The benefits of investing in fertilizer may be lower on more fertile soils, unless there are complementarities between different types of nutrients or between organic practices and use of inorganic fertilizer (Palm, et al. 1997). The presence of land investments such as SWC structures may promote greater use of inputs such as fertilizer, by increasing the return to such inputs (e.g., because they conserve soil moisture which may be complementary to fertilizer, seeds or other inputs). On the other hand, such structures may reduce the need for inputs (since less may be lost through erosion). Furthermore other types of land investments may be oriented more to livestock or other production (e.g., paddocks, fish ponds) and thus may tend to reduce farmers' use of crop inputs. Clearly, the

theoretical impacts of natural capital endowments on land management practices are ambiguous, and empirical research is needed to identify the actual impacts in a particular context. Since the impacts of natural capital on land management are theoretically ambiguous, impacts on land degradation will also be ambiguous. The same can be said regarding the impacts of most other endowments as well.

3. *Physical capital* includes the value of farm buildings, equipment and other durable goods, number of livestock, etc. As with natural capital, these assets may have mixed impacts on land management. Ownership of marketable assets in general increases the household's ability to finance investments and purchase of inputs, which may favor use of purchased inputs such as inorganic fertilizer. On the other hand, ownership of livestock will increase the supply of manure available to the household, which may substitute for purchased inorganic fertilizer. Farm equipment may increase the productivity of labor in crop production, thus increasing the demand for labor, or may substitute for labor. Farm equipment and durable goods such as a bicycle or motorcycle may promote use of bulky organic inputs by making them easier to transport and incorporate into the soil, or may reduce use of such inputs by increasing the opportunity cost of the farmer's labor.

4. *Human capital* includes assets embodied in people's knowledge and abilities, such as education, experience (measured by primary livelihood strategy), sex, training, and the quantity of labor endowment. These affect farmers' ability to make land management decisions. For example, due to imperfect labor markets, households that are well endowed with family labor are more likely to use labor intensive land management practices. Likewise, an experienced farmer knows well the biophysical and socio-economic environment to an extent that she makes informed decisions on land management. Holding all else constant, a better educated household head is likely to better collect and interpret extension messages, hence more

likely to adopt improved land management practices where these are being promoted by extension and suitable to the farmer's needs. On the other hand, education offers alternative livelihood strategies such as non-farm activities, which may increase labor opportunity costs and compete with agricultural production (Scherr and Hazell 1994). Since education of all household members may matter, and not only the education of the household head (Joliffe 1997), and since there may be differences in impacts of female vs. male education on agricultural activities (Pender, et al. 2004), we represent education using the level education of men and women in the household separately.

5. *Financial capital* includes household liquid financial assets and access to credit. We measure access to financial capital by whether farmers participate in rural credit and savings organizations. Limited access to credit has been cited by many studies as one of the constraints to improved land management (Sharma and Buchernrieder 2002; Fafchamps 2000; Fafchamps and Minten 1999). Lack of access to financial capital may limit farmers' ability to purchase inputs such as fertilizer or to hire labor, and may limit their ability and incentive to invest in land improvements by causing households to have high discount rates (Pender 1996; Holden, et al. 1998; Pender and Kerr 1998). On the other hand, access to financial capital may enable households to invest more in non-farm activities and increase their opportunity cost of labor, thus possibly reducing their interest in investing in agricultural production and land management activities (Pender and Kerr 1998), especially if the profitability of these activities is low.

In general, household capital endowments have ambiguous impacts on land management, crop productivity and land degradation, depending on the nature of market imperfections, as discussed in the previous section. However, most endowments that require household investment are expected to contribute to higher household income (since this is part of the reason why households invest in them), though larger household size may lead to lower income per capita if there are diminishing returns to additional labor in the household, or because larger households tend to have a higher share of dependents.

Land tenure relationships also can have important influence on land management decisions and agricultural productivity. If land tenure is insecure, this will tend to reduce farmers' incentive to invest in land conservation and improvement, since the returns to such investments will be at risk (Feder, et al. 1998; Place and Hazell 1993; Besley 1995; Gavian and Fafchamps 1996). Tenure insecurity can also reduce farmers' ability to invest in land improvement and inputs, since it reduces the collateral value of land and thus farmers' access to credit (Ibid.). The collateral value of land will also be reduced or even eliminated if there are restrictions on the transferability of land (Pender and Kerr 1999). Transfer restrictions or imperfections in land markets can also inhibit investments in land improvement because farmers may be unable to recoup the value of their investments by selling land assets, causing land investments to be irreversible investments, thus increasing farmers' option value of waiting to invest in the presence of uncertainty (Fafchamps and Pender 1997; Pender and Kerr 1999). These arguments imply that land investment and adoption of purchased inputs should generally be greater on freehold land that is fully titled, with secure and full rights to transfer and mortgage as well as use land, than on customary land that has more limited rights, or on leased or occupied land subject to greater insecurity and more limited rights. However, there are also theoretical and empirical counter-arguments. Often customary land is quite secure in terms of use and bequest rights, and land titling efforts can actually increase rent seeking and hence tenure insecurity (Atwood 1990; Platteau 1996). Tenure insecurity may be associated with greater incentives to invest, if investment will help to increase tenure security (Besley 1995; Otsuka and Place 2001). Furthermore, land management may be influenced by regulations, community norms and responsibilities to manage the land sustainably as well as by farmers' formal rights, and these may be more influential in affecting management of customary land than freehold or leasehold land.

In Uganda, there are four major land tenure types: customary, mailo, freehold and leasehold. Each land tenure system is associated with its own land rights and obligations and different degrees of permanence and security of land rights (Republic of Uganda 1998).

a. *Customary land tenure* is the most common land tenure system in Uganda and is regulated by customary rules. Under customary tenure, an individual, family or traditional institution may occupy a specific area of land as prescribed by the customary laws. Customary tenure often involves limitations on the individual's right to sell or mortgage land, though usufruct and bequest rights are usually fairly secure. Customary tenure may also carry informal obligations concerning land use and management that do not influence other tenure categories. Under the 1998 Land Act, customary landholders may apply for a certificate of ownership from the District Land Board. Once such a certificate is issued, the land holder(s) may lease, mortgage, sell, sub-let, give or bequeath by will the land or part of it (Ibid). However, implementation of the Land Act is still limited.

b. *Freehold land tenure* allows the landholder to own the land for an unlimited time. The landholder can use the land for any lawful purposes; may sell, rent, lease or use it as collateral to get a loan from a bank, may allow other people to use it or may give or bequeath it by will, and has the first priority to buy land from persons who are occupying his/her land (tenants by occupancy) and are willing to sell their land (Ibid). This form of tenure provides owners the most complete rights, with the least obligations or restrictions on use. This has ambiguous impacts on land management, depending on the nature of obligations existing under other tenure systems.

c. *Leasehold land tenure* is a form of tenure created either by contract or by operations of law. Under this system a person referred to as the *tenant* or *lessee*, occupies land through an agreement between him/herself and the owner of the land referred to as the *landlord* or *lessor.* Under this system, the landlord allows the tenant to use the land for a specific period, usually five, forty-nine or ninety nine years without any disturbance by the owner as long as the lessee abides with the law. The tenants are usually but not necessarily required to pay rent or premiums or both or may be asked to render services (Ibid). The lessee may change a lease ownership to freehold, can sell, sub-let, mortgage, give or bequeath by will the land for the period he or she is entitled to hold the land. The rights under leasehold are similar to those under freehold, except that the term is limited. Where long-term leases are involved, the land management of leasehold land is therefore likely to be similar to management of freehold land.

d. *Mailo land tenure* is a system where the landholder owns the land forever in the same way as a freehold owner. However, in most cases, *mailo* land has long been occupied by long-term occupants. The 1998 Land Act recognizes and protects the rights of lawful and *bona fide* occupants[4] of that land as well as their improvements on that land. The landholder may

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[4] The Land Act, 1998 recognizes three types of occupants on registered land namely; the lawful occupants, the *bona fide* occupants and the non *bona fide* (unlawful) occupants. The lawful occupant is a person who entered the land with consent of the registered landholder or a person who occupies land by virtue of the repealed *busuulu* and *envujjo* law of 1928; or the Tooro or Ankole landlord and tenant law of 1937. A *bona fide* occupant is a person who before coming into force of the constitution had occupied or utilized or developed any land unchallenged by the registered owner or agent of the registered owner for twelve years or more. A *bona fide* occupant may also be a person settled on land by government or agent of the government, which may include a local authority. The unlawful occupant is the one who does not qualify as a lawful or *bona fide* occupant but holds land under unlawful means.

> lease, mortgage, pledge or sell, give away or bequeath by will his interest in the land or part of it. However, the Land Act prohibits landholders from evicting *bona fide* occupants from land. Thus *bona fide* occupants have a substantial degree of tenure security. Nevertheless, they are often restricted by owners from making land investments, since this reduces the rights of the absentee owner, who owns the land but not the developments made on the land by *bona fide* occupants. Thus, occupants of *mailo* land may be inhibited from investing in land improvement, even though they may have secure use rights to the land.

Access to agricultural technical assistance services can increase adoption of inputs and land management practices by increasing farmers' awareness of and ability to effectively use new agricultural inputs and practices. The impacts of extension will depend on the type of enterprises and technologies that are promoted, however, as well as the suitability of these to the farmers' conditions. Thus, extension may have mixed impacts on agricultural production and land management practices, depending on the approach and emphasis of the program. In this study, we distinguish households that are participating in the traditional government agricultural extension programs from those participating in the new extension approach, the National Agricultural Advisory Services (NAADS).[5] The new extension approach is more demand-driven in nature than the traditional approach. It emphasizes development of farmer organizations and promotion of new commercial agricultural enterprises that are expected to be more profitable for farmers than traditional production. The likely impacts on land management are not clear, since land management is not a major emphasis of the approach, although to the extent that more profitable cash crops are adopted, one could expect this to promote

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[5] The old extension approach used local government employed extension workers, who are still active in the non-NAADS and to some extent in the NAADS sub-counties.

greater adoption of purchased inputs such as seeds and fertilizer, and greater labor intensity in crop production.

In addition to household level capital endowments, land tenure, and participation in technical assistance programs, there are other factors that affect land management at village, regional, national or international level. Village or higher level factors that determine local comparative advantages and hence the profitability of labor use, land management and input use include agro-ecological conditions, access to markets, infrastructure, local wages, and population density. Rainfall regimes and other biophysical factors greatly influence farming systems and land management. Likewise, infrastructure development heavily influences farmer decisions on land management since it affects local prices, availability of inputs and market information, and other socio-economic aspects.

Local wage levels reflect the scarcity of labor and can thus affect the labor intensity of agricultural production, as well as affecting households' ability to finance purchase of inputs. Controlling for wage levels, farm size and household size, population density reflects mainly scarcity of natural resources at the community level, since household level scarcity is reflected by household endowments. This may influence land management on private land to the extent that there are interactions between use of common and private land. For example, greater scarcity of communal fuelwood or fodder supplies in densely populated communities may cause households to rely more on animal manure and crop residues for fuel and fodder, thus limiting the ability of farmers to apply such inputs to their private cropland.

Below we describe these factors and how they were measured in detail.

Agro-climatic zones: There are several classifications of agroecological, agro-climatic and farming systems in Uganda. The distinction among these classifications is fairly fuzzy. Kyamanywa (1987) and the Ministry of Natural Resources (1994) divided Uganda into eleven agro-climatic zones and twenty ecological zones while Semana and Adipala (1993) identified four agro-ecological zones (AEZ). A study by Wortmann and Eledu (1999) divides Uganda into 33 agroecological zones that depict a detailed representation of natural resource endowment and will therefore be used in this study. However, AEZ by Wortmann and Eledu fall into eleven major categories that are spatially represented in Figure 1. Below, we discuss the six agro-climatic zones that were covered in this study:

1. The Lake Victoria Crescent zone has a high level of rainfall distributed throughout the year in a bimodal pattern (“bimodal high rainfall”) and is characterized by the dominant banana-coffee farming system. The zone runs along the vicinity of Lake Victoria from the east in Mbale district, through the central region to Rakai district in southwestern Uganda along the shores of Lake Victoria.
2. Northwest farmland: This area is characterized by unimodal low to medium rainfall and covers the west Nile districts of Arua, Nebbi and Yumbe. Common crops grown in the zone are coarse grain (sorghum, millet, bulrush, etc), maize, tubers, and tobacco.
3. North-moist farmland: This zone is also characterized by unimodal low to medium rainfall and covers most of the northern districts. The common crops grown are coarse grain, maize, tubers, cotton, and a variety of legumes.
4. Mount Elgon farmlands: This zone is on the slopes of Mount Elgon in the east and is characterized by unimodal high rainfall, high altitude and hence cooler temperatures and relatively fertile volcanic soils. The only district covered by our survey in this zone is Kapchorwa. The major crop in Kapchorwa is maize. Farmers in this zone also plant bananas and raise livestock.

5. Southwestern grass-farmland: This zone receives medium to low rainfall in a bimodal distribution. The only district covered by our survey in this zone is Mbarara. The common crops in the district are banana, coarse grains, maize and tubers. Many farmers in the district also keep a large number of livestock.
6. Southwestern highlands (SWH) zone. This zone receives bimodal high rainfall and has high altitude, hence cooler climate, and relatively fertile volcanic soils. The common crops in the SWH are bananas, Irish potatoes and other tubers, sorghum, maize, and vegetables.

Market and road access: The geographic coordinates of the survey households were linked to geographic information on indicators of market access and population density. Areas of relatively high market access were classified by Wood, et al. (1999) using the Potential Market Integration (PMI) index, an index of travel time of each location to the nearest five markets, weighted by the population size of those markets (a higher value of PMI indicates better market access). The areas classified as having relatively high market access include most of the Lake Victoria crescent region and areas close to main roads in the rest of the country (Figure 2). Access to roads was classified based on information from the community survey on the distance of the community to an all-weather road. Access to markets and roads are expected to favor adoption of purchased inputs, by increasing their availability and reducing their costs relative to farm level commodity prices, and by favoring commercial production of higher value crops. Better access to markets and roads are also expected to contribute to higher value of crop production and higher incomes per capita, the latter both by increased value of crop production as well as increased opportunities for other sources of income (e.g., non-farm activities, livestock production). The impacts on adoption of labor or land intensive land management practices, however, is ambiguous, since market and road access can increase the opportunity costs of labor and land, as well as increasing the marginal returns to labor and land inputs. The impacts on land degradation are also, therefore, theoretically ambiguous.

Population density and wage rates: The population density data were collected in the IFPRI-UBOS survey (discussed below) by measuring the area of LC1 and asking community leaders to report the number of people in the LC1. As mentioned above, this variable reflects community level scarcity of natural resources, since we are also controlling for household endowments. Greater scarcity of resources may constrain households from using some organic land management practices, but may also promote greater investment in resource improvement at the household level.   Local average agricultural wage rates in the study communities were also included in the analysis, as indicators of the scarcity of unskilled casual labor. We expect higher local wages to contribute to lower labor intensity and less adoption of labor intensive land management practices, while they may promote greater use of purchased inputs by increasing households' access to cash.

Figure 1--Agro-climatic zones in Uganda

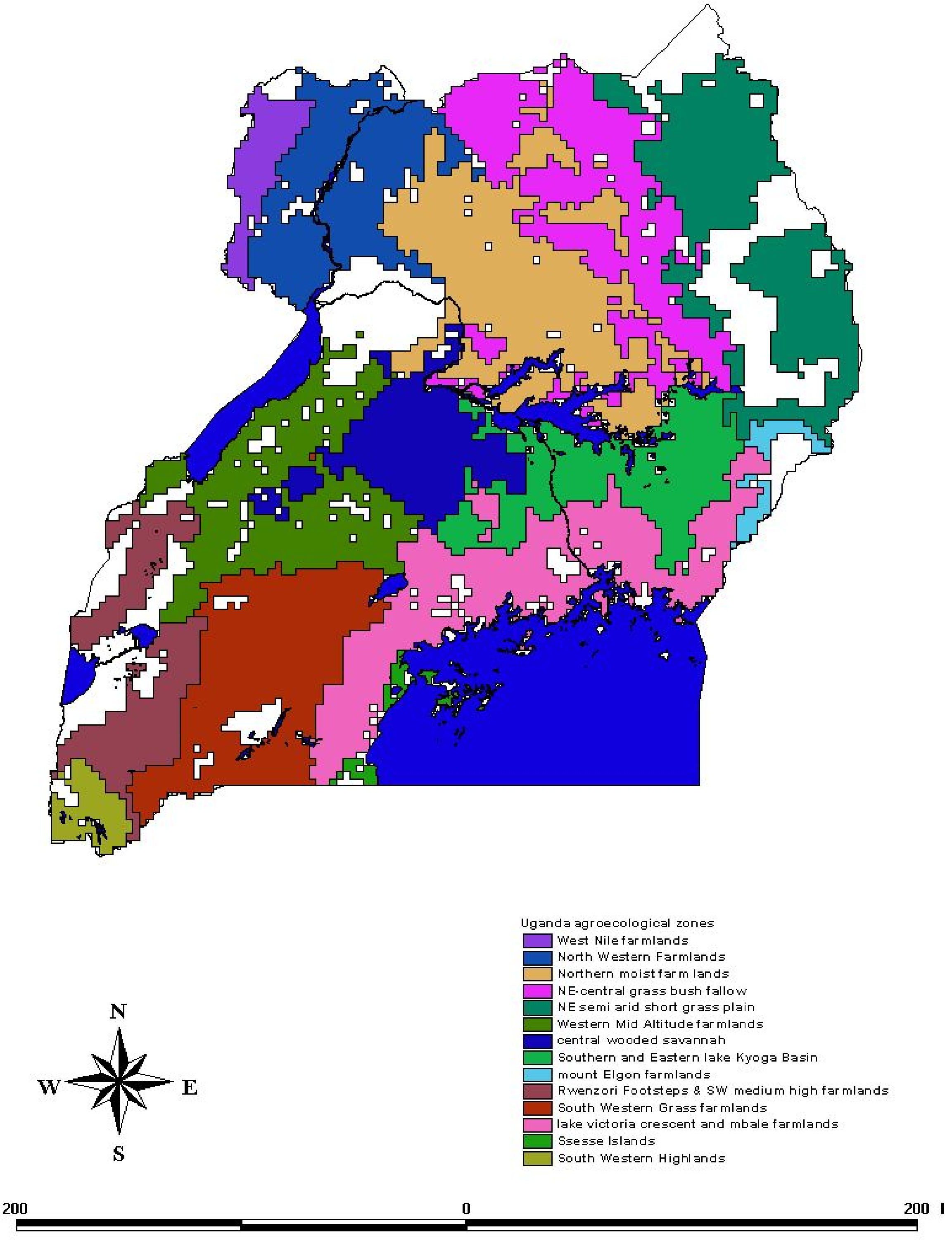
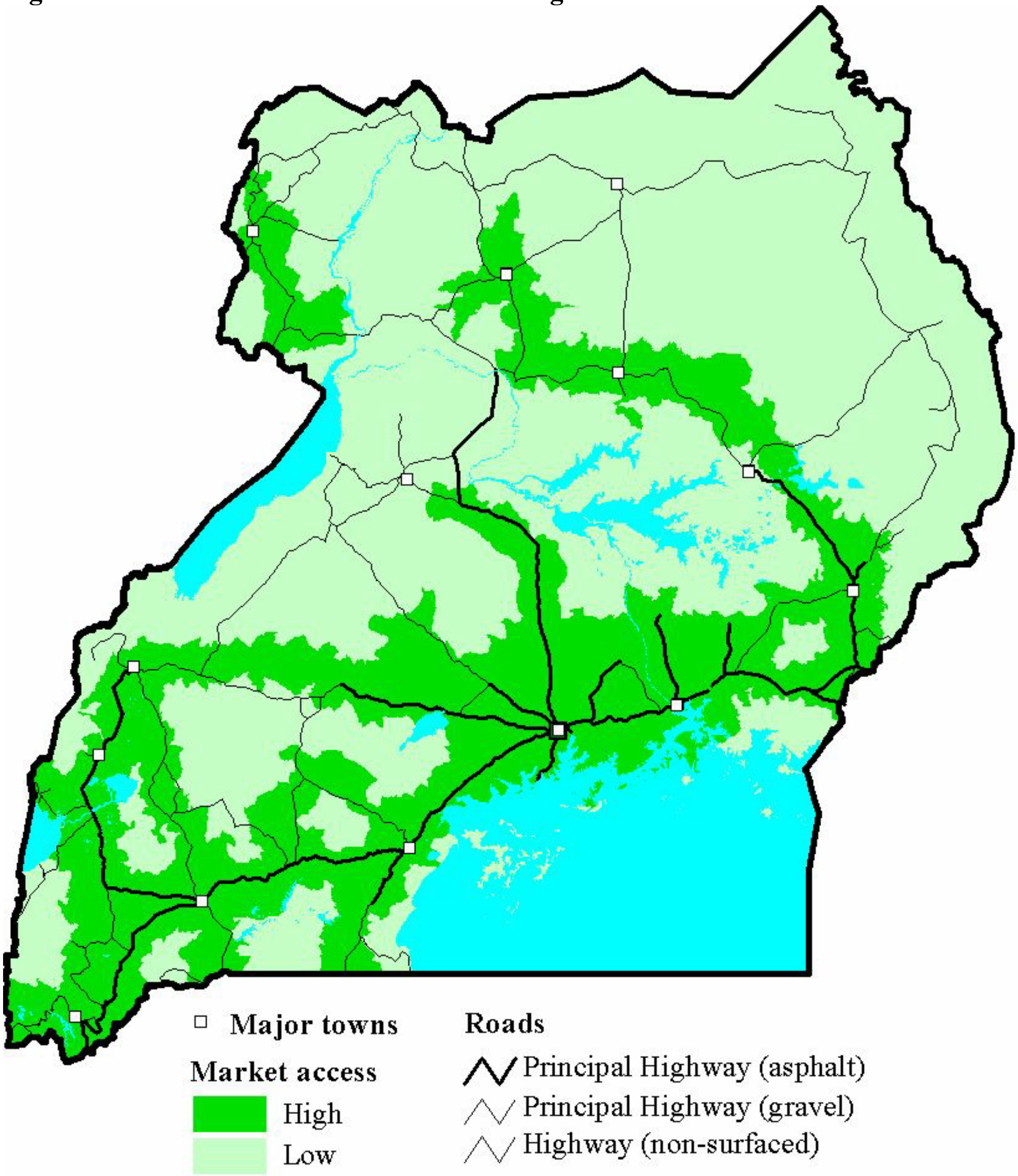


Figure 2--Classification of market access in Uganda



Source: Wood, et. al. (1999)

DATA:

The data used in this research were linked to the 2002/03 Uganda National Household Survey (UNHS). A stratified two-stage sampling was used to draw a sample for the UNHS 2002/03. Using the 56 districts as strata, 972 enumeration areas (565 rural and 407 urban) were randomly selected at the first stage sampling, from which a total of 9,711 households were randomly selected at second stage sampling.[6] For this research, a survey of household land management practices was conducted during 2003 by the International Food Policy Research Institute (IFPRI) and the Uganda Bureau of Statistics (UBOS), based on a sub-sample of the 2002/03 UNHS. The sampling was weighted using population of each district and a total of 123 enumeration areas were sampled from the UNHS 2002/03. Since the aim of this paper is to study the poverty-NRM linkage, the criteria used for sub-sampling the UBOS communities were the level of poverty and the endowment of natural resources at district level. Eight districts were purposively selected using these criteria (Table 1).

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[6] Only 55 of the 56 districts were covered in the survey. One district (Pader) was not covered due to insecurity during the time of the survey. Some enumeration areas in Gulu and Kitgum were also not covered for the same reason. An enumeration area is the smallest unit used for census purposes and it covers one or more local council 1 (LC1), which are the lowest administrative units in Uganda.

Table 1--Selected Districts, Communities and households

District	# of communities selected	# of hhds selected	Poverty headcount [1] (%)	Poverty Status[2]	Natural resource endowment (Agricultural potential)[3]	Region
Arua	16	112	66.6	Medium	Low potential (Unimodal medium)	West Nile
Iganga	16	112	52.5	Low	High potential (bimodal high rainfall)	Lake crescent
Kabale	16	112	71.8	High	High potential (highlands)	West
Kapchorwa	8	55	43.4	Low	High potential (highlands)	East
Lira	17	112	64.8	Medium	Low potential (Unimodal medium)	North
Masaka	20	139	50.8	Low	High potential (bimodal high rainfall)	Lake crescent
Mbarara	20	139	52.4	Low	Medium potential (bimodal low rainfall)	West
Soroti	10	70	79.0	High	Low potential (Unimodal medium)	Northeast
Total	123	851	60.4			

1. Using the National level, poverty status of a district was ranked as follows:
   Below 55: Low; Between 55 to 70 Medium; Above 70: High
2. Poverty count is a broad indicator of poverty that measures the percentage of people living in households with real consumption per adult equivalent below the poverty line of the region. This indicator does not measure the depth of poverty, i.e. how far below the poverty line are the poor (UBOS 2003).
3. Agricultural potential is an abstraction of many factors—including rainfall level and distribution, altitude, soil type and depth, topography, presence of pests and diseases, presence of irrigation, and others—that influence the absolute (as opposed to comparative) advantage of producing agricultural commodities in a particular place.

As was the case with the UNHS 2002/03 survey, the number of sample communities from each district was computed using population as weights. Seven households per enumeration area were randomly selected for the IFPRI-UBOS survey from those who participated in the UNHS 2002/03 survey (see Table 1 for details on number of households selected from each district). A total of 851 households were selected for the household and plot level survey.

This report analyzes the household and plot level surveys only.[7] Most of the data used in this research were obtained from the IFPRI-UBOS survey, though some data from the UNHS 2002/03 survey were also used. The data obtained from the UNHS 2002/03 survey are: non-crop income, the level of education and gender of household members, the value of buildings, the primary source of income of household members, and household size.

We will elaborate on how we measured the soil quality characteristics of plots, and education since their method of measurement may not be clear to readers. The soil quality characteristics were measured by visiting the plot, measuring its slope using a clinometer, taking soil samples at a depth of 0-20cm and analyzing the samples (as will be elaborated further below) and measuring the topsoil depth. The enumerators also measured the area of the plot using Global Positioning System (GPS) units that automatically measured the area of a polygon as the enumerator walked along the sides of the polygon (i.e. borders of the plot).

Household members pursue different activities that portray a clear division of labor. For example, Gladwin and Thompson (1999) note that women produce much of the household food and do most of the land management activities. This suggests that the level of education of female and male members of the household is likely to have different impacts on land management. We therefore used eight variables that represent the level of education as shares of female and male members of household who have attained the following levels of education: (a) no formal education, (b) primary education, (c) secondary education, and (d) post-secondary education

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[7] For the community level and UNHS 2002/03 survey results, see Nkonya, et al. 2004b and UBOS 2004.

Soil samples obtained from a depth of 0-20 cm were collected from plots. A total of 1887 soil samples were analyzed in the lab to determine the biophysical characteristics and contribute to the computation of the soil nutrient flows and balances. The pH, organic matter, total nitrogen (N), extractable phosphorus (P), exchangeable potassium (K) and calcium (Ca), and texture were measured using the analytical method according to Foster (1971).[8] Information on farm management practices; crop-livestock interactions; crop diversity; and other variables that affect nutrient flow was obtained from the household and plot level surveys. These data were used to determine estimates of annual nutrient inflows and outflows for each plot. We will restrict our analysis to the three major macronutrients, i.e. N, P, and K. The sources of inflows and outflows used in this study are according to de Jager, et al. (1998) and Smaling, et al., (1993). The nutrient inflows are mineral fertilizers, organic inputs from outside the plot, atmospheric deposition, BNF, and sedimentation. The major sources of outflows are: crop products and residues taken off the plot, leaching, soil erosion, and gaseous losses.

DATA ANALYSIS

Since there are considerable differences in how farmers manage land depending on the characteristics of specific plots, we analyze land management practices, crop productivity, soil nutrient flows and balances at plot level. Only household income is analyzed at household level since it is an aggregation of all sources of income – farm and non-farm.

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[8] For details on the soil nutrient analysis methods and results, see Kaizzi, (2004).

Descriptive analysis: Before turning to the determinants of soil fertility management, we will analyze the severity of soil nutrient depletion using descriptive data analysis. Even though knowing the impact of soil nutrient depletion on crop yield is more important than just quantifying the depletion, there are no studies known to the authors that have measured agricultural productivity loss due to soil nutrient depletion in Uganda. We therefore use a simpler measure to estimate this impact. This measure is called the economic nutrient depletion ratio (ENDR) (der Pol 1993). ENDR is the share of farm income derived from mining soil nutrients.[9] Soil nutrient mining is the practice of growing crops with insufficient replacement of nutrients taken up by crops. Mathematically,

$$\text{ENDR} = \frac{NDMV}{GM} \text{ x } 100$$

where: (NDMV) is nutrient deficit market value, which is the value of nutrients mined per hectare if such nutrients were to be replenished by applying fertilizer purchased from the cheapest sources.

GM is the gross margin of the household from agricultural activities per hectare.

ENDR measures the cost of replenishing nutrient depleted relative to farm income, and not the benefit. Holding other factors constant, decreasing fertilizer prices will both increase returns to use of fertilizer and reduce ENDR.

Econometric models: We assume that the value of crop production per acre (we also refer to it as crop productivity) by household h on plot p (Y_{hp}) is determined by labor use per acre on the plot (L_{hp}), land management practices (LM_{hp}) on the plot (including

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[9] Farm income includes income from crop, livestock and other agricultural activities. It excludes income from non-farm activities, transfers, etc.

use of inputs), the natural capital (size and quality) of the plot (NC_{hp}), the tenure of the plot (T_{hp}), the household's endowments of physical capital (PC_h), human capital (HC_h), and financial capital (FC_h), the household's access to agricultural technical assistance (AS_h), village and higher level factors influencing comparative advantage (agro-climatic potential, access to markets and roads, population density, and wage level) (X_v), and other random factors such as weather in a given year and location (e^v_{vhp}) (equation 1). Some of these factors may have only indirect impacts on crop production, by influencing use of labor and land management practices (e.g., population density and the wage level). However, we include these in the full specification of the structural model, and then use hypothesis testing to eliminate such factors that have statistically insignificant impacts.

The structural model of crop production is thus:

1) Value of crop production/acre: $Y_{hp} = f(L_{hp}, LM_{hp}, \mathbf{NC}_{hp}, \mathbf{PC}_h, \mathbf{T}_{hp}, \mathbf{HC}_h, \mathbf{FC}_h, \mathbf{AS}_h, \mathbf{X}_v, \mathbf{e}^{\mathbf{y}}_{vhp})$

We also estimate the following general reduced form model for each set of the dependent variables[10]: .

2) Value of crop production/acre: $Y_{hp} = f(\mathbf{NC}_{hp}, \mathbf{PC}_h, \mathbf{T}_{hp}, \mathbf{HC}_h, \mathbf{FC}_h, \mathbf{AS}_h, \mathbf{X}_v, \mathbf{e}^{\mathbf{yr}}_{vhp})$

3) Labor use/acre: $\mathbf{L}_{hp} = f(\mathbf{NC}_{hp}, \mathbf{PC}_h, \mathbf{T}_{hp}, \mathbf{HC}_h, \mathbf{FC}_h, \mathbf{AS}_h, \mathbf{X}_v, \mathbf{e}^{\mathbf{l}}_{vhp})$

4) Land management practices: $\mathbf{LM}_{hp} = f(\mathbf{NC}_{hp}, \mathbf{PC}_h, \mathbf{T}_{hp}, \mathbf{HC}_h, \mathbf{FC}_h, \mathbf{AS}_h, \mathbf{X}_v, \mathbf{e}^{\mathbf{lm}}_{vhp})$

5) Household income: $I_h = f(\mathbf{NC}_h, \mathbf{PC}_h, \mathbf{T}_{hp}, \mathbf{HC}_h, \mathbf{FC}_h, \mathbf{AS}_h, \mathbf{X}_v, \mathbf{e}^{\mathbf{I}}_{vh})$

6) Soil erosion: $\mathbf{E}_{hp} = f(\mathbf{NC}_{hp}, \mathbf{PC}_h, \mathbf{T}_{hp}, \mathbf{HC}_h, \mathbf{FC}_h, \mathbf{AS}_h, \mathbf{X}_v, \mathbf{e}^{\mathbf{E}}_{hp})$

7) Soil nutrient balances: $\mathbf{Nutbal}_{hp} = f(\mathbf{NC}_{hp}, \mathbf{PC}_h, \mathbf{T}_{hp}, \mathbf{HC}_h, \mathbf{FC}_h, \mathbf{AS}_h, \mathbf{X}_v, \mathbf{e}^{\mathbf{NB}}_{vhp})$

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[10] See Nkonya, et al. (2004b) for a derivation of this empirical model.

Where

- I_h is income per capita of household h;
- E_{hp} is estimated erosion on plot p of household h, using the RUSLE;
- $\mathbf{Nutbal}_{hp}$ is a vector of soil nutrient balances of macronutrients, namely nitrogen (N), phosphorus (P), potassium (K) and total nutrient balance (NPK) from household h at plot p;
- $\mathbf{e}^{\mathbf{yr}}_{vhp}$, $\mathbf{e}^{\mathbf{lm}}_{vhp}$, $\mathbf{e}^{\mathbf{I}}_{vh}$, $\mathbf{e}^{\mathbf{In}}_{vhp}$, $\mathbf{e}^{\mathbf{Out}}_{vhp}$, and $\mathbf{e}^{\mathbf{NB}}_{vhp}$ are unobserved random factors affecting the dependent variables in village v for household h at plot p.

It is likely that the error terms across equation (1)-(7) are not independently distributed hence the need to estimate the models using a system of equations. Estimating them as single equations reduces the efficiency of estimation because correlation in error terms across equations cannot be accounted for and cross equation restrictions cannot be imposed. However, estimation of a system of equations using such methods as three-stage least squares is not possible because some of the dependent variables are limited dependent variables, hence their determinants cannot be consistently estimated using standard linear models (Maddala 1983). However, the inability to estimate a system of equation to account for cross equation correlation among the error terms does not cause the estimated coefficients to be inconsistent or biased, as long as the error terms are not correlated with the explanatory variables (Davidson and Mackinon 2004). Hence, each equation is estimated independently using econometric models suitable to the nature of each dependent variable.

Equation (4) is estimated using a probit model since the dependent variables are dichotomous (e.g. whether or not farmer used inorganic fertilizer, organic fertilizer, purchased seeds, crop rotation, slash-and-burn land preparation method, short-term soil and water conservation practices such as trash-lines, deep tillage, zero tillage, fallow, incorporation of crop residues). All other equations are estimated using ordinary least squares (OLS), correcting for sample weights and plot clustering (possible non-independence of error terms across plots within a household) at household level.

Equation (1) includes endogenous choices that could cause endogeneity bias. The endogenous choices are land management practices (including inputs) and pre-harvest labor input. The participation variables, namely participation in agricultural extension or rural finance organizations could also lead to endogeneity bias. To address this problem, we also use IV estimation for equations (1) – (3) and (5) – (7); i.e., those equations whose dependent variable is a continuous variable.

IV estimation results in consistent estimates of the model coefficients, provided that a unique solution to the estimation problem exists and the instrumental variables are uncorrelated with the error term in the model (Davidson and MacKinnon 2004). However, in finite samples, IV estimates are generally biased, and can be more biased than OLS estimates if the instrumental variables used are weak predictors of the endogenous explanatory variables (Ibid., pp. 324-329; Bound, et al. 1995). Furthermore, identification of the coefficients of a linear IV model is impossible unless restrictions are imposed on the model, such as excluding some of the instrumental variables from the regression. In linear IV estimation, it is necessary to have as many restrictions as endogenous explanatory variables to be able to identify the model, and additional restrictions ("overidentifying restrictions") can help to increase the efficiency of the model, provided that these exclusion restrictions are valid and that the excluded instrumental variables are significant predictors of the endogenous explanatory variables.

In our IV regressions, we use several community level variables as instrumental variables that are excluded from the regression model, including whether or not a community had enacted a bylaw related to natural resource management and the degree of cropland degradation in a community (which are indicators of awareness of the need for improved land management practices in a community), the number of program and organizations of different types present in a community (indicators of access to extension and credit), and ethnicity (a proxy for social factors that may influence participation in programs, livelihood and land management decisions). We hypothesize that such variables are significant predictors of the endogenous variables (i.e., they are "relevant"), but that they do not add additional explanatory power to the regression after controlling for the participation variables and other variables (i.e., the overidentifying restrictions are valid). In estimating equation (1), we also exclude from the regression and use as instrumental variables those explanatory variables that were jointly statistically insignificant in the less restricted version of the model (including factors such as land tenure, access to markets and roads, population density and wage levels). These are factors that were found to influence crop production only indirectly, via their impacts on labor use and land management decisions.

In all cases, we statistically test the assumptions that the excluded instrumental variables are relevant by testing their joint statistical significance in predicting the endogenous explanatory variables (Bound, et al. 1995). We test the overidentifying restrictions using Hansen's J statistic (Davidson and MacKinnon 2004, pp. 366-368), which is consistent under heteroskedasticity (Baum, et al. 2002). We also test the consistency of OLS relative to IV using a Durban-Wu-Hausman test (Davidson and MacKinnon 2004, pp. 338-340). Since OLS estimation is more efficient than IV estimation if the OLS model is consistent, we prefer the OLS model if the Hausman test fails to reject the consistency of OLS. Regardless of the results of these tests, we report the OLS and IV results, since IV estimation may be biased in finite samples, as noted above.[11]

Other estimation and data issues considered included sampling weights, heteroskedasticity, multicollinearity, and outliers. The distribution of each variable was examined and an appropriate monotonic transformation towards normality was determined using the ladder of power test, because this improves the model specification (i.e., reduces problems of nonlinearity, outliers and heteroskedasticity) (Mukherjee, et al. 1998; Stata 2003). The following variables were found to be severely skewed and were transformed towards normality using natural logarithm:[12] stock of soil nutrients, tropical livestock units (TLU),[13] distance from plot to residence and roads, value of equipment, crop productivity, household income, pre-harvest labor intensity, soil erosion, population density, and village wage rate.

In addition to the direct effects of the regressors, some combinations of variables may have interaction effects on value of crop production per acre as a result of complementarity or substitutability between different factors. For example, the marginal

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[11] As observed earlier, we also report median regression results for comparison purposes.

[12] To preserve observations with zero, the log-transformation was done as follows ln(x+1), where x is the variable being transformed. Hence zero of the untransformed variable will correspond to zero of the transformed variable.

[13] A standard animal with live weight of 250 kg is called TLU (Defoer, et al. 2000). Average TLU for each livestock category is: Cow = 0.9, oxen = 1.5, sheep or goat = 0.20, and calf = 0.25.

impact of improved soil fertility may depend upon the level of rainfall or access to markets. Such interaction effects can be determined by including the interaction terms of the variables in the regression. We examined the interaction terms of some key variables and then tested for their validity (using a Wald test), and their impact on multicollinearity among the explanatory variables (using the variance inflation factor test). The variables that we suspected to have significant interaction effects on value of crop production per acre were: market access, soil quality indicators, and agroecological zone. We tested the interaction terms among these variables and observed that it was only the southwestern grasslands x distance to all-weather road and the southwestern highlands x distance to all-weather road that passed the Wald test and did not cause variance inflation factors larger than 10. Hence we included these two interaction terms in the value of crop production per acre regression.

Regression statistics (coefficients and standard errors) were also adjusted for sample weights, stratification and cluster sampling. Multicollinearity was tested using pair-wise correlations and variance inflation factors (VIF). Pair wise correlation showed very strong correlation of some variables. For example, ethnicity showed a very strong correlation of over 0.7 significant at p=0.001 with agroecological zones. We therefore dropped ethnic group variables from the original specification. The overidentification tests (none of which were significant) verified that this and other exclusion restrictions in the IV models are valid. In the final specifications, multicollinearity was not a major concern (maximum VIF = 7) (Mukherjee, et al. 1998).

4. DISCUSSION OF RESULTS

DESCRIPTIVE RESULTS

Table 2 shows that only about 10 percent of plots received plant or animal organic matter while around 20 percent were fallowed or had crop rotation. Use of inorganic fertilizer is even lower as only about 9 percent of the plots sampled received fertilizer, at an average rate 48 kg/acre on plots that received fertilizer. Inorganic fertilizer is used mainly by large scale plantation farmers who account for 95 percent of fertilizer consumption in Uganda (NARO and FAO 1999). The remaining 5 percent is accounted for by small scale farmers – mainly maize producers in Kapchorwa and tobacco farmers in the west Nile. The majority of smallholder fertilizer users in the rest of the country use fertilizer on small plots planted with vegetables or other high value crops. Adoption of soil and water conservation (SWC) measures is also low, as only about 13 percent plots were affected by short-term SWC practices (including trash lines, deep tillage, zero tillage, and cultivation along contour lines). The results show the low level of use of organic land management practices and even lower rate of use of inorganic fertilizer. The low adoption of improved soil fertility management technologies has important implications for soil nutrient depletion.

Table 2--Descriptive statistics of plot and household level variables

Variable	Observations	Mean	Std. Dev.	Min	Max
Dependent variables					
Use slash & burn? Yes=1, 0=no	3738	0.198	0.399	0	1
Practice fallow? Yes=1 no=0	3738	0.206	0.404	0	1
Practice crop rotation? yes=1 no=0	3738	0.220	0.414	0	1
Use organic residues? yes=1 no=0	3738	0.097	0.297	0	1
Practice short-term SWC? yes=1 no=0	3738	0.127	0.333	0	1
Use inorganic fertilizer? yes=1, no=0	3607	0.022	0.145	0	1
Use purchased seed? Yes = 1, no = 0	3607	0.392	0.488	0	1
Pre-harvest labor (hours per acre)	2614	362.000	374.95	0.628	374.95
Value of crop production per acre (‘000 Ush)	3135	784.71	1020.52	2.19	5982.14
Per capita household income (‘000 Ush)	851	759.18	1765.63	-1.091	22445.59
Independent variables					
Natural capital					
Average slope (%)	2750	8.024	9.363	0	60
Topsoil depth (cm)	2504	27.660	11.389	4	80
Land investment on plot dummies (yes = 1, no = 0)					
Practice agroforestry?[1]	3625	0.399	0.490	0	1
Have SWC structures?[2]	3625	0.209	0.407	0	1
Have other NRM investment?[3]	3625	0.053	0.223	0	1
Type of crop produced (cf annual crop)					
Perennial	3570	0.231	0.422	0	1
Pasture	3570	0.031	0.172	0	1
Farm size (acres)	851	4.316	5.087	0.123	51.819
Physical capital					
Tropical Livestock Unit (TLU) (#)[4]	851	2.930	3.265	0	51718.5
Value of buildings (‘000 Ush)	851	777.508	190.572	0	30,000
Value of agricultural equipment (‘000 Ush)	851	87.800	541.006	0	10,000
Human capital					
Share of education level of household female members (cf no formal education)					
Primary	851	0.380	0.447	0	1
Secondary	851	0.092	0.258	0	1
Post-secondary	851	0.026	0.134	0	1

Continued

Table 2--Descriptive statistics of plot and household level variables (Continued)

Variable	Observations	Mean	Std. Dev.	Min	Max
Share of education level of household male members (cf no formal education)					
Primary	851	0.463	0.457	0	1
Secondary	851	0.148	0.315	0	1
Post-secondary	851	0.070	0.229	0	1
Sex of household head (male =1, female=0)	851	0.817	0.387	0	1
Household size	851	5.314	2.568	1	17
Share of farm area owned by female	851	0.134	0.326	0	1
Primary source of income of household head (cf crop production)					
Non-farm activity	851	0.306	0.461	0	1
Livestock	851	0.022	0.146	0	1
Access to market & services					
Distance from homestead to plot (km)	3625	1.518	1.674	0	157.25
Potential Market Integration (PMI)	3625	192.514	90.890	3.4838	415.073
Distance to all weather road (km)	3625	2.492	1.995	0	45.4167
# of extension visits	851	0.960	3.803	0	48
Is there NAADS program in sub-county? Yes=1, no=0	851	0.240	0.427	0	1
# of programs & organizations with focus on agriculture & environment	851	1.873	1.694	0	7
# of programs & organizations with focus on credit	851	1.245	1.368	0	6
Land tenure of plot: Customary	3625	0.450	0.498	0	1
Mailo	3625	0.118	0.323	0	1
Freehold	3625	0.419	0.494	0	1
Leasehold	3625	0.020	0.109	0	1
Village level factors					
population density	851	9.679	3.025	1.264	402.333
Community wage rate (Ush)	851	1279.683	1.881	475	10000
Agroecological zones (cf Lake Victoria crescent)					
Northwestern farmlands	851	0.133	0.340	0	1
Northern moist farmland	851	0.203	0.402	0	1
Mt. Elgon farmland	851	0.041	0.198	0	1
Southwestern grass-farmland	851	0.137	0.343	0	1
Southwestern highlands	851	0.241	0.428	0	1

1 Includes: Live barriers, planting trees in plot and on bunds.

2 Includes: stone bunds, fanya juu & fanya chini (bench terraces), drainage trenches, irrigation structures, and grass or other vegetative strips.

3 Includes fish ponds, fences, paddocks, and pasture management

4 A standard animal with live weight of 250 kg is called TLU (Defoer, et al 2000). Average TLU for common livestock in Uganda area: Cow=0.9, oxen = 1.5, sheep or goat = 0.20, and calf = 0.25.

Note: Number of observations for each variable varies because some are plot level observations and some are household level observations. Numbers also vary due to missing observations.

Table 3 shows that the major sources of nitrogen inflow are organic matter and BNF. Inorganic fertilizer contributes only 1 percent of N inflow. Plant organic matter is the major source of phosphorus while animal manure is the major source of potassium (Table 4 and 5).

Table 3--Major sources of nitrogen inflows and channels of outflows at plot level

Nutrient flow	NW farmlands	North moist farmlands	Mt. Elgon farmlands	SW grass-farmland	Lake Victoria crescent	SWH	All zones
Total inflows (kg/ha)	13.79	18.79	25.58	25.38	19.53	12.13	18.05
			% contribution to total inflow				
Inorganic fertilizer	5.00	0.00	11.00	0.00	0.00	0.00	1.00
Plant organic matter	0.00	0.00	16.00	4.00	11.00	0.00	5.00
Animal manure & droppings	22.00	46.00	26.00	54.00	26.00	23.00	35.00
BNF	38.00	27.00	28.00	27.00	41.00	38.00	33.00
Atmospheric deposition	34.00	27.00	19.00	15.00	23.00	39.00	25.00
Total outflows (kg/ha)	55.00	75.89	116.75	132.56	114.38	137.00	104.20
			% contribution to total outflow				
Crop harvest	33.00	21.00	38.00	54.00	56.00	17.00	37.00
Animal grazing	26.00	41.00	24.00	22.00	4.00	1.00	15.00
Leaching & denitrification	21.00	29.00	13.00	12.00	15.00	13.00	17.00
Soil erosion	20.00	8.00	25.00	11.00	24.00	69.00	31.00

Table 4--Major sources of phosphorus inflows and channels of outflows at plot level

Flow sources and channels	NW farmlands	North moist farmland	Mt. Elgon farmlands	SW grass-farmland	Lake Victoria crescent	SWH	All zones
Total inflows (kg/ha)	1.30	1.74	4.09	4.00	3.37	1.51	2.46
			% contribution to total inflow				
Inorganic fertilizer	10.00	0.00	25.0	0.00	0.00	0.00	3.00
Plant organic matter	0.00	0.00	28.00	12.00	37.00	1.00	17.00
Animal manure & droppings	30.00	52.00	28.00	73.00	42.00	47.00	50.0
Atmospheric deposition	60.00	48.00	19.00	16.00	22.00	52.00	31.00
Total outflows (kg/ha)	10.06	7.77	20.32	12.84	16.94	41.25	18.09
			% contribution to total outflow				
Crop harvest	29.00	29.00	20.00	46.00	37.00	6.00	22.00
Animal grazing	17.00	42.00	19.00	24.00	3.00	0.00	9.00
Soil erosion	55.00	30.00	60.00	30.00	59.00	94.00	69.00

Table 5--Major sources of potassium inflows and channels of outflows at plot level

Flow sources and channels	NW farmlands	North moist farmland	Mt. Elgon farmlands	SW grass-farmland	Lake Victoria crescent	SWH	All zones
Total inflows (kg/ha)	6.01	12.40	10.33	13.25	15.73	4.36	10.45
			% contribution to total inflow				
Inorganic fertilizer	2.00	0.00	11.00	0.00	0.00	0.00	1.00
Plant organic matter	0.00	0.00	15.00	15.00	66.00	4.00	27.00
Animal manure & droppings	46.00	73.00	44.00	66.00	16.00	25.00	44.00
Atmospheric deposition	52.00	27.00	30.00	19.00	18.00	72.00	29.00
Total outflows (kg/ha)	46.99	50.23	124.83	202.37	111.32	303.29	141.33
			% contribution to total outflows				
Crop harvest	29.00	24.00	42.00	69.00	62.00	6.00	34.00
Animal grazing	30.00	65.00	20.00	15.00	5.00	0.00	11.00
Leaching	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil erosion	41.00	11.00	37.00	16.00	33.00	94.00	55.00

Crop harvesting is the major outflow for N, contributing over one third of total nutrient outflows. Soil erosion is the most important channel of outflows for both P and K, accounting for more than one half of the total outflow. Soil erosion is an especially important outflow for phosphorus as it contributes over two thirds of its total outflow. This is partly due to the fact that P does not leach significantly. The amount of P lost through crop harvest is the lowest of the three macronutrients.

These results underscore the low-external input agriculture practiced in Uganda and the consequent severe depletion of soil nutrient stocks. In most plots surveyed, the total nutrient outflow exceeds total nutrient inflow. Only about 20 percent of plots had positive nitrogen or potassium balances, but about a quarter of the plots had positive phosphorus balances (Table 6). The Lake Victoria Crescent region has the second largest rate of nitrogen depletion after the southwestern grassland AEZ (Mbarara) and the second largest rate of phosphorus depletion after the southwestern highlands (Kabale). The average amount of nitrogen depleted in all regions during the 2002 cropping seasons was about 2 percent of total nitrogen stock in the top 20 cm. of the soil (most critical zone for crops), which includes both the available and inert stocks.[14] The corresponding average rate of nutrient stock depletion for phosphorus and potassium are 0.5 percent of extractable P and 1 percent of exchangeable K in the top 20 cm. of the soil, respectively.

Table 6--Severity of soil nutrient depletion and its economic magnitude

	NW farmland	North moist farmland	Mt. Elgon farmland	SW grass-farmland	Lake Victoria crescent	SWH	All zones
Nitrogen							
Nutrient balances (kg/ha/year)	-35.55	-53.11	-70.01	-99.22	-82.19	-73.18	70.60
% of plots with positive balances	21.16	19.17	22.58	14.73	14.75	28.40	20.14
N stock (kg/ha)	1944.2	2897.0	6017.3	3842.0	3700.5	4746.1	3695.0
N balance as % of total N stock	1.83	1.83	1.16	2.58	2.22	1.54	1.91
NDMV (US$)/farm[1]	66.17	139.06	106.50	190.41	145.16	75.65	124.80
ENDR[2] (%)	12.0	23.0	6.0	13.0	11.0	6.0	11.0
Phosphorus							
Nutrient balances (kg/ha/year)	-6.29	-4.97	-8.01	-7.33	-9.29	-18.55	-9.98
% of plots with positive balances	25.19	26.11	33.45	26.94	19.32	32.16	26.41
P stock (kg/ha)	1160.2	1412.1	3127.8	1655.2	1828.7	2759.8	1916.5
N balance as % of total P stock	0.54	0.35	0.26	0.44	0.51	0.67	0.52
NDMV (US$)/farm[1]	13.21	14.69	13.75	15.88	18.53	21.62	19.91
ENDR[2] (%)	2.00	2.00	1.00	1.00	1.00	2.00	2.00
Potassium							
Nutrient balances (kg/ha/year)	-31.97	-34.17	-81.25	-172.95	-78.75	-143.70	-94.85
% of plots with positive balances	23.11	30.53	14.42	15.50	14.10	30.70	22.99
K stock (kg/ha)	4207.5	3407.2	11992.6	10888.4	6560.1	18579.9	9618.9
K balance as % of total N stock	0.76	1.00	0.68	1.59	1.20	0.77	0.99
NDMV (US$)/farm[1]	30.71	46.17	63.79	171.30	71.79	76.56	86.54
ENDR[2] (%)	5.56	7.67	3.75	11.29	5.26	6.32	7.78
All Nutrients (N,P,K)							
Nutrient balance (kg/ha)	-73.82	-99.48	-159.27	-279.50	-178.10	-235.53	-178.80
Nutrient balance as % of stock	1.01	1.29	0.75	1.71	1.47	0.90	1.17
% of plots with positive balances	19.14	17.99	20.00	13.18	11.23	26.58	18.05
ENDR[2] (%)	19.94	33.21	10.82	24.90	17.25	14.34	20.80

1. 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).
2. Economic Nutrient Depletion Ratio (ENDR) is share (%) of farmers' income derived from mining soil nutrients (Ibid).

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[14] A total nutrient stock is a sum of the inert nutrients that are not readily available and the soluble stock, which is readily available to plants in the short term. The inert stock establishes a stable equilibrium with the soluble solution, whereby inert stocks dissolve and become available to plants over a long period of time, depending on the parent material, weather condition and soil physical, biological and chemical characteristics.

Even though the depletion rates are 1.2 percent for all nutrients combined, this does not mean that the nutrient stocks would be depleted in less than 100 years. Firstly, the inert stocks are not readily available in a short term; hence their depletion rates are much slower. The amount depleted comes mainly from the soluble component of the nutrient stock. Secondly, as crops deplete nutrients, their yields decline exponentially, decreasing the rate of depletion since crop harvest is the leading channel of nutrient outflow. Evidence of declining yields and soil fertility in Uganda since the early 1990's (Deininger and Okidi 2001; Pender, et al. 2001) supports the hypothesis that soil fertility declines are causing yield declines. Thirdly, the regeneration of soils from parent material is not included as a nutrient inflow. Finally, we are not including nutrient stocks below the top 20 cm. of soil, which can be available to deeper rooting crops and trees, or as a result of fallowing or deep tillage.

One measure of the economic magnitude of the loss of soil nutrients is the economic nutrient depletion ratio (ENDR), which measures the share of farm income that would be required to replenish the lost nutrients using the cheapest available fertilizers (van der Pol 1993). If farmers were to buy the cheapest source of nutrients to replenish the nutrients depleted, the average cost of fertilizer bought would be equivalent to one fifth of the total household farm income in the eight districts studied.[15] Due to the low farm income in the northern moist farmland, farmers in this AEZ would have to use more than a third of their farm income to replenish mined nutrients, as compared to only about 11 percent for the case of the Mt. Elgon farmers who have greater income and practice better soil fertility management practices. The nutrient requiring the largest cost to

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[15] Household farm income includes only income from the farm enterprise, and excludes non-farm income, gifts, and other forms of transfers. The average household income in 2002/03 was Ush 3.04 million, which is about US$1788.

replenish is nitrogen, followed by potassium. These results show the heavy reliance of smallholder farmers on mining soil fertility. Using a fifth of farm income to avoid nutrient depletion would be very difficult for most farmers, who depend on agriculture as their primary source of income. This begs the question of what could be done to help farmers to practice sustainable land management practices, which are the focus of the next section.

ECONOMETRIC RESULTS

Determinants of land management practices

Household ownership of physical assets has mixed impacts on land management practices (Table 7). As expected, larger farms are more likely to fallow since they have enough land for crop production while resting part of their land. Larger farms are less likely to use short-term SWC measures such as trash lines, deep tillage, and zero tillage, and less likely to incorporate crop residues on a given plot.

Table 7--Determinants of land management practices (Probit models)

Variable	Slash & burn	fallow	Crop rotation	Crop residue	Short-term SWC
Natural capital					
Ln(Average slope (%))	0.074	0.000	0.060	0.181**	0.262***
Ln(Top soil depth (cm))	0.048	0.140	0.218**	0.133	-0.175
Nutrient stock (kg/ha)					
Ln(nitrogen)	0.005	0.140*	-0.033	-0.138	0.024
Ln(Phosphorus)	0.083	-0.076	0.039	-0.021	0.019
Ln(Potassium)	-0.082	-0.030	0.016	0.046	0.022
Investment on plot dummies (yes=1, no=0)					
Agroforestry	-0.087	0.182**	0.138*	0.137	0.052
SWC structures	0.077	0.104	0.055	0.444***	0.198
Perennial crop (cf annual crop)	-0.265***	-0.353***	-0.240**	-0.199*	-0.252**
Other NRM investment	0.186	0.108	0.268*	0.475***	0.062
Ln(plot area in acres)	0.120***	-0.015	-0.001	0.067	0.124**
Ln(farm area in acres)	-0.062	0.168***	0.059	-0.132*	-0.264***
Physical capital					
Ln(TLU)	0.010	-0.127***	-0.112*	-0.088	0.146*
Ln(value of equipment in 000' Ush)	0.023	-0.009	0.015	0.055*	-0.008
Human capital					
Proportion of female household members with …. (cf no formal education)					
Primary education	-0.038	-0.043	-0.097	0.169	-0.008
Secondary education	-0.265	-0.074	-0.211	0.034	0.133
Post secondary	-0.315	-0.413	0.118	0.162	-0.105
Proportion of male household members with …. (cf no formal education)					
Primary education	0.009	-0.065	-0.038	-0.027	-0.145
Secondary education	-0.372**	-0.159	0.204	0.054	-0.329
Post secondary	0.003	0.118	0.385**	0.213	-0.732**
Male household head	0.107	-0.122	0.147	0.282	0.137
Ln(household size)	-0.082	-0.058	0.009	-0.142	-0.007
Proportion of land owned by women	0.144	-0.054	0.281	0.380	0.134
Primary source of income (cf crop production)					
Nonfarm	-0.237**	0.248***	0.004	-0.119	-0.135
Livestock production	-0.183	-0.482	-0.231	0.075	-0.032
Access to market and services					
Ln(distance from plot to residence in km)	0.119	0.099	-0.289***	0.054	0.232***
PMI	0.000	-0.000	-0.000	0.001	0.002**
Ln(distance to all weather road in km)	0.129**	-0.060	-0.049	0.020	-0.007
Household has access to credit	0.011	-0.060	-0.249***	-0.172	-0.090
Ln(# of contact hours with extension worker/year)	0.074	-0.036	-0.007	0.081	0.124
Household participates in NAADS program	0.244	-0.119	-0.190	0.176	-0.291
Land tenure system (cf freehold and leasehold)					
Customary	0.329**	-0.146	-0.143	0.537***	-0.244
Mailo	-0.014	-0.320	-0.096	0.193	-0.506**

Table 7--Determinants of land management practices (Probit models) (Continued)

Village level factors					
Ln(population density per km^2)	0.006	-0.002	-0.016	0.015	0.024
Ln(village wage rate in Ush/day)	0.147	0.003	0.166*	0.151	0.123
Agroecological zones (cf Lake Victoria crescent)					
Northwest moist zone (West Nile)	-0.109	0.421*	-0.087	0.107	-0.085
Northern moist zone	-0.501**	0.807***	0.522***	0.254	-0.461
Mt Elgon zone	-0.570*	-0.023	0.404	1.286***	0.236
Southwestern grassland	-0.499**	0.042	-0.035	0.471*	-0.632**
Southwestern highlands	-0.554**	0.641***	1.080***	-0.104	-2.701***
Constant	-1.932	-1.617	-3.187***	-3.163**	-2.122
Number of observations	2834		2834	2568	2568
% of plots affected by practice	20.20	21.00	22.53	10.43	13.31

These results are consistent with Boserup’s (1965) theory of agricultural intensification and the findings of Tiffen, et al. (1994), concerning the impacts of population pressure on intensity of land use and propensity to invest in SWC measures, but are contrary to a long-term study in Kabale district, which found that fallowing increased with population pressure (Lindblade, et al. 1996). Controlling for farm size and other factors, population density has no impact on fallowing or other land management practices, however.

Greater ownership of livestock is associated with less likelihood of using crop rotation and fallowing. This is perhaps because crop rotation and fallowing are less necessary for soil fertility management if farmers own more livestock, because of the soil fertility benefits of manure. Households who own more farm equipment are more likely to incorporate crop residues, probably because mechanical equipment such as plows makes this practice easier to accomplish.

The human capital of the household has mixed impacts on land management practices. Secondary education of males is associated with lower probability of using slash and burn for clearing land, possibly because secondary education increases households’ awareness of negative impacts of slash and burn or reduces their need to clear new land for cultivation. Post-secondary education of males is associated with greater likelihood of practicing crop rotation but lower likelihood of using SWC practices. These results may be due to higher opportunity costs of labor in more educated households, reducing adoption of labor-intensive SWC practices, while possibly encouraging crop rotation as a less labor intensive means of addressing concerns about soil fertility, pests and weeds. Other aspects of human capital, including the gender of the household head and the size of the household, have statistically insignificant impacts on land management practices.

The livelihood strategy of the household, measured by the primary source of income of the household head, has limited impact on most land management practices. Non-farm activity as a primary source of income increases the probability to fallow relative to households for whom crop production is the primary activity. This suggests that non-farm activities enable and encourage less intensive crop production, by providing households with alternative sources of income and increasing the opportunity cost of family labor. Having non-farm activity as a primary source of income reduces the probability to use slash and burn, possibly because such households have less need to clear new land for production. We find no statistically significant differences in land management practices between households whose primary income source is livestock vs. crop production.

Natural capital has significant impacts on several land management practices. Farmers are more likely to incorporate crop residues and practice short-term SWC technologies on steeper slopes. This is probably because the need for and benefits of SWC practices are greater on steeper slopes. Crop rotation is more likely to be used on deeper soils. This suggests that farmers take advantage of deeper and more fertile soils to practice better management to maximize returns since the response to better land management practices on more fertile soils may be higher (Kaizzi 2002). Surprisingly, fallowing is more likely to be practiced on plots with higher soil stocks of nitrogen (N), though this result is only weakly statistically significant (10 percent level). This may reflect reverse causality (fallowing causes higher soil N stocks). We find insignificant impacts of soil nutrient stocks on other land management practices.

Prior investments on the plot also influence land management practices. The presence of SWC structures such as stone bunds, terraces, grass or vegetative strips, and irrigation structures increase the probability that the farmer applies crop residues to the plot, probably because such structures reduce losses and/or increase the return to applying such inputs by conserving soil moisture (Pender and Kerr 1998). Fallowing and crop rotation are more common on plots where agroforestry (non-crop) trees have been planted, perhaps because of adoption of agroforestry trees in an improved fallow rotation system. Other land investments (fish ponds, fences, paddocks and pasture improvement) also increase the probability to incorporate crop residues and practice crop rotation. Some of these investments which are associated with livestock management (fences, paddocks and pasture improvement), the availability of which can facilitate incorporation of crop residues using ox-plowing. These results are consistent with results of Nkonya, et al., (2004b), who also observed that prior land investments influence current land management practices.

All of the land management practices considered (slash and burn, fallowing, crop rotation, incorporation of crop residues, and SWC practices) are less likely on plots where perennials dominate than where annual crops dominate. Clearly, these are practices associated with production of annual crops.

Access to markets, as measured by the potential market integration (PMI), and access to all-weather roads have limited impact on most land management practices. However, better access to markets is associated with higher probability to adopt SWC practices, while slash and burn practices are more likely farther from an all-weather road. These results are consistent with the findings of Tiffen, et al. (1994) that better market access can promote more sustainable land management practices by increasing the return to labor and other inputs invested in the effort. Nevertheless, the impacts of market and road access on land management practices in Uganda are generally mixed (Nkonya, et al. 2004b; Pender, et al. 2004).

Access to agricultural technical assistance services (measured by the number of contact hours of the household with agricultural extension agents and participation of household in the NAADS program) has statistically insignificant impacts on the land management practices considered. These programs are apparently focusing more on other technologies such as use of inorganic fertilizer. Consistent with this, we find in results discussed in the next section that use of inorganic fertilizer is more likely where access to these technical assistance programs is greater.

Access to rural finance organizations has statistically insignificant impacts on most land management practices, except a negative impact on crop rotation. The negative association of credit with crop rotation may be because credit is used to facilitate non-farm activities, rather than efforts to increase soil fertility and crop production. Consistent with this, we find that participants in rural finance organizations use less fertilizer and obtain lower crop productivity, but higher per capita income (findings discussed below). These findings suggest that credit constraints are not a major impediment to adoption of improved land management practices, and that access to credit may promote less intensive land management practices by facilitating more remunerative non-farm activities. This result is similar to findings of Nkonya, et al. (2004b) and Pender, et al. (2004).

There are significant differences in some land management practices across different land tenure types. Slash and burn and incorporation of crop residues are more common on plots under customary tenure than freehold plots, while use of SWC practices is less common on *mailo* than freehold plots. Customary tenure is associated with cereal production (Nkonya, et al. 2004; Pender, et al. 2004), which is probably the reason for its association with slash and burn and incorporation of crop residues. *Mailo* tenure is associated with perennial crop production, which, as already noted, is associated with less use of short-term SWC practices.

Other factors that significantly influence land management practices include the size of the plot, distance of the plot from the household residence, and the agro-ecological zone/farming system. We will not emphasize the impacts of such factors in this report, as they are static factors and not directly related to the issues of poverty and access to markets and services, which are the main focus of this report.

USE OF INPUTS

Use of farm inputs, including labor, fertilizer, and purchased seeds, is influenced by many of the same factors as land management practices. Larger farms are less likely to use purchased seeds and use less labor per acre (Table 8 and 9). These results are consistent with the Boserup theory of intensification and the findings of Nkonya, et al. (2004b) and Pender, et al. (2004), and with the finding reported below that larger farms obtain lower value of crop production per acre.

Table 8--Determinants of input use (purchased seed, inorganic fertilizer and organic residues applied) (Probit models)

Variable	Purchased seed	Inorganic fertilizer	Organic residues
Natural capital			
Ln(Average slope (%))	-0.027	-0.121	0.025
Ln(Top soil depth (cm))	-0.062	0.209	-0.218**-
Nutrient stock (kg/ha)			
Ln(nitrogen)	-0.074	-0.041	0.048
Ln(Phosphorus)	-0.020	0.195	0.078
Ln(Potassium)	-0.058	-0.069	0.106*+
Investment on plots dummies (yes=1, no = 0)			
Practice agroforestry	-0.039	-0.094	-0.109
Have SWC structure?	0.102	0.228	-0.060
Perennial as dominant crop on plot? (cf annual crop)	0.008	-0.070	0.354***+++
Have other NRM investment?	-0.285*-	-0.075	-0.301
Ln(plot area in acres as measured by GPS)	0.093**++	-0.057	0.031
Log(farm area in acres)	-0.185***---	0.178	-0.013
Physical capital			
ln(Tropical livestock unit)	-0.011	0.039	0.060
Ln(value of equipment in Ush '000)	-0.024	-0.053	0.044*+
Human capital			
Share of female household members with …. (cf no formal education)			
Primary education	-0.066	-0.151	0.099
Secondary education	-0.362**--	-0.468	0.345*++
Post-secondary education	-0.038	-0.940	-1.094*-
Share of male household members with …. (cf no formal education)			
Primary education	0.169*+	1.154***+++	-0.147
Secondary education	0.035	1.128***+++	-0.222
Post-secondary education	0.250	1.576***+++	-0.155
Sex of household head. Male = 1, No = female	-0.034	-0.430--	0.283*
Ln(Household size)	0.023	0.264	0.164
Share of farm owned by women	-0.227	-0.595-	0.278
Primary source of income of household head (cf crop production)			
Non-farm	-0.087	0.055	-0.160
Livestock	0.107	-	-0.391
Access to markets and services			
Ln(Distance from plot to residence in km)	-0.168**--	-0.067	-0.277**--
Potential market integration (PMI)	-0.000	0.004	0.001
Ln(Distance from plot to all-weather road+1)	0.100*+	0.187	-0.097
Ln(Number of extension visits+1)	0.020	0.321**	0.062
Household participate in NAADS activities? Yes=1, no=0	0.127	0.608*	-0.025
Household has access to credit? Yes=1 no =0	-0.157*	-0.875***	0.059

Table 8--Determinants of input use (purchased seed, inorganic fertilizer and organic residues applied) (Probit models) (Continued)

Land tenure of plot (cf freehold and leasehold)			
Customary	0.067	-0.751*-	0.028
Mailo	0.005	Dropped	0.557**++
Village level factors			
Ln(population density per km^2)	0.003	-0.092	-0.034
Ln(village wage rate per day in Ush)	0.034	0.228++	-0.098
Agroecological zone (cf (Lake Victoria crescent)			
Northwest moist zone	-0.557***--	3.083***+++	-0.065
Northern moist zone	-1.032***---	0.691+	-1.162***---
Mt Elgon zone	-0.664**--	3.518***+++	0.946***+++
Southwestern grassland	-0.329*--	-	0.401*+
Southwestern highlands	-0.041	0.488	-0.354
Constant	1.581	-7.973**---	-2.362
Number of observations	3060	2604	3060
% of plots affected by practice	42.77	1.10	11.00

Legend: * p<.1; ** p<.05; *** p<.01

+/-, ++/--, +++/--- means the associated coefficient is significant at p<.1; p<.05; and p<.01 in the reduced model equation that excluded potentially endogenous variables

Table 9--Determinants of intensity of pre-harvest labor

Variable	Ln(pre-harvest labor)	
Natural capital	OLS	IV
Ln(average slope %)	0.003	0.011
Ln(topsoil depth (cm))	-0.036	0.013
Ln(nitrogen stock kg/ha)	0.140*++	0.143*
Ln(P stock kg/ha)	0.030	-0.000
Ln(K stock kg/ha)	0.001	0.001
Land investment on plot dummies (yes=1 no=0)		
Practice agroforestry?	-0.055	-0.034
Have SWC structure?	0.060	0.078
Perennial crop as dominant crop grown on plot? (cf annual crop)	-0.034	-0.052
Have other NRM investment?	-0.039	0.008
Log(farm area in acres)	-0.260***---	-0.251***
Physical capital		
ln(Tropical livestock unit)	0.000	0.034
Ln(value of equipment in Ush '000)	0.005***	0.008
Human capital		
Share of female household members with …… (cf no formal education)		
Primary education	0.230***+++	0.229**
Secondary education	-0.022	-0.008
P-secondary education	-0.511**--	-0.454*
Share of male household members with …… (cf no formal education)		
Primary education	0.121	0.111
Secondary education	-0.020	-0.003
Post-secondary education	-0.045	-0.025
Sex of household head. Male = 1, No = female	-0.035	-0.061
Ln(Household size)	0.100	0.094
Share of farm owned by women	0.010	0.001
Primary source of income of household head (cf crop production)		
Non-farm	-0.156*-	-0.164*
Livestock	-0.109	0.022
Access to markets and services		
Ln(Distance from plot to residence in km)	0.016	0.019
Potential market integration	0.000	0.000
Ln(Distance from plot to all-weather road+1)	-0.024	0.012
Ln(Number of extension visits+1)	0.084	-0.141
Household has access to credit? (yes=1 no=0)	-0.178*	-0.216
Does household participate in NAADS activities? Yes=1, no=0	0.019	0.613
Land tenure of plot (cf freehold and leasehold)		
Customary	0.315***++	0.266**
Mailo land	0.291*+	0.335*
Village level factors		
Ln(population density per km^2)	-0.078*-	-0.075**
Ln(village wage rate per day in Ush)	0.005	0.002
Agroecological zone (cf Lake Victoria crescent)		
Northwest moist zone	-0.144	-0.138
Northern moist zone	-0.077	-0.085
Mt Elgon zone	0.104	0.084
Southwestern grassland	0.390**+	0.336*
Southwestern highlands	0.404**+	0.310
Constant	4.052***+++	4.138***

Table 9--Determinants of intensity of pre-harvest labor (Continued)

Number of observations		2807	2807
Wu-Hausman test of exogeneity of participation variables (P>χ^2)			1.000
Relevance tests of excluded variables (P>χ^2); Participation in:	Extension		0.000
	NAADS		0.000
	Credit		0.387
Hansen J test overidentification restrictions (P>χ^2)			0.067

Legend: * p<.1; ** p<.05; *** p<.01
+/-, ++/--, +++/--- means the associated coefficient is significant at p<.1; p<.05; and p<.01 in the reduced model equation that excluded potentially endogenous variables.

Ownership of physical capital significantly and positively influences use of several inputs. Greater ownership of livestock is associated with greater use of labor per acre in crop production, perhaps because of greater ability of wealthier households to hire labor. Ownership of farm equipment is associated with greater use of labor per acre and greater likelihood of using organic matter. Farm equipment is apparently complementary to labor use, and likely helps in transporting and using organic inputs.

Human capital has mixed impacts on use of inputs. Primary education of both males and females is associated with greater labor intensity. Perhaps households having more members with primary education have more young members who contribute to labor intensity in crop production. Female secondary education is associated with less likelihood of using purchased seeds but greater likelihood of using organic inputs, while female post-secondary education is associated with lower likelihood of using organic inputs. The negative impact of post-secondary education on organic inputs use is as expected, and likely due to the higher labor opportunity cost of more educated women. We are not sure why secondary education has mixed impacts on organic inputs and purchased seeds. Male education at all levels is strongly associated with higher probability of using inorganic fertilizer. This may be because more educated farmers are more aware of the benefits of using inorganic fertilizer, or because they are better able to afford to purchase fertilizer.

Male headed households are less likely to use inorganic fertilizer but more likely to use organic inputs than female headed households. These results may reflect labor constraints facing female headed households, limiting their ability to apply organic materials, and causing them to rely more on inorganic fertilizer instead. However, we find no statistically significant difference between male and female headed households in terms of labor intensity. Larger households use more labor per acre than smaller ones (weakly significant), probably due to their greater supply.

Household livelihood strategies have limited impacts on input use in crop production. Households with non-farm activities as the primary income source use labor less intensively in crop production, consistent with the findings reported earlier that they are more likely to fallow. We find no differences in other input use associated with livelihood strategies.

Natural capital also influences input use in crop production. Labor is used more intensively on steeper slopes, probably because more effort is required to farm on slopes. Less labor is used and use of organic fertilizer is less likely on deeper soils, probably because organic inputs and the associated labor are less needed and thus yield lower return on deeper soils. However, labor is used more intensively on plots that have more soil nutrients, suggesting that the return to investing labor in land management practices and crop production is greater on more fertile soils, consistent with the findings of Kaizzi (2002) in eastern Uganda. Use of organic inputs is also more likely (weakly significant) on soils that have greater stocks of K; the reason for this is not clear.

The presence of land investments also influences input use, but in mixed ways. The presence of SWC structures is associated with greater labor intensity (weakly significant), while agroforestry trees are associated with less labor intensity. SWC structures may require labor to maintain, and may also increase the return to labor in crop production by increasing soil moisture and responsiveness to inputs. The presence of non-crop trees likely reduces labor requirements, by reducing the share of the plot requiring labor inputs for crop production. The presence of other land investments such as fish ponds, fences, paddocks, and improved pasture reduce the likelihood of using purchased seeds, probably because these investments promote livestock or aquaculture rather than crop production on the plot.

Investment in perennials also influences input use. Labor is used less intensively on perennials than on annual plots, although use of organic inputs is more likely on perennial plots. These findings are consistent with findings of Nkonya, et al. (2004b).

Use of purchased seeds and organic inputs is less likely on plots more distant from the residence, probably because of the costs of transporting such bulky inputs (especially organic inputs). This result is similar to findings of Nkonya, et al. (2004b). By contrast, the amount of labor used per acre is greater on more distant plots. This is probably because the time involved in walking to such plots is included in the labor inputs for managing them.

Access to markets and roads has a positive impact on labor intensity, likely because this increases the return to labor invested in crop production. Surprisingly, however, use of purchased seeds is more likely (weakly significant) further from an all-weather road.

Participation in traditional agricultural extension is associated with greater labor intensity, while both traditional extension and the new NAADS program are associated with greater likelihood of using inorganic fertilizer. Surprisingly, however, participation in rural finance organizations has a negative association with labor intensity in crop production and use of inorganic fertilizer. This finding suggests that farmers use credit to engage in non-farm activities, which are likely to have higher returns than agricultural production, and that access to credit is not a binding constraint to labor or inorganic fertilizer use. Consistent with this explanation, we find that inorganic fertilizer use is not very profitable for farmers in our study districts (results discussed in next section).

Land tenure has statistically insignificant impacts on labor intensity. However, inorganic fertilizer is less likely to be applied on plots under customary tenure than freehold plots, while organic inputs are more likely to be applied to plots under *mailo* tenure. The positive association of freehold tenure with inorganic fertilizer use is consistent with the hypothesis that land titles facilitate purchased input use by increasing access to credit (Feder, et al. 1988; Place and Hazell 1993; Besley 1995), although the importance of this impact is questionable given other evidence already discussed that rural finance appears not to be a binding constraint to inorganic fertilizer use. The association of *mailo* tenure with organic inputs may be due to the association of *mailo* tenure with banana production, for which use of mulch and other organic inputs is relatively common. This finding is consistent with findings of Nkonya, et al. (2004b) and Pender, et al. (2004).

Surprisingly, labor intensity is lower in more densely populated communities and higher where wage rates are higher. The positive association with wage rates may be due to reverse causality; i.e., higher labor demand for crop production may lead to higher local wage rates. The negative association of labor intensity with population density is hard to explain, but this is not the total effect of population density on labor intensity, since population pressure likely affects other household variables that influence labor use, such as farm and household size. The total effect of population density is thus not clear. Use of fertilizer is more likely where wages are higher (significant in the reduced form model only), possibly because higher wages enable households to purchase fertilizer.

There are also significant differences in input use across the agro-ecological zones, as expected.

CROP PRODUCTIVITY AND INCOME PER CAPITA

Several inputs and land management practices have a positive impact on crop productivity in the structural OLS model, including pre-harvest labor, purchased seeds, inorganic and organic fertilizers, and incorporation of crop residues (Table 10).

Table 10--Factors affecting value of crops produced per acre

Variable	Ln(value of crops/acre)		
	OLS full	OLS Reduced	IV[1]
Natural capital			
Ln(value of seed purchased in Ush+1)	0.013**		0.071
Ln(value of inorganic fertilizer purchased in Ush+1)	0.040***		0.030
Ln(value of organic fertilizer applied in Ush+1)	0.023*		0.113
Ln(pre-harvest labor used on plot+1)	0.084***		0.344
Were the crop residues incorporated into plot? Yes=1 no=0	0.215***		1.440*
Ln(average slope %)	-0.084**	-0.078	-0.045
Ln(topsoil depth (cm))	0.236***++	0.261	0.205*
Ln(nitrogen stock kg/ha)	0.252***+++	0.281***	0.212**
Ln(P stock kg/ha)	-0.026	-0.022	-0.013
Ln(K stock kg/ha)	-0.025	-0.006	0.028
Land investments on plot dummies (yes=1 no=0)			
Practice agroforestry	0.241***+	0.211**	0.258**
Have SWC structure?	0.385***+++	0.347***	0.311**
Perennial as dominant crop grown on plot? (cf annual crop) Yes=1, no=0	0.201***++	0.169**	0.168*
Have other NRM investment?	-0.076	-0.031	-0.078
Ln(plot area in acres as measured by GPS)	-0.076**---	-0.142***	0.131
Log(farm area in acres)	-0.563***---	-0.562***	-0.530***

Table 10--Factors affecting value of crops produced per acre (Continued)

Physical capital			
ln(Tropical livestock unit)	0.106***+	0.145*	0.171**
Ln(value of equipment in Ush ‘000)	-0.027**	-0.035	-0.042
Human capital			
Share of female household members with …. (cf no formal education)			
Primary education	0.037	0.053	-0.007
Secondary education	-0.165	-0.129	-0.038
Post-secondary education	0.860***++	0.754**	1.207***
Share of male household members with …. (cf no formal education)			
Primary education	0.068	0.064	-0.077
Secondary education	0.729***+++	0.771***	0.672***
Post-secondary education	0.210	0.243	0.057
Sex of household head. Male = 1, No = female	0.374***+	0.447*	0.317
Ln(Household size)	0.564***+++	0.585***	0.470***
Share of farm owned by women	0.179	0.162	0.203
Primary source of income of household head (cf crop production)			
Non-farm	0.110**	0.071	0.190
Livestock	-0.828***---	-1.013***	-1.043***
Access to markets and services			
Ln(Distance from plot to residence in km)		-0.009	
Potential market integration		0.001	
Ln(Distance from plot to all-weather road+1)		0.002	
Ln(Number of extension visits+1)	0.130***+	0.145*	0.040
Does the household participate in NAADS activities? Yes=1, no=0	0.149***		0.135
Household has access to credit? (yes=1 no=0)	0.292***+	0.306**	0.380***
Land tenure system (cf freehold & leasehold)			
Customary		0.196	
Mailo land		0.151	
Village level factors			
Agroecological zone (cf Lake Victoria crescent)			
Northwest moist zone	-0.629***--	-0.803**	-0.410
Northern moist zone	-0.576***--	-0.856***	-0.228
Mt Elgon zone	0.462**	0.411	0.276
Southwestern grassland	1.095***++++	1.054***	1.216***
Agroecological zone x distance to all-weather road interaction^2			
Southwestern grasslands x ln(distance to all-weather road in km+1)	-0.433***-	-0.449*	-0.363
Southwestern highlands x ln(distance to all-weather road in km +1)	0.425***++	0.541**	0.592***
Constant	1.536***	2.131	-0.333

Table 10--Factors affecting value of crops produced per acre (Continued)

Number of observations	2808	2808	2467
Wu-Hausman test of exogeneity of land management practices and participation variables ($P>\chi^2$)			0.928
Relevance tests of excluded variables ($P>\chi^2$)		Value of seed	0.000
		Value of inorganic fertilizer	0.0080
		Value of organic fertilizer	0.000
		Labor	0.000
		Crop residue	0.000
Hansen J test overidentification restrictions ($P>\chi^2$)			0.805

[1] The identification of the land management and input use variables was a problem when we included the participation variables (participation in NAADS program and traditional extension services and access to credit) as endogenous variables. We tested the exogeneity of the participation variables by running a model that excluded the land management and input use variables – thus assuming the participation variables were the only endogenous variables. The Wu-Hausman test of the model failed to reject the exogeneity of the participation variables at $p = 1.000$. The relevance test of the excluded variables also showed a $P> \chi^2 =0.000$ for NAADS, Extension and Credit endogenous variables. The corresponding Hansen J test of overidentification $P>\chi^2 = 0.552$. Hence to improve identification of the land management practices and input use variables, we treated the participation variables as exogenous variables in the IV model reported in this table.

[2] Interaction terms for other agroecological zones that are not reported jointly failed the Wald Test at $p=0.10$

Legend: * $p<.1$; ** $p<.05$; *** $p<.01$

+/-, ++/--, +++/--- means the associated coefficient is significant at $p<.1$; $p<.05$; and $p<.01$ in the reduced model equation that excluded potentially endogenous variables

None of these inputs or practices has a statistically significant impact on productivity in the IV regression at $p = 0.05$, although the magnitude of the estimated coefficients was larger in the IV model in most cases. This indicates that identification problems in the IV model are limiting the ability of that model to identify significant impacts of these endogenous variables, despite the fact that the relevance tests show that the instrumental variables are highly relevant. The Hausman test fails to reject statistical exogeneity of these inputs and practices, so the OLS model is the preferred model. Other inputs and land management practices had statistically insignificant impacts on crop production in both regressions.

The positive impact of labor intensity on crop production is consistent with the findings of Nkonya, et al. (2004b) and Pender, et al. (2004). The positive impact of seeds and inorganic fertilizer are also consistent with the findings of Pender, et al. (2004).

However, the positive impacts found for organic fertilizer and crop residues contrasts with the results of Pender, et al. (2004) and Nkonya, et al. (2004b), who found insignificant impacts of organic fertilizer on crop production, perhaps because of differences in the sample frames or the way organic fertilizer was measured in these different studies. The coefficient of production response to fertilizer in the OLS regression in Table 10 (0.040) is quite similar in magnitude to the magnitude of the coefficient of impact of inorganic fertilizer estimated by Pender, et al. (2004) (0.036 in their OLS model). Use of inorganic fertilizer appears not to be profitable where it is being used. Households using fertilizer realize an average value of production of Ush 814,000/acre and apply fertilizer at an average cost of Ush 43,457/acre. With an estimated elasticity of production response to fertilizer of 0.027, a one percent increase in mean fertilizer use, worth Ush 434/acre, would increase the predicted value of production by only Ush 326/acre (Ush 814,000 x 0.01 x 0.040), which translates to a marginal value/cost ratio (VCR) of fertilizer use of only 0.75 (326/434). A minimum VCR of at least one is needed for additional fertilizer use to be profitable, and it is estimated that a marginal value/cost ratio of at least 2 is needed for significant adoption of fertilizer (CIMMYT, 1988). Thus, even if the true elasticity of crop production response to fertilizer were two to three times our estimate, fertilizer would only be marginally profitable for our sample households, and substantial increases in fertilizer use would be unlikely without substantial reduction in the price of fertilizer and/or increases in crop prices. The low profitability of inorganic fertilizer explains its low adoption in Uganda, and suggests that major improvements in the market environment facing Ugandan farmers are a prerequisite for substantial adoption to occur. Similar findings were reported by Pender, et al., (2004) and Woelcke (2002).

In addition to the fact that Uganda is a landlocked country, there are many other factors that contribute to the high cost of fertilizer in the country relative to its neighbors. For example, Omamo (2002) observed that Uganda fertilizer procurement and distribution is dominated by retail-level trade and high prices that discourage farmers to use fertilizer and low net margins that discourage traders to market fertilizer (Omamo 2002). Faced with low smallholder demand for fertilizer, traders in Uganda appear to be unwilling to invest in measures that might reduce fertilizer farm-gate prices. In early 2005, the retail price of a ton of Diammonium Phosphate (DAP) in Kampala was US$508 (APEP 2005), while the same quantity costs US$265 in Nairobi and US$240 in Dar es Salaam (The Sunday News 2005). Transportation contributes a large share of the high fertilizer price in Kampala. For example, transporting one ton of fertilizer from Mombasa port to Kampala costs US$100 (Sanchez 2004). This does not include a number of transit taxes, warehouse costs, etc. All these factors contribute to the low profitability of fertilizer in Uganda that we observe in this study.

Controlling for use of inputs and land management practices, land quality, and other factors, larger farms have lower per acre value of crop produced, supporting the inverse farm size – land productivity relationship observed in many empirical studies in developing countries (e.g. Chayanov 1966; Heltberg 1998; Carter 1984, Sen 1975; Berry and Cline 1979; Barrett 1996; Bhalla 1998; Lamb 2003; Nkonya, et al. 2004; Pender, et al. 2004). We find this inverse relationship even when controlling for use of labor, other inputs and land management practices, plot size and observable land quality indicators, implying not only that smaller farmers tend to farm more intensively, as we have already seen, but are more productive in the use of their inputs.[16] These results suggest that market imperfections (such as limitations in the markets for some factors of production or in insurance and output markets) limit the productivity of larger farms (Carter 1984, Feder, 1985; Barrett 1996; Heltberg 1998), but unobserved differences in land quality operated by larger vs. smaller farms may also account for part of this (Bhalla 1988; Lamb 2003). For example, soils in northern Uganda where farms are larger tend to be of sandier texture, and we have not controlled for this aspect of land quality, although we have controlled for agro-ecological farming system zones and soil depth and nutrient stock, which are significantly correlated with soil texture (Ssali 2002). Despite having lower land productivity, larger farms have higher per capita household income (Table 11), suggesting that they have higher labor productivity (Pender 1998). Thus wealthier households have higher incomes, as expected.

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[16] Nkonya, et al. (2004b) noted a similar finding from their analysis of data from a different sample in Uganda.

Table 11--Factors affecting per capita household income

Variable	Ln(per capita income) OLS	 IV
Natural capital		
Ln(average slope %)	-0.004	-0.003
Ln(topsoil depth (cm))	0.005	0.005
Ln(nitrogen stock kg/ha)	0.060	0.074
Ln(P stock kg/ha)	0.265***+++	0.250***
Ln(K stock kg/ha)	-0.083	-0.101
Land investment on plot dummies (yes=1 no=0)		
Practice agroforestry?	0.180	0.172
Have SWC structure?	0.474***+++	0.508***
Perennial as dominant crop on plot? (cf annual crop) Yes=1, no=0	0.421***+++	0.408***
Have other NRM investment?	0.953**++	1.102**
Log(farm area in acres)	0.388***+++	0.418***
Physical capital		
ln(Tropical livestock unit)	0.222***+++	0.209***
Ln(value of equipment in Ush ‘000)	0.025	0.030
Human capital		
Share of female household members with ….(cf no formal education)		
Primary education	0.052	0.096
Secondary education	-0.244	-0.210
Post-secondary education	0.378	0.198
Share of male household members with ….(cf no formal education)		
Primary education	0.168	0.099
Secondary education	0.404**++	0.342*
Post-secondary education	0.369+	0.164
Sex of household head. Male = 1, No = female	0.228+	0.218
Ln(Household size)	-0.206	-0.301**
Share of farm owned by women	0.100	0.206
Non-farm as primary source of income for household head? Yes=1, no=0	0.207*++	0.162
Livestock as primary source of income for household head? Yes=1, no=0	-0.516	-0.766**
Access to markets and services		
Ln(distance from plot to residence +1 in km)	0.155*++	-0.173**
Potential market integration	0.001	0.000
Ln(distance from plot to all-weather road in km +1)	-0.155**-	0.147
Household member belongs to savings & credit association	0.449***	0.874*
Does the household participate in NAADS activities? Yes=1, no=0	0.035	1.376**
Ln(Number of extension visits+1)	0.004	-0.048
Land tenure system		
Share of land under ….. tenure of (cf freehold and leasehold)		
Mailo	-0.053	-0.023
Customary	0.204	0.182
Village level factors		
Ln(population density per km^2)	0.013	0.023
Ln(village wage rate per day in Ush)	0.078	0.056
Northwest moist zone	-0.354	-0.538*
Northern moist zone	0.241	0.069
Mt Elgon zone	0.066	-0.124
Southwestern grassland	0.651***+++	0.410
Southwestern highlands	0.229	-0.004
Constant	2.685**++	3.215**

Table 11--Factors affecting per capita household income (Continued)

Wu-Hausman test of exogeneity of participation variables ($P>\chi^2$)			1.000
Number of observations		749	749
Relevance tests of excluded variables ($P>\chi^2$): Participation in …..	Extension		0.353
	NAADS		0.000
	Credit		0.000
Hansen J test overidentification restrictions ($P>\chi^2$)			0.235

Legend: * p<.1; ** p<.05; *** p<.01
+/-, ++/--, +++/--- means the associated coefficient is significant at p<.1; p<.05; and p<.01 in the reduced model equation that excluded potentially endogenous variables

Livestock assets increase crop productivity and per capita income, as expected. Consistent with Nkonya, et al. (2004b), livestock ownership increases crop productivity, perhaps due to the synergies between the two enterprises. Farmers with livestock have a supply of manure and in some areas use animal power for plowing and transportation. Livestock thus contribute to higher per capita income by contributing to crop income as well as to livestock income.

Ownership of farm equipment is surprisingly associated with lower crop productivity, controlling for land management practices and input use, but has a statistically insignificant effect in the IV model and in the reduced form model that excludes these variables. It is hard to see why ownership of farm equipment would reduce productivity. Perhaps ownership of farm equipment is negatively correlated with unobserved aspects of land quality, such as soil texture (e.g., use of plows may be more common in lighter textured sandy soils, which are less productive than clay soils), or is more associated with livestock than crop production. The main impacts of mechanization may be to enable farmers to farm on a larger area, rather than increasing their productivity on a given area. However, we find statistically insignificant impacts of farm equipment on household income per capita (Table 11). Thus, if farm equipment is enabling some farmers to farm on a larger area, this may mainly be offsetting the lower productivity per unit area that larger farmers attain.

Post secondary education of females and secondary education of males are associated with higher crop productivity as compared to those with no formal education. Thus, even though post-secondary education reduces labor intensity, as noted previously, it increases the productivity of labor and other inputs in production. The net impact on value of production per acre is positive, despite reduced labor intensity (as indicated by the positive impact of female post-secondary education in the reduced form model). Since male secondary education increases productivity of inputs, and was not found to reduce labor intensity or use of other inputs, it is not surprising that this also has a strong positive net impact on crop production (in the reduced form model). Male secondary education and post-secondary education also are associated with significantly higher income per capita (Table 11), as expected, and consistent with other studies of income determinants in Uganda (Nkonya, et al. 2004b; Appleton 2001b; Deininger and Okidi 2001) and numerous other developing countries.[17]

Male headed households and larger households obtain higher crop productivity, possibly because of labor and management constraints faced by female-headed households and households with a smaller family labor supply, in the context of imperfect markets for labor and management. However, family size decreases per capita household income (significant only in the IV model), suggesting that the agricultural intensification practiced by larger families and the resulting higher value of crop per acre does not compensate for the effect of dependency ratio, which tends to depress per capita

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[17] The impact of post-secondary education was significant only in the reduced form model excluding participation in extension and credit organizations, however.

income and which is generally higher in larger families, and/or that there are diminishing (though positive) returns to increased labor supply.[18]

Non-farm activity as the primary income source of the household head is positively associated with the value of crop production per acre and household income per capita: predicted crop productivity is 25 percent higher and per capita income is 23 percent higher for households dependent on non-farm activity rather than crop production as the primary income source. The positive impact of non-farm activity on the value of crop production is consistent with findings of Nkonya, et al. (2004b). The positive impact on crop productivity may be related to the fact that non-farm activities reduce the probability to practice slash and burn and increases the probability to fallow (Table 7), both of which may improve soil fertility and increase productivity over time. Non-farm activity also reduces labor-intensity in crop production, which may lead to higher marginal labor productivity in crop production if there are diminishing marginal returns to labor in crop production. Notice that the impact of non-farm activity is positive only in the structural model reported in Table 10 but not in the reduced form model, consistent with this interpretation (i.e., households pursing non-farm activities obtain higher crop productivity when controlling for labor input, but not when excluding labor input from the regression, because they use less labor per acre). The positive impact of non-farm activities on household income per capita is as expected, although Nkonya, et al. (2004b) did not find a statistically significant impact of non-farm activities on household income.

In contrast to the positive impacts of non-farm activities, households dependent upon livestock income as their primary source of income obtain substantially lower crop

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[18] The dependency ratio was excluded from our regression specification since it was highly positively correlated with family size.

productivity than primary crop producers. This result contrasts to the positive impact of livestock ownership on crop productivity. Ranchers and pastoralists that depend primarily on livestock income are probably not much focused on crop production, and tend to live in areas that are less suitable for crop production.[19] Thus, while crop-livestock producers tend to have higher crop productivity when they have more livestock assets, ranchers and pastoralists more focused on livestock production tend to have lower productivity, controlling for the amount of livestock owned and other factors. However, we do not find statistically significant differences between per capita incomes of households dependent on livestock vs. crop production. This result contrasts with findings of Nkonya, et al. (2004b), who found that households dependent on livestock income obtained higher incomes.

Not surprisingly, natural capital also influences crop productivity. Deeper soils and N stock in the topsoil have large positive impacts on crop productivity, as expected. A 1 percent increase in topsoil depth is associated with 0.24 percent higher productivity, while a 1 percent increase in N stock in the topsoil is associated with 0.25 percent higher productivity. However, neither topsoil depth nor the N stock have a significant impact on per capita income, although the soil P stock has a positive association with income (the reason for this is not clear).

Even though agroforestry trees and SWC structures have a potential of competing with crops for space, light, and moisture, we find that these investments significantly increase crop productivity. Predicted productivity is 24 percent higher on plots with agroforestry trees and 38 percent higher on plots with SWC structures. These

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[19] Although we controlled for many factors that influence suitability for crop production, omitted climatic and land quality factors may still be correlated with reliance on livestock as a primary source of income.

investments can help increase crop productivity by reducing soil erosion, fixing nitrogen if leguminous trees and shrubs are planted, improving moisture conservation and soil physical characteristics. SWC structures and other land investments are associated with significantly higher per capita incomes perhaps due to their positive impact on crop productivity. It is possible that reverse causality contributes to this positive relationship (i.e., people with more income are more able to invest), although we have controlled for many factors that determine the capacity to invest.

Investments in perennial crop production also increase productivity and income. The value of crop production per acre and income per capita is significantly higher on plots and for households where perennial crop production dominates than where annual crop production dominates (Table 10 & 11). Perennial crop production increases the predicted value of crop production per acre by about 17 percent compared to annual crop production. These results are consistent with findings of Nkonya, et al. (2004b).

Access to markets and roads has statistically insignificant impacts on crop productivity, consistent with results of Nkonya, et al. (2004b) and Pender, et al. (2004).[20] Nevertheless, proximity to roads is associated with significantly higher per capita income, probably because it promotes off-farm activities (Table 11). This result is contrary to that of Nkonya, et al., (2004b) who observed a puzzling negative association between access to an all-weather road and household income, but is more consistent with results of Pender, et al. (2004), who found that better road access is associated with higher incomes in the central region of Uganda (but insignificant association in other

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[20] These variables were included in a full version of the structural models reported in Table 10 and found to be jointly statistically insignificant in both models, as well as in the reduced form model. These and other variables were dropped in the reported models to improve efficiency of these models. Results of other models are available upon request.

regions), and Fan, et al. (2004), who found that road investment (especially in rural feeder roads) contributes to higher income growth and reduced poverty in Uganda. Thus the impacts of road access on income appear to be positive, though these impacts may be location-specific.

Agricultural technical assistance programs appear to have favorable impacts on agricultural productivity. Participation in the regular traditional agricultural extension program and in the NAADS program is associated with significantly higher value of crop production per acre. For example, based on the regression results in Table 10, the value of crop production per acre in 2002/2003 is predicted to be 15 percent higher for households that participated in the NAADS program than those who didn't, while a 10 percent increase in number of contact hours with traditional agricultural extension would lead to a predicted 1.3 percent increase in productivity (i.e., elasticity = 0.13). The positive association of NAADS with value of crop production per acre may have less to do with changing farming practices than with promoting production of higher value crops, since we found insignificant impacts of NAADS presence on most land management practices and input use (Tables 7 and 8). We do not find robust statistically significant impacts of NAADS or other extension programs on income per capita, however.[21] These results are consistent with the findings of Nkonya, et al. (2004) concerning the positive impacts of access to agricultural extension and training on the

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[21] We do find a large positive and statistically significant impact of NAADS participation on income per capita in the IV model (reported in Table 11), but this impact is not robust in the OLS model, which is the preferred model given the Hausman test results supporting that model. Given the weakness of the instrumental variables used in predicting participation in NAADS (p-value =0.353 in the relevance test for this variable), this could result in more biased results in the IV model than in the OLS model (Bound, et al. 1995).

value of crop production, and Fan, et al. (2004) concerning the positive agricultural productivity impacts of expenditures on agricultural research and extension in Uganda.[22]

It is possible that these positive associations are due in part to selection bias; i.e., these programs may be operating in areas where productivity was already higher prior to the NAADS program, or program participants may be those who were more productive even before the program. We have sought to address this concern by including numerous explanatory factors influencing productivity potential in the regressions, but it is still possible that some excluded factors that are associated with technical assistance program placement or participation are partly responsible for these positive associations.[23] To address the endogeneity of program participation and possible selection bias, we estimated the model using instrumental variables (IV) regressions. The impact of participation in regular extension or the NAADS program on crop productivity is not significant in the IV model, though similar in magnitude for both types of extension. This result may be due to difficulties of identifying such impacts in the IV models, rather than due to actual lack of impact. Since the Hausman test fails to reject the OLS model, which is the preferred model because it is more efficient (and less prone to bias caused by weak instruments (Bound, et al. 1995).

We also estimated the model using the presence of NAADS in a sub-county rather than household level participation as the explanatory variable, and found similar positive

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[22] However, Pender, et al. (2004) found mostly statistically insignificant impacts of agricultural extension on crop productivity and income. Shortcomings in that study, as discussed previously, may have limited its ability to discern such effects.

[23] Participants to regional seminars that were carried out to disseminate findings of this study also expressed concern of potential NAADS program bias. However, NAADS program site selection criteria were based on compliance with local government development program, which is not supposed to be influenced by income levels, and to reflect variety with respect to nature of local agricultural economy and agro-ecological zones.

impacts of the presence of NAADS on productivity.[24] This finding reduces our concern that household level selection bias is responsible for the positive association of productivity with NAADS participation. However, there still could be bias caused by the initial placement of NAADS in more productive sub-counties.

We investigated the possibility of bias in selection of NAADS sub-counties using data from the 1999/2000 UNHS and survey data from this study. Tables 12 and 13 show the differences in mean value of crop production per acre and per capita income in 1999/2000 between NAADS and non-NAADS sub-counties in the districts where our study was conducted.[25]

Table 12--Pre-NAADS value of crop production per acre in NAADS vs non-NAADS sub-counties of sample districts

District	First Year in NAADS	Mean Value of Crop Production per Acre, 1999/2000 ('000 USh./acre) (no. of observations)				Statistical significance (p level)
		Non-NAADS sub-counties		NAADS sub-counties		
		mean	Standard error	mean	Standard error	
Arua	2001/2002	246.2 (234)	18.1	253.5 (65)	20.7	0.8417
Kabale	2001/2002	**470.5 (137)**	**60.7**	**303.3 (n=146)**	**23.3**	**0.0105****
Soroti	2001/2002	124.8 (143)	26.4	126.4 (65)	12.9	0.9405
Iganga	2002/2003	272.8 (303)	11.3	318.0 (65)	47.4	0.1598
Lira	2002/2003	99.3 (229)	6.5	78.5 (61)	10.5	0.1420
Mbarara	2002/2003	298.4 (247)	12.9	342.2 (31)	50.5	0.2912
All six districts		246.7 (1293)	9.5	242.6 (433)	12.6	0.8059

** Difference in means is statistically significant at 5 percent level.
Source: Data from 1999/2000 UNHS

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[24] Results of these regressions using presence of NAADS in a sub-county, rather than household level participation were included in an earlier version of this paper, and are available upon request.

[25] NAADS had not yet begun to operate in the other two districts covered by this study (Masaka and Kapchorwa) in the year covered by the IFPRI-UBOS survey (2002/03).

Table 13--Pre-NAADS income per capita in NAADS vs. non-NAADS sub-counties of sample districts

District	First Year in NAADS	Mean Income per Capita, 1999/2000 ('000 USh.) (no. of observations)				Statistical significance (p level)
		Non-NAADS sub-counties		NAADS sub-counties		
		mean	Standard error	mean	Standard error	
Arua	2001/2002	238.5 (233)	12.5	213.5 (65)	23.3	0.3524
Kabale	2001/2002	258.0 (137)	14.5	264.8 (146)	17.4	0.7686
Soroti	2001/2002	205.8 (143)	39.6	226.5 (65)	26.6	0.7002
Iganga	2002/2003	232.9 (303)	16.2	254.8 (65)	20.9	0.4654
Lira	2002/2003	143.5 (229)	8.4	131.7 (61)	28.3	0.5972
Mbarara	2002/2003	328.8 (247)	17.7	320.7 (31)	32.6	0.8835
All six districts		236.1 (1292)	6.7	235.1 (433)	9.9	0.9436

Source: Data from 1999/2000 UNHS

Table 14--Determinants of soil erosion [ln(Soil erosion)]

Variable	OLS	IV
Natural capital		
Ln(average slope %)	0.760***+++	0.726***
Ln(topsoil depth (cm))	-0.080-	-0.099
Land investment on plot dummies (yes=1 no=0)		
Practice agroforestry?	-0.227**--	-0.177*
Have SWC structure?	0.070	0.098
Perennial as dominant crop on plot? (cf annual crop) yes=1 no=0	0.011	0.052
Have other NRM investment?	-0.359**	-0.372*
Ln(plot area in acres as measured by GPS)	-0.031	0.001
Log(farm area in acres)	-0.055-	-0.040
Physical capital		
ln(Tropical livestock unit)	-0.087	-0.211**
Ln(value of equipment in Ush '000)	0.012	-0.008
Human capital		
Share of female household members with ..... (cf no formal education)		
Primary education	0.195**	0.105
Secondary education	-0.184	-0.317
Post-secondary education	0.348*+	-0.006
Share of male household members with ..... (cf no formal education)		
Primary education	-0.045	-0.116
Secondary education	0.194	0.175
Post-secondary education	-0.038	-0.093
Sex of household head. Male = 1, No = female	0.052	0.370*
Ln(Household size)	0.295**+++	0.269*
Non-farm as primary source of income for household head? Yes=1, no=0	-0.007	-0.009
Livestock as primary source of income for household head? Yes=1, no=0	-0.697***	-1.445***
Access to markets and services		
Ln(Distance from plot to residence in km)	0.028	0.074
Potential market integration	0.000	0.000
Ln(Distance from plot to all-weather road+1)	0.041	0.058
Ln(Number of extension visits+1)	0.001	0.782***
Does the household participate in NAADS activities? Yes=1, no=0	0.166	-0.282
Household has access to credit? Yes=1 no=0	-0.016	0.043
Land tenure of plot (cf freehold and leasehold)		
Customary	0.161	0.276*
Mailo	0.394**+	0.239
Share of farm owned by women	0.137	0.521**
Village level factors		
Ln(population density per km^2)	-0.030--	-0.002
Ln(village wage rate per day in Ush)	-0.245***---	-0.276***
Agroecological zone (cf Lake Victoria crescent)		
Northwest moist zone	-0.956***---	-1.054***
Northern moist zone	-1.086***---	-1.279***
Mt Elgon zone	0.105	-0.022
Southwestern grassland	-0.692***---	-0.753***
Southwestern highlands	0.938***+++	1.036***
Constant	3.931***+++	3.848***

Table 14--Determinants of soil erosion [ln(Soil erosion)] (Continued)

Wu-Hausman test of exogeneity of participation variables ($P>\chi^2$)		0.763
Relevance of excluded variables ($P>\chi^2$) Participation in:	Extension	0.000
	NAADS	0.000
	Credit	0.000
Hansen J test of over identifying restrictions ($P>\chi^2$)		0.377

Legend: * p<.1; ** p<.05; *** p<.01
+/-, ++/--, +++/--- means the associated coefficient is significant at p<.1; p<.05; and p<.01 in the reduced model equation that excluded potentially endogenous variables

The results in these tables show that there was no bias towards selecting sub-counties where productivity or income was already higher. In only one district (Kabale) was there a statistically significant difference in pre-NAADS productivity between NAADS and non-NAADS sub-counties and in that case pre-NAADS productivity was higher in the non-NAADS sub-counties. In all other cases, average pre-NAADS productivity was quite similar in the NAADS vs. non-NAADS sub-counties, and for all six sub-counties, the average difference in pre-NAADS productivity was less than 2 percent (slightly lower in the NAADS sub-counties). In no district was there a statistically significant difference in pre-NAADS income per capita between NAADS and non-NAADS sub-counties, and the average differences are quantitatively small (less than 0.5 percent difference in all six districts).

These results strengthen our confidence that NAADS is indeed having significant positive impacts on crop productivity. It is still theoretically possible that some other factors besides the introduction of NAADS or the factors that we control for in our regressions have changed since 1999/2000 in NAADS and non-NAADS sub-counties, and are responsible for the higher current productivity in the NAADS sub-counties and among NAADS participants. But it is difficult to imagine what those factors are, given that we have controlled for so many factors affecting productivity, or why such factors would have affected NAADS vs. non-NAADS sub-counties differentially, in favor of NAADS sub-counties. These results therefore provide support to the emphasis in the PMA on increasing the availability of agricultural technical assistance in Uganda through expansion of NAADS. Nevertheless, more focused research on the impacts of NAADS to better understand whether and how the NAADS program is having these favorable impacts in the trail-blazing districts and whether such favorable impacts are being scaled-out in these and other districts, would be very useful.

Participation in rural finance organizations is associated with significantly higher crop productivity and per capita incomes (Table 10 & 11). These results are robust in the IV as well as OLS versions of the models, where the instrumental variables used to predict participation in rural finance organizations are strong predictors. These results indicate that selection bias or reverse causality are not the likely explanation for these findings. These results are consistent with findings of Pender, et al. (2004), who also found a positive impact of access to rural credit on the value of crop production, but not with those of Nkonya, et al. (2004b), who found insignificant impacts of credit access. It is not clear how such organizations contribute to crop productivity, since we found that they are associated with less intensive use of labor and less use of inorganic fertilizer. Perhaps the availability of rural finance is more important in helping farmers in marketing their crops and shifting to higher value crops, which can result in higher value of production even if the quantity of production is not affected. For example, households with access to credit may have no liquidity constraints that force many farmers to sell their produce immediately after harvest when agricultural prices are normally at their lowest levels. Rural finance also can help households to pursue off-farm activities, which may be part of the reason for its positive contribution to income.

Land tenure has statistically insignificant impacts on crop productivity and income per capita.[26]. Consistent with Nkonya, et al. (2004b) and Pender, et al. (2004), these results suggest that lack of land titles and other differences in land tenure are not major constraints to crop productivity and income in Uganda. Similar findings of limited impacts of land titles in areas of secure customary tenure have also been observed elsewhere in Africa (e.g., Place and Hazell 1993; Platteau 1996).

Not surprisingly, agroecological zones influence both crop productivity and income, as expected. Productivity is highest in the Mt. Elgon highlands and the southwest grasslands, and lowest in the northern zones. Income per capita is highest in the southwest grasslands. These results are fairly consistent with the findings of Nkonya, et al. (2004b) and Pender, et al. (2004) (although the classification of zones in this study is somewhat different).

The impact of interaction of all-weather roads x agroecological zones on value of crop production per acre is negative for the southwestern grassland. Holding the zone constant, the result suggest that all-weather roads in this zone lead to higher value of crop produced per acre as expected. However, holding distance to all-weather constant, the result implies that farmers in the zone realized higher value of crop production per acre (as results in Table 10 suggest). The results for the southwestern highlands x distance to

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[26] The coefficients of the land tenure variables were jointly statistically insignificant in a fuller version of the OLS and IV models for crop productivity presented in Table 10, and were dropped from the regressions. They were also jointly insignificant in the reduced form model. Results available upon request.

all-weather road interaction are contrary to those of the southwestern grasslands x distance to all-weather road.

SOIL EROSION

Predicted soil erosion is not significantly affected by the size of the farm or the household's physical assets (Table 14). Female primary and post-secondary education are associated with more erosion, though the reasons are not clear. In the case of primary education, this may be related to the association of primary education with labor intensive crop production. Larger households have significantly higher erosion, probably because of more labor intensive crop production by larger households.[27] This contradicts the optimistic "more-people, less-erosion" hypothesis (Tiffen, et al. 1994) at the household level, and is consistent with findings of Nkonya, et al. (2004b). Not surprisingly, soil erosion is greater on steeper slopes, and is reduced by investments in agroforestry or other land investments. Access to markets and roads has insignificant impacts on erosion, as does access to agricultural technical assistance and credit. These findings are consistent with the limited impacts of these factors on land management practices, discussed earlier. Erosion is lower for households dependent on livestock activities as their primary source of income than for households dependent upon crop income, probably because such households use the land less intensively, and with greater permanent soil cover on pastures than annually cropped fields. Erosion is greater on *mailo* tenure than freehold, though the reasons are not clear. This result contradicts a finding of Nkonya, et al. (2004b), who found that *mailo* tenure was associated with lower

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[27] Even though labor availability may theoretically positively influence adoption of labor intensive soil erosion control practices, Table 7 shows that greater family labor endowment is not associated with adoption of SWC and other organic land management practices. Furthermore, labor availability may lead to adoption of erosive practices such as frequent weeding and cultivation.

erosion. Erosion differs across agro-ecological zones, being the worst in the southwest highlands and least in the northern zones.

SOIL NUTRIENT BALANCES

The determinants of soil nutrient balances are shown in Table 15.

Table 15--Determinants of nutrient balances

	Nitrogen (N)		Phosphorus (P)	
Variable	OLS	IV	OLS	IV
Natural capital				
Ln(average slope %)	-21.657***---	-21.541***	-5.064***---	-6.430
Ln(topsoil depth (cm))	6.082	5.474	0.321	-2.560
Land investment on plot dummies. Yes=1 no=0				
Practice agroforestry?	9.758	8.732	2.416++	-0.714
Have SWC structure?	26.928**++	22.581*	5.069***+++	-5.059***
Perennial as dominant crop on plot? (cf annual)	-29.334***---	-29.739***	-2.712-	-2.848
Have other NRM investment?	3.461	6.932	-3.052	-0.262
Ln(plot area in acres)	4.169+	3.993	1.155*+	2.037
Log(farm area in acres)	-2.613	-2.762	-0.499	3.814*
Physical capital				
ln(Tropical livestock unit)	-12.191**---	-6.130	-0.455	-3.470
Ln(value of equipment in Ush '000)	-1.090	-0.179	0.291	1.047
Human capital				
Share of female household members with ….. (cf no formal education)				
Primary education	-17.569**-	-14.809	-2.455	-0.595
Secondary education	-15.613	-11.389	3.306	1.065
Post-secondary education	-2.957	15.927	-4.065	0.541
Primary education	10.930	14.545	1.557	-2.247
Secondary education	12.046	15.403	0.268	4.960
Post-secondary education	-35.376-	-26.943	-7.774*-	1.252
Sex of household head. Male = 1, No = female	-0.789	-8.034	-1.890	2.451
Ln(Household size)	8.671	9.697	2.844	1.842
Share of farm owned by women	-3.485	-14.508	-2.158	-4.365
Major source of income of household head (cf crop production)				
Non-farm	4.005	6.356	3.414	4.247*
Livestock	-12.006	15.386	11.646	17.334
Access to markets and services				
Ln(Distance from plot to residence in km+1)	4.738++	3.220	1.407+	-4.897
Potential market integration	0.029	0.014	-0.013	-2.940
Ln(Distance from plot to all-weather road+1)	-8.665	-8.296	-4.024***--	3.984
Ln(Number of extension visits+1)	0.817	-26.776	-1.426	0.730
Household participates in NAADS activities? Yes=1, no=0	8.626	12.064	3.030	-0.017
Household has access to credit	4.213	-6.177	1.826	-4.097***
Land tenure of plot (cf freehold and leasehold)				
Customary	13.559	10.475	0.374	-0.131
Mailo land	-32.360*	-22.519	-0.562	1.898
Village level factors				
Ln(population density per km^2)	-5.438	-6.639*	-0.872	-1.123
Ln(village wage rate per day in Ush)	11.029	11.395	1.480	1.392

Table 15--Determinants of nutrient balances (cont'd)

Agroecological zone (cf Lake Victoria crescent)				
Northwest moist zone	16.006+	23.812	-0.398	1.012
NM zone	5.203	9.336	1.391	2.855
Mt Elgon zone	17.815	25.987	4.670+	8.168
SW grass	-10.801	-5.111	3.394+	6.364
SWH	6.823	9.723	-9.271***---	-7.092
Constant	-127.400	-116.484	-9.682	-6.338
Wu Hausman Test of exogeneity of participation variables (P>χ^2)		1.000		1.000
Relevance of excluded variables (P>χ^2)	Extension	0.000		0.000
	NAADS	0.780		0.780
	Credit	0.000		0.000
Hansen J test of over identifying restrictions (P>χ^2)		0.708		0.259

Legend: * p<.1; ** p<.05; *** p<.01
+/-, ++/--, +++/--- means the associated coefficient is significant at p<.1; p<.05; and p<.01 in the reduced model equation that excluded potentially endogenous variables

Table 15--Determinants of nutrient balances (cont'd) (Part 2)

	Potassium (K)		NPK	
Variable	OLS	IV	OLS	IV
Natural capital				
Ln(average slope %)	-24.822**---	-81.727**	-57.470***---	-111.710**
Ln(topsoil depth (cm))	5.341	32.778	22.167	43.447
Land investment on plot dummies (yes=1 no=0)				
Practice agroforestry?	23.324	140.264*	39.669*+	132.028
SWC structure?	7.703	-22.719*	29.617	-56.014***
Perennial as dominant crop on plot? (cf annual crop) Yes=1, no=0	-49.909**--	-46.808**	-89.473***---	-87.451***
NRM investment?	7.205	15.222	28.907	32.278
Ln(plot area in acres +1)	2.367	22.624	9.915+	40.870*
Log(farm area in acres)	8.016	11.340	0.523	29.388
Physical capital				
Ln(Tropical livestock unit)	-7.037	24.136	-20.679--	52.029
Ln(value of equipment in Ush '000)	3.499	2.641	-0.486	10.626
Human capital				
Share of female household members with … (cf no formal education)				
Primary education	-5.207	8.992	-28.749	1.340
Secondary education	-26.403	-1.061	-26.458	-9.583
Post-secondary education	16.468	4.106	3.840	1.340
Share of male household members with … (cf no formal education)				
Primary education	-4.652	11.169	4.718	-10.038
Secondary education	-3.412	-31.331	16.497	-31.931
Post-secondary education	-33.209	26.848	-67.749	26.234
Sex of household head. Male = 1, No = female	11.360	2.567	17.810	13.313
Ln(Household size)	13.834	-16.320	28.303	1.124
Share of farm owned by women	9.305	-18.864	-2.022	-42.155
Primary source of income of household head (cf crop production)				
Non-farm	25.328	22.449	26.015	23.557
Livestock	143.301	213.152	36.236	125.897
Access to markets and services				
Ln(Distance from plot to residence in km)	7.808	-40.475	11.475	-71.358
Potential market integration	-0.026	-17.525	0.013	-19.217
Ln(Distance from plot to all-weather road+1)	-34.231***--	-1.277	-41.986**-	13.620
Ln(Number of extension visits+1)	0.457	13.904	-1.564	18.028
Does the household participate in NAADS activities? Yes=1, no=0	16.472	-0.054	28.152	-0.013
Household has access to credit	3.558	-31.724***	13.768	-38.866**
Land tenure of plot (cf freehold and leasehold)				
Customary	43.307**+	32.559	50.608	35.662
Mailo	-28.277	-20.292	-87.790*	-74.356
Village level factors				
Ln(population density per km^2)	-8.572	-10.684	-15.925	-18.889*
Ln(village wage rate per day in Ush)	6.319	13.556	17.783	25.926
Agroecological zones (cf Lake Victoria crescent)				
Northwest moist zone	-6.158	11.983	14.694	45.168
NM zone	-14.710	-16.377	-7.969	-3.752
Mt Elgon zone	-20.962	-41.043	-15.476	-34.609
SW grass	-108.721***---	-137.370***	-119.893***--	-148.522***
SWH	-79.381*--	-112.145**	-89.355	-122.200**
Constant	-93.835	-121.973	-242.256	-267.752

Table 15--Determinants of nutrient balances (cont'd) (Part 2)

Wu-Hausman test of exogeneity of participation variables ($P>\chi^2$)	--		0.976
Extension	0.000	Extension	0.000
NAADS	0.780	NAADS	0.780
Credit	0.000	Credit	0.000
Hansen J test of over identifying restrictions ($P>\chi^2$)	0.583		0.580

Legend: * p<.1; ** p<.05; *** p<.01
+/-, ++/--, +++/--- means the associated coefficient is significant at p<.1; p<.05; and p<.01 in the reduced model equation that excluded potentially endogenous variables

Most of the factors investigated have statistically insignificant impacts on soil nutrient balances. Livestock ownership is, surprisingly, associated with more rapid depletion of N. This is likely due to feeding crop residue to livestock after harvest, which is a common practice in areas with large cattle population. The resulting nutrient outflows through crop harvests and grazing outweigh their positive impact on nutrient inflows of organic matter.

Human capital endowments have mixed impacts on nutrient balances. Female primary education is associated with more negative N balances, and all levels of female education are associated with greater depletion of total N, P, and K. This likely relates to the association of female education with erosion noted earlier. In the case of households with higher female education, they are less likely to use organic inputs but obtain higher productivity, which also causes nutrient depletion. By contrast, male education is not significantly associated with nutrient balances, except a weakly statistically significant negative association of male post-secondary education with P balances. This may be related to the fact that male post-secondary education is negatively associated with use of SWC practices, as noted earlier. The gender of the household head and size of the household have insignificant impacts on soil nutrient balances.

Soil nutrient balances are more negative on steeper slopes as a result of greater erosion. They are more favorable on plots with SWC or agroforestry investments. By contrast, soil nutrient balances are much more negative on perennial than annual plots, especially for K. This is due to high rates of soil nutrient depletion in banana production (Kaizzi and Kato 2004; Wortmann and Kaizzi 1998).

Access to markets has insignificant impacts on soil nutrient balances, while better road access is associated with more favorable nutrient balances. The beneficial impacts of road access may be in part because this reduces use of slash and burn (Table 7), which depletes soil fertility.

Participation in extension and credit has insignificant impacts on soil nutrient balances, even though these have significant impacts on use of inorganic fertilizer, as noted previously. The use of inorganic fertilizer is too uncommon for this to have much effect on average nutrient balances, while extension and credit have limited impacts on organic land management practices.

Customary land has more favorable K balances than land under freehold tenure, while *mailo* land has more negative balances of N and total NPK than freehold land. The association of *mailo* land with banana production may be part of the reason for greater nutrient depletion on *mailo* land. We are not sure why K balances are more favorable on customary than freehold land, though this may be due to less banana production on customary than freehold land. In any case, these results do not support the common concern that land degradation may be greater on customary land due to inadequate incentives of farmers to conserve such land.

There are also differences across agro-ecological zones in soil nutrient depletion, with the greatest depletion rates in the southwest zones, due to banana production in these zones and higher erosion rates in the southwest highlands.

5. CONCLUSIONS AND POLICY IMPLICATIONS

The land degradation in the form of soil erosion and soil nutrient depletion is a serious problem in Uganda. Our study shows that farmers in the eight districts studied (representing six major agro-ecological/farming system zones) deplete an average of 179 kg/ha of nitrogen, phosphorus and potassium, which is about 1.2 percent of the nutrient stock stored in the topsoil (0 – 20cm depth). The value of replacing the depleted nutrients using the minimum price of inorganic fertilizer is equivalent to about one fifth of the household income obtained from agricultural production. This underscores the reliance of smallholder farmers on soil nutrient mining for their livelihoods and the high costs that would be required to solve this problem. The findings of this study also underscore the great concern that soil nutrient depletion poses since it contributes to declining agricultural production in the near term as well as the longer term. For example, we find that a 1 percent decrease in the nitrogen stock in the topsoil leads to a predicted 0.25 percent reduction in crop productivity. This loss in agricultural productivity likely contributes to food insecurity. Furthermore, soil nutrient depletion may contribute to deforestation and loss of biodiversity since farmers may be forced to abandon nutrient-depleted soils and cultivate more marginal areas such as hillsides and rainforests.

These results highlight the challenges that Uganda faces as it accelerates the implementation of the Plan for Modernization of Agriculture (PMA) and rolling out the new extension program, the National Agricultural Advisory Services (NAADS), to more districts. To forestall potential medium and long-term impact of land degradation, policy makers need to design strategies to reduce soil nutrient depletion and other forms of land degradation. Such strategies include, but are not limited to, reducing the cost of inorganic fertilizer and developing and promoting organic soil fertility technologies that are cost effective and relevant to local farming systems. Such strategies could contribute to increasing agricultural productivity and farm income as well as reducing land degradation.

The qualitative results of the econometric analysis are summarized in Table 16.

Table 16--Qualitative results (summary)

Variable	Slash & burn	fallow	rotate	residue	SWC	Inorganic fertilizer	Organic fertilizer	Value of seed	Preharvest labor	Crop productivity	Per capita income	Erosion	N balance	P balance	K balance	NPK bal
Use purchased seed? Yes=1, no=0										++						
Use inorganic fertilizer? Yes=1 no=0										+++						
use organic fertilizer? Yes=0 no=0										+						
Ln(preharvst labor+1)										+++						
Crop residue incorporated										+++						
Ln(plot slope %)				++	+++					--		+++	---	---	--	---
Ln(top soil depth in cm)			++				--			+++						
Ln(N stock kg/ha)		+							+	+++						
Ln(P stock kg/ha)											+++					
Ln(K stock kg/ha)							+									
Have ag forestry?		++	+							+++		--				+
Have SWC structures?				+++						+++	+++		++	+++		
Have other NRM investment?			+	+++				-			++	--				
Ln(plot area acres)	+++				++			++		--				+		
Ln(farm area acres)		+++		-	---			---	---	---	+++					
Ln(TLU)		---	-		+					+++	+++		--			
Ln(value of equipment 000Ush+1)				+			+			--						
Share of female household members with …. (cf no formal education)																
Primary education									+++			++	--			
Secondary education							+	--								
Post secondary education							-		--	+++		+				
Share of male household members with ….. (cf no formal education)																
Primary education						+++		+								

Table 16--Qualitative results (summary) (Continued)

Variable	Slash & burn	fallow	rotate	residue	SWC	Inorganic fertilizer	Organic fertilizer	Value of seed	Preharvest labor	Crop productivity	Per capita income	Erosion	N balance	P balance	K balance	NPK bal
Secondary education	--					+++				+++	++					
Post secondary education			++		--	+++								-		
Sex of household head							+			+++						
Household size										+++		++				
Share of farm owned by women																
Ln(Distance from plot to residence in km+1)			---		+++		--	--			+					
Potential market integration					++											
Ln(Distance to all weather road in km+1)	++							+			--			---	---	--
Ln(# of contact hours with extension agent +1)						++		-		+++						
Participate in NAADS program?						+				+++						
Have access to credit?			---			---			-	+++	+++					
Land tenure of plot (cf freehold and leasehold)																
Customary	++			+++		-			+++						++	
Mailo					--		++		+			++	-			-
Primary source of income of household head (cf crop production)																
Non-farm	--	+++							-	++	+					
Livestock										---		---				
Ln(Population density)									-							
Ln(village wage rate Ush/day)			+									---				
Perennial crop	---	---	--	-	--		+++			+++	+++		---		---	---

Table 16--Qualitative results (summary) (Continued)

Variable	Slash & burn	fallow	rotate	residue	SWC	Inorganic fertilizer	Organic fertilizer	Value of seed	Preharvest labor	Crop productivity	Per capita income	Erosion	N balance	P balance	K balance	NPK bal
Agroecological zone (cf Lake Victoria crescent)																
Northwest moist		+				+++		---		--		---				
Northern moist	--	+++	+++				---	---		--		---				
Mt Elgon zone	-			+++		+++	+++	--		++						
Southwestern grassland	--			+	--		+	-	++	+++	+++	---			---	---
Southwestern highlands	--	+++	+++		---				++			+++		---	-	
Southwestern grasslands x distance to road interaction										---						
Southwestern highlands x distance to road interaction										+++						
Constant			---	--		--			+++		++	+++				

The results provide evidence of linkages between poverty and land management practices. We find that natural capital in the form of some prior land investments contributes to better current land management practices, higher productivity and income, reduce erosion and, in the case of SWC structures, improve soil nutrient balances. These findings imply that SWC investments can lead to win-win-win outcomes since they increase income and crop productivity and conserve natural resources.

As expected, land management practices, namely use of purchased seed, organic and inorganic fertilizers, labor, and use of crop residues increase the value of crop production per acre. However, the profitability of inorganic fertilizer is low. The estimated marginal value cost ratio of fertilizer is less than 1, suggesting that adoption of fertilizer is likely to remain low unless its price is reduced substantially or crop prices improve substantially. Hence efforts to improve the market environment through investments in infrastructure and market institutions are necessary for substantial adoption of fertilizer to occur in the regions studied.

Not surprisingly, the quality of the land also influences land management practices and outcomes. For example, average plot slope increases the likelihood to incorporate crop residues, use short-term soil and conservation (SWC) practices but it leads to greater erosion and consequently lower nutrient balances. Plots with deeper soils are more likely to be used for crop rotation and likely to give higher productivity.

We observed an inverse farm size – crop productivity relationship, due to lower farming intensity by larger farms. Although smaller farms obtain higher value of production per acre, this does not fully compensate for the fact that they have less land, and they earn lower per capita incomes as a result. These findings are consistent with those of Nkonya, et al. (2004b) and Pender, et al. (2004) for Uganda, and with numerous studies from other developing countries. Despite these differences related to farm size, we find no significant differences in soil erosion or soil nutrient depletion due to farm size. Thus, improving access of small farmers to land, for example by improving the functioning of land markets, can increase aggregate agricultural production and small farmers' incomes in Uganda, with no apparent tradeoff in terms of land degradation.

Non-land assets, including livestock and value of equipment, have mixed impacts on land management practices and outcomes. Value of equipment increases labor intensity and but decreases crop productivity. Livestock ownership decreases the probability to fallow and the level of nitrogen balances but increases crop productivity and per capita income. These results suggest that livestock poor farmers are likely to remain in poverty with low productivity.

Human capital has mixed impacts on land management practices, productivity and land degradation. Female primary education is associated with more erosion and soil nutrient depletion, while female post-secondary education is also associated with more soil erosion as well as less labor intensity in crop production, but also with higher crop productivity. Male education is associated with greater use of inorganic fertilizer, higher crop productivity, and, in the case of secondary education, higher income per capita. In general, female education has less positive impacts on land management practices, productivity and sustainability than male education. This may be due to a greater tendency of educated females to focus on other livelihood activities.

These results imply that simply investing in education will not solve the problem of land degradation in Uganda, even though education is critical to the long-term success of poverty reduction efforts. These findings support the objective within the Plan for Modernization of Agriculture to introduce agricultural and natural resource management education into school curricula in order to prepare students to become better farmers who manage natural resources sustainably.

Larger families use more erosive practices but realize higher value of crop production per acre but have lower per capita income, suggesting that the returns from agricultural intensification do not compensate for a higher dependency ratio in larger families, which tends to depress per capita income. These results imply that population pressure has negative impacts on per capita income and land degradation at the household level, though it contributes to more intensive and productive use of the land (similar to the effects of farm size, and also consistent with Boserup's (1965) theory). These results demonstrate the need to promote reproductive health as one way of reducing poverty and land degradation.

Access to financial capital, in the form of household participation in programs and organizations providing financial services, decreases the probability to practice crop rotation or apply inorganic fertilizer but is associated with higher crop productivity and per capita income, suggesting that households borrow mainly to finance non-agricultural activities that appear to have greater returns than agriculture. This highlights the need to promote development of rural microfinance institutions (MFIs) with specific focus on agriculture, as most MFIs focus more on financing urban and rural nonfarm activities than on financing agriculture. For example Sasakawa Global 2000 offers in-kind agricultural input loans that are likely to attract only borrowers who have intention to borrow for agricultural production purposes.

Access to markets and roads significantly affects some land management practices and outcomes. In areas closer to major markets, farmers are more likely to use SWC practices. However, this does not contribute to higher per capita income or crop productivity or better nutrient balances. Farmers closer to all-weather roads are less likely to use destructive slash and burn practices, obtain higher per capita income, and have less soil nutrient depletion. These findings are consistent with the favorable impacts of market and road access found in some other studies in East Africa (e.g., Tiffen, et al. 1994; Pender, et al. 2001; Fan, et al. 2004), though findings of such favorable impacts are not universal (e.g., Nkonya, et al. 2004b). These results support the Ugandan government's efforts to build rural roads as investments that can reduce poverty, as well as potentially helping to reduce land degradation. However, the impacts of roads and potential market integration on most land management practices are not clear and require further investigation.

Access to agricultural technical assistance services, measured by contact with government extension agents and participation in the NAADS program, has a positive association with crop productivity, as expected. We investigated whether the positive associations of participation in NAADS program with higher production may be due to selection bias (i.e., initial operation of NAADS in higher productivity sub-counties), and our results ruled out this explanation. Our findings thus provide support for the NAADS approach, suggesting that NAADS is already having substantial positive impacts due to the introduction of profitable strategic enterprises. However, further focused research is needed to better understand whether and how the NAADS approach is leading to greater crop productivity, and whether such benefits are being realized in other districts and sub-counties as the program expands.

The positive impacts of agricultural extension on productivity that we find are consistent with the findings of Nkonya, et al (2004b), and suggest that remote areas with poor access to technical assistance (Jagger and Pender 2003) are likely to continue to face low productivity and poverty. This suggests the need to give incentives for technical assistance programs to operate in remote areas.

The agricultural technical assistance programs analyzed in this research have generally limited impacts on organic land management practices, which are important given the high cost and low profitability of inorganic fertilizer. This suggests the urgent need for NAADS to give greater attention to promoting organic land soil fertility practices in order to address the potential soil fertility depletion resulting from promotion of adoption of more profitable farming enterprises.

Changes in household livelihood strategies, whether promoted by NAADS or resulting from other factors such as education, population growth or market and road development, can have important implications for land management, productivity, incomes and land degradation. Households pursuing non-farm activities are more able to fallow their land and less likely to use slash and burn practice, and obtain higher value of production per acre and per capita income. These results imply that non-farm activities can be complementary to crop production, by enabling households to fallow and by reducing households' exposure to agricultural price and production risks. Hence promotion of non-farm activities has potential of achieving win-win-win outcomes, increasing productivity, reducing poverty and conserving natural resources. Efforts to increase rural households' formal and vocational education, rural electrification programs, road development and development of rural microfinance institutions can help increase opportunities to participate in non-farm activities. Such efforts are likely to be especially important for poor farmers and women, who often lack access to off-farm opportunities (Barrett, et al. 2001; Gladwin 1991).

Households pursuing livestock production as their primary livelihood strategy also have less erosion but their productivity in crop production is lower. Thus, promotion of livestock production can help to improve the sustainability of natural resource management, though it may involve some tradeoff in terms of reduced crop production (though recall that controlling for livelihood strategies and other factors, greater livestock ownership is associated with higher crop productivity).

Among crop producers, perennial crop producers use less slash and burn, crop rotation, short-term SWC or fallow but obtain higher value of crop production and income than annual crop producers. However, they deplete soil nutrients more rapidly (especially nitrogen and potassium), despite the common application of mulch and other organic materials to perennial crops. Thus, perennial crop production involves tradeoffs among the objectives of increasing productivity, reducing poverty and ensuring sustainable use of natural resources, at least given the land management practices currently used in Uganda. Promoting measures to restore soil nutrients in perennial (especially banana) production should be a high priority for agricultural technical assistance programs.

The land tenure system also is associated with some differences in land management practices and land degradation. For example, use of slash and burn, crop residues and labor are greater on customary land than freehold land, leading to more favorable potassium balances. Despite these differences, we find no differences in crop productivity or income per capita associated with differences in land tenure systems. These findings call into question the assumption of the 1998 Land Act that conversion of customary land to freehold tenure would lead to improvements in land productivity and more sustainable land management practices. Nevertheless, there is still need to facilitate access to credit in customary tenure areas, since owners of land under customary tenure are unable to pledge their land as collateral in the formal credit service, and this research has shown that such services could help to improve crop productivity and reduce poverty.

Our findings suggest that some modernization strategies can achieve win-win-win outcomes, simultaneously increasing productivity, reducing poverty, and reducing land degradation. Examples of such strategies include promoting investments in SWC and road development. Some strategies appear able to contribute to some positive outcomes without significant tradeoffs for others, such as promotion of non-farm activities, agricultural extension programs and rural finance.

Other strategies are likely to involve tradeoffs among different objectives. For example, investing in livestock appears to improve crop productivity and household income, but also is associated with more rapid soil nutrient depletion. Expansion of banana production is likely to cause more soil nutrient depletion as well as higher income and productivity, unless greater efforts to restore soil nutrients are made. Female education may contributes to improved health, nutrition or other development indicators not analyzed in this research, but also appears to contribute to some indicators of land degradation. The presence of such tradeoffs is not an argument to avoid such strategies;

but rather is an argument to recognize and find ways to ameliorate such negative impacts where they may occur. For example, incorporating teaching of principles of sustainable agriculture and natural resource management into educational curricula, as well as in the technical assistance approach of NAADS and other organizations, is one important way of seeking to address such tradeoffs.

Overall, our results provide support for the hypothesis that promotion of poverty reduction and agricultural modernization through technical assistance programs and investments in infrastructure and education can improve agricultural productivity and help reduce poverty. However, they also show that some of these investments do not necessarily reduce land degradation, and may contribute to worsening land degradation in the near term. Thus, investing in poverty reduction and agricultural modernization is not sufficient to address the problem of land degradation in Uganda, and must be complemented by greater efforts to address this problem.

Beyond these policy implications, we recommend that the government of Uganda, led by UBOS, NARO and Makerere University, continue to collect systematic data on natural resource management and degradation linked to the socioeconomic surveys of UBOS, building upon the surveys conducted for this project. Future crop production surveys led by UBOS would be more useful if they collected information on land management practices, input use and crop production at the plot level, and also collect soil samples from the same households surveyed previously every five to ten years, so that changes in soil conditions and their linkages to productivity and poverty assesses. This project has established a baseline of information that can be used in conjunction with future surveys to be able to analyze the dynamic linkages between poverty and natural resource degradation, and the medium and longer term effects of the PEAP, PMA and other policies and programs in addressing these problems.

To the World Bank and other development organizations, we recommend that similar efforts to collect and analyze systematic information on NRM linked to socioeconomic surveys be instituted in other developing countries. Much of the information about natural resource degradation, its linkages to poverty, and how it responds to policies and development investments remains anecdotal or based upon a small number of case studies that may not be representative of broader contexts. As we have seen in this study, natural resource degradation can account for a large share of real net farm income (with soil nutrient depletion worth more than 20 percent of farm income in our sites). Continuing to ignore such a large component of real income is likely to lead to serious biases in conclusions about the effectiveness of poverty reduction efforts in developing countries. This project has demonstrated an approach that can be useful in helping to address this information gap.

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