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LINKAGES BETWEEN POVERTY AND LAND MANAGEMENT IN RURAL UGANDA: EVIDENCE FROM THE UGANDA NATIONAL HOUSEHOLD SURVEY, 1999/00

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ABSTRACT

This study investigates the impacts of rural poverty on farmers' land management decisions, crop production and incomes, based upon analysis of data from the 1999/2000 Uganda National Household Survey. We find that the impacts of rural poverty on land management, crop production and income depend upon the type of poverty (i.e., what asset or access factor is constrained) and the type of land management considered.

Ugandan households that are poorer in terms of access to land use labor more intensively and are less likely to use several land management practices and inputs, though among households that do use non-labor inputs, land-poor households use many of these inputs more intensively. As a result, land-poor households obtain higher value of crop production per acre, though they have substantially lower incomes per capita than land rich households. Thus, access to land is a key factor affecting intensity of land management and rural poverty.

Households with access to poorer quality land use less labor and most non-labor inputs, and obtain lower crop production and income. To the extent that land quality is declining as a result of soil nutrient depletion and other land degradation problems, these results suggest a downward spiral of land degradation→ declining land quality → lower investment in land management → further land degradation.

Households that are poorer in terms of ownership of physical assets are less apt to adopt most land management practices and non-labor inputs. Households with less livestock obtain lower crop yields, and households with less of other assets obtain lower income. This suggests another negative cycle: low assets → low investment in land management and low income→ continued land degradation and low assets.

Households who are poorer in terms of males' access to education invest less in most inputs and land management technologies, and obtain lower incomes. Households in which females lack education use labor more intensively in agriculture but also obtain lower incomes. These households may be locked into a similar cycle of low education → low investment in land management and low incomes → land degradation and continued low assets.

Households in communities with lower wage rates use labor more intensively in agriculture, but use several non-labor inputs less intensively, and obtain lower value of crop production and incomes. Thus lack of off-farm opportunities may contribute to keeping poor households in a poverty and land degradation trap.

Households without access to extension, market information or credit are less apt to use several modern non-labor inputs, likely resulting in lower crop production. Households with poor access to roads use less organic or inorganic fertilizer, which can contribute to land degradation. Poorer road access is also associated with lower value of crop production per acre in the Eastern and Western regions and lower income in the Central region. Thus lack of access to infrastructure and services also may prevent households from exiting the poverty-land degradation trap, though the impacts may be location specific.

Our results suggest that improvement in smallholders' access to land, other assets, education, extension, market information, credit, roads, and off-farm opportunities can help to break the downward cycle of poverty and land degradation, and put farmers on a more sustainable development pathway. Access to land (area and quality), other assets, education and off-farm opportunities appear to be particularly important in addressing poverty directly, while other interventions are likely to have more indirect impacts, as they influence land management, crop choice, and other livelihood decisions. Given the importance of land as the major asset owned by poor rural households in Uganda, investing in land quality maintenance and improvement is a critical need. However, we found low marginal returns to investments in organic or inorganic fertilizer and other land management practices, suggesting that it will be difficult to get farmers to make such investments in the present environment. Improvements in the market environment as well as development of more profitable land management technologies appears essential to address this need.

KEYWORDS: Uganda, Land management, rural poverty, land degradation, household income

TABLE OF CONTENTS

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1. INTRODUCTION

Poverty reduction is the overarching development goal of the Ugandan government. 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 from 44 percent in 1997 to below 10 percent in 2017 (MFPED 2001). The PEAP key strategies for poverty reduction include improvement of health care, roads, primary education, rural water and modernization of agriculture (Ibid). The Plan for Modernization of Agriculture (PMA 2000) is one of the central pillars of the government's poverty reduction strategy. Nearly all (96 percent) of the poor live in rural areas, and the vast majority of these (84 percent) depend primarily on agriculture for their livelihood (MFPED 2001). The PMA emphasizes the critical need for small farmers to become more productive and commercially oriented, and to manage natural resources in a more sustainable manner.

In the past decade, Uganda has registered impressive progress towards reducing poverty. Appleton, (2001a) observed that absolute poverty in Uganda decreased from around 56 percent of the population in 1992 to 35 percent in 1999/00. One of the major reasons behind this impressive achievement is the sound macro and micro economic reforms that the government of Uganda implemented in the past decade.

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Despite the progress made in the past decade, substantial challenges remain in reducing poverty, increasing productivity and ensuring sustainable use of natural resources. Although poverty declined in Uganda between 1992 and 1999, it has since increased somewhat (to 38 percent in 2002/2003), driven mostly by worsening poverty in rural areas, especially among crop farmers (Appleton and Ssewanyana 2003). The decline in poverty since the early 1990s is less in rural than in urban areas, and in many rural areas—especially in the north—little reduction in poverty has occurred. Agricultural productivity has stagnated or declined for most farmers (Deininger and Okidi 2001; Pender, et al. 2001), and declining soil fertility is perceived as one of the major causes (Pender, et al. 2001; MAAIF 2000).

Scientific studies of land degradation in Uganda are limited, but 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. 2004). 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). Most communities perceive that other natural resources are also degrading and that food insecurity is worsening (Pender, et al. 2001; APSEC 2001).

There is widespread concern that poor households in Africa face a downward spiral of land degradation and poverty (Cleaver and Schreiber 1994). Land degradation may contribute to poverty by reducing agricultural productivity, while poverty may in turn 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 management 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 available data from the 1999/2000 Uganda National Household Survey (UNHS). It is the first component of a larger study investigating linkages between poverty and natural resource management in Uganda, led by the International Food Policy Research Institute, the World Bank Environment Department, Makerere University, the Uganda Bureau of Statistics (UBoS), the National Agricultural Research Organization (NARO), and the Agricultural University of Norway.

This initial study seeks to learn as much as possible about poverty and land degradation linkages based on analysis of the 1999/2000 UNHS. There are substantial limitations to this, because the UNHS was not designed with this objective in mind and because many of the linkages are dynamic in nature and cannot be adequately understood using only cross sectional analysis of household survey data. Addressing such shortcomings of existing data is the main objective of the broader project of which this study is a part. Nevertheless, it is useful to see what can be learned from the data that are already available. Some of the linkages between poverty and land degradation can be investigated using these data, such as the near term impacts of asset and access poverty on land management, productivity and incomes. Other linkages, such as the impacts of land management on land degradation and the impacts of land degradation on poverty over time require further investigation.

The remainder of the paper is organized as follows: In the next section, the discussion of the methods and the empirical strategy employed is presented, followed by a discussion of the key variables and data sources. The empirical results are presented in the third section, and conclusions and implications are discussed in the final section.

2. METHODOLOGY

LINKAGES BETWEEN POVERTY AND NATURAL RESOURCE MANAGEMENT

There are many hypotheses in the literature concerning the linkages between poverty and natural resource management. One common theme is the prospect of a downward spiral of resource degradation and poverty. According to this view, natural resource degradation contributes to declining agricultural productivity and reduced livelihood options, thus worsening poverty and food insecurity, while poverty and food insecurity in turn contribute to worsening resource degradation by desperate households lacking alternatives to degrading their natural capital stock (Durning 1989; Leonard 1989; Cleaver and Schreiber 1994; Pinstrup-Andersen and Pandya-Lorch 1994).

This view has been challenged on both theoretical and empirical grounds. Theoretically, there is no necessary causal link from resource degradation to worsening poverty. People may choose to degrade natural resources while investing in other assets yielding higher returns. In this case resource degradation represents a process of substituting one type of capital for another, and may be associated with overall improvement in incomes and welfare (Pender 1998). Of course, private decisions to disinvest in natural capital may not be socially optimal if there are external benefits resulting from natural capital (e.g., if conserving forests prevents sedimentation of streams, flooding and reduces atmospheric CO_2) or external costs of other forms of capital (e.g., negative effects of agrochemical use on water quality). But the implications of such externalities do not necessarily depend on whether people are poor.

The process of disinvesting in natural capital may continue until private rates of return to investing in different types of capital are relatively equal, after which households are likely to make complementary investments in natural capital and other forms of capital (Ibid.). On the other hand, people may disinvest in all types of capital, or investment may fail to keep pace with rapid population growth, if the rate of return on available investments is not sufficiently high relative to people's rate of time preference and the rate of population growth (Ibid.). In this case, households are caught in a poverty-degradation trap, though it is the relatively low rate of return to all investments and not the linkages between poverty and resource management that cause the trap.[3] Still, resource degradation can and does contribute to declining productivity and thus may contribute to poverty when other compensating investments are not sufficient.

There is also no necessary causal link from poverty to resource degradation. If markets are perfect, land and other resources will be allocated to their most profitable uses and all investments yielding a positive net present value will be made (Singh, et al. 1986). In this (admittedly unrealistic) case, resource management and investment decisions will be independent of the characteristics of owners of resources, including their level of poverty. Even with one missing market, resources can be efficiently allocated if all other markets are functioning competitively. For example, households facing binding cash or labor constraints may lease their land out to other households with more cash or family labor and thus able to farm the land more profitably and more able to

[3] To the extent that poverty contributes to high fertility rates (e.g., due to inadequate social security or low education of girls), however, it may contribute to high population growth rates and thus to the likelihood that a poverty-resource degradation trap occurs.

make investments in the land. Thus it requires at least two market failures for household characteristics such as poverty to influence private resource management decisions.

If there are market failures, poverty may indeed affect natural resource management and resource degradation, though the possible relationships are complex, depending upon the nature of the market failures, 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 (since wealthier ones can more readily hire labor or purchase other required inputs for such investments), other factors being equal, and thus may suffer greater land degradation (Pender and Kerr 1998). On the other hand, wealthier households are also more able to invest in livestock, mechanical equipment, or other assets that may contribute to 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 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 fallowing less or not at all, farming on steep slopes, tilling more frequently, applying manure or mulch, investing in soil and water conservation measures, etc., as argued by Boserup (1965) and others. Such intensification of labor may have mixed impacts on resource degradation, potentially increasing soil fertility depletion as a result of declining fallow use or increasing erosion as a result of farming on steep slopes, or restoring soil fertility and reducing erosion as a result of adoption of labor-intensive soil fertility management and soil and water conservation measures.

In an imperfect markets setting, the nature of poverty also is important in determining the impacts on natural resource management and degradation. Households that are not poor by welfare criteria such as minimum levels of consumption may 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 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. 2004).

EMPIRICAL MODEL

To investigate some of these relationships, we use econometric analysis of the 1999/2000 UNHS data, using an empirical model that draws from the literature on agricultural household models (Singh, et al. 1996; de Janvry, et al. 1991) and on sustainable livelihoods (Carney 1998). The empirical model is based on a theoretical dynamic household model in which rural households seek to maximize their welfare over time, subject to their endowments of physical, human, natural, financial and social capital, land tenure, access to information and services, and to the biophysical, market and institutional constraints present in their socioeconomic and physical environment.[4]

In the empirical model, we consider what factors determine household decisions relating to land management (broadly defined to include crop choice, use of labor, soil fertility management technologies and other inputs), including household endowments of different types of "capital" (physical, human, natural, financial and social). These relationships are used to identify the impacts of "investment poverty" (Reardon and Vosti 1995) on land management. We also investigate the impacts of land management decisions on the value of agricultural production (and hence indirectly on income), thus quantifying some of the linkages from land management to poverty. Finally, we investigate the impacts of endowments on crop production and household income in reduced form, through which the total effects of asset holdings on income poverty (via impacts on land management and other mechanisms of impact) can be assessed.

Value of Crop Production

For agricultural production, we focus on the value of crop production per acre, as this is by far the largest component of agricultural income, and closely related to land management. We assume that the value of crop production by household h (y_h) is determined by the vector of shares of area planted to different types of crops (C_h); the amount of labor used per acre (L_h); the vector of non-labor inputs/land management practices used (LM_h); the "natural capital" of the household (NC_h) (including the amount and quality of land held); the tenure characteristics of the land held (e.g., land rights status, how parcel acquired, time since acquisition) (T_h); the household's endowments of

[4] The theoretical dynamic household model is presented in the appendix.

physical capital (e.g., livestock, equipment, buildings, durable goods), human capital (e.g., education, age and gender distribution of household members, health status) (HC_h), and "social capital" (social relationships affecting the household's productive and marketing capacities); access to information and services relevant to agricultural productivity (e.g., extension services, market information, credit) (IS_h); village level factors that determine local comparative advantages, including agro-ecological conditions, access to markets and infrastructure, local wages, population density, and region (X_v); and random factors (u_{yh}):

$$y_h = y(C_h, L_h, LM_h, NC_h, T_h, PC_h, HC_h, SC_h, IS_h, X_v, u_{yh}) \qquad (1)$$

Equation 1 is not strictly a production function, since we are focusing on the value, not quantity, of production per acre. We do this because many different crops are produced in Uganda, often on the same plot, making estimation of single crop production functions difficult. The value of crop production depends on the choice of crops (C_h) and farm level prices of these crops, the inputs and land management practices used in producing them (L_h, LM_h), and the natural conditions of the land (NC_h). Since different households in different locations in Uganda produce different crops, we are not able to explicitly include crop prices as determinants of the value of crop production, because the price of every crop is unobserved in many locations. Instead, we assume that farm level prices are determined by village level factors determining local supply, demand and transportation costs of commodities (X_v) and household level factors affecting households' transactions costs and marketing abilities (PC_h, HC_h, SC_h, IS_h). If factor markets are imperfect, households' endowments of physical and other forms of capital and access to information and services can also influence production decisions and productivity, even if they have no influence on farm level commodity prices (de Janvry, et al. 1991). In addition, agro-ecological conditions (part of X_v) also influence agricultural productivity by affecting production conditions. Land rights and tenure characteristics (T_h) may influence crop production by affecting tenure security, land marketability, land values, and/or access to credit, hence affecting farmers' incentive and ability to invest in land improvements or to apply inputs (Feder et al. 1988; Place and Hazell 1993; Besley 1995; Pender and Kerr 1999).

Crop Choice, Labor Use and Land Management

In the context of imperfect factor markets, crop choice, labor use and land management decisions all may be affected by the household's endowments of natural, physical, human and social capital; by land tenure, by the household's access to information and services; the household's vulnerability status; and by the village level factors determining local comparative advantage:

$$C_h = C(NC_h, T_h, PC_h, HC_h, SC_h, IS_h, X_v, u_{ch}) \quad (2)$$

$$L_h = L(NC_h, T_h, PC_h, HC_h, SC_h, IS_h, X_v, u_{lh}) \quad (3)$$

$$LM_h = LM(NC_h, T_h, PC_h, HC_h, SC_h, IS_h, X_v, u_{lmh}) \quad (4)$$

The determinants of value of crop production will be estimated using the structural model represented by equation 1), as well as in reduced form. The reduced form is obtained by substituting equations 2) – 4) into equation 1):

$$y_h = y'(NC_h, T_h, PC_h, HC_h, SC_h, IS_h, X_v, u'_{yh}) \quad (5)$$

Household Income

In reduced form, household income is determined by the same factors as in equations 2) – 5):

$$I_h = I(NC_h, T_h, PC_h, HC_h, SC_h, IS_h, X_v, u_{Ih}) \quad (6)$$

ECONOMETRIC APPROACH

Equations 1) to 6) are the basis for the econometric estimation. Ideally these equations would be estimated as a linear system using a system method such as three-stage least squares estimation. However, this is not possible because some of the dependent variables are censored variables (i.e., C_h are constrained to be between 0 and 1 and LM_h are constrained to be non-negative), hence their determinants cannot be consistently estimated using standard linear models (Maddala 1983). Instead, each equation is estimated independently using econometric models suitable to the nature of each dependent variable.[5]

Equations 1), 3), 5) and 6) are estimated using ordinary least squares (OLS) and instrumental variables (IV) estimators, to address possible bias from inclusion of endogenous explanatory variables (more on this below). Equation 2) is estimated using a two-limit tobit model (Ibid., pp. 160-162) to account for left and right censoring of C_h. Equation 4) is estimated using a Heckman sample selection model (Davidson and MacKinnon 2004, pp. 486-488), using maximum likelihood estimation. This model accounts for left censoring of LM_h variables, and is more general than a standard tobit model, since it allows for different variables to determine whether or not a land management practice is used than the variables determining the intensity of use, and allows for different impacts of the same variables on these decisions. We test some of

[5] Compared to a systems approach, estimating each equation independently reduces the efficiency of estimation because correlation in error terms across equations cannot be accounted for and cross equation restrictions (such as those implied by the fact that the shares of land planted to different crop mixes must sum to 1) cannot be imposed. The inability to account for such cross equation relationships does not cause the estimated coefficients to be inconsistent or biased, however.

the restrictions implied by the tobit model—namely that the coefficients in the selection equation are proportional to the coefficients of the corresponding variables in the second stage regression equation (Davidson and MacKinnon 2004, pp. 485-486) (with the proportionality constant equal to $1/\sigma$, the standard error of the regression)—and reject this hypothesis in all cases. We therefore report the results of the Heckman model rather than the tobit model, as well as the results of the tests of the tobit model restrictions.

Inclusion of the household's choice to participate in agricultural extension, access market information or take a loan (indicators of IS_h) as explanatory factors in all equations could lead to endogeneity bias. For example, households may be less likely to take out a loan if they have information indicating that production is likely to be low, and if this information is not adequately controlled for in the regression, it could cause the loan variable to pick up the effect of such unobserved (by the econometrician) factors on production and input use. In addition, equation 1) includes also endogenous choices of C_h, L_h, and LM_h that could also cause endogeneity bias. To address this problem, we use IV estimation of equations 1), 3), 5) and 6).

IV estimation results are 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 indicators of distance and travel time to the most common market, the location of the nearest market, the common transportation modes used to the nearest market, availability of formal and informal credit, and the sources of credit. We hypothesize that such variables are significant predictors of household access to extension, market information and loans (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, and access to markets and roads). These factors apparently affect the value of crop production only indirectly (by affecting crop choice, labor use and land management), but not directly after controlling for these factors.

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 heteroskedasticty (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 both the OLS and IV results, since IV estimation may be biased in finite samples, as noted above. For equations 3), 5) and 6), we also report the significance of results of an alternative OLS model in which the potentially endogenous explanatory variables (contact with extension, access to market information, and use of credit) are excluded, to investigate the impacts of these variables on the results. We have more confidence in results that are robust in both of the OLS models and the IV model.

For equations 2) and 4), we cannot use linear IV estimation since the model is a limited dependent variable model in both cases. For IV estimation of equation 4), we estimate the second stage of the Heckman two-stage model using only the observations having positive values of LM_h, incorporating the selection correction term (the inverse Mills ratio) from a first stage probit selection model. Since this second stage regression model is linear, we can use IV estimation to estimate it. We report the robustness of the coefficients of the second stage of the Heckman selection model when estimated by IV estimation. For equation 2), we are not aware of a consistent method to estimate a two-limit tobit model using IV estimation. However, as for the OLS models discussed above, we investigate the robustness of our results in estimating equations 2) and 4) by leaving out the potentially endogenous explanatory variables in one specification.

Other estimation and data issues considered included sampling weights, heteroskedasticity, clustering (possible non-independence of observations from the same sampling unit), multicollinearity, and outliers. In all cases, appropriate univariate and regression statistics (means and standard errors) are reported, which are adjusted for sample weights (thus representative of the population of Uganda) and robust to heteroskedasticity and clustering (StataCorp 2003). Multicollinearity was tested using variance inflation factors and found not to be a major concern (maximum variance inflation factor = 3.2) (Mukherjee, et al. 1998). Regarding outliers, some observations with unbelievable data values were dropped. Problems of leverage and outliers were also addressed by transforming most continuous variables using logarithms, which resulted in more normally distributed variables, thus improving the performance of the regression (Ibid.). For nonnegative continuous variables having zero values for some households (e.g., non-labor input use, asset values), the variable (x) was transformed using the transformation ln(x+1), so that the transformed value is zero when x = 0, and increasing monotonically in x.

Data

This study uses household and community level-data from the Uganda National Household Survey (UNHS) conducted by the Uganda Bureau of Statistics (UBoS). This survey was conducted during August 1999– July 2000 covering all districts except the districts of Kitgum, Gulu, Kasese and Bundibugyo, which were excluded from the survey because of insurgencies at the time of the survey. A multi-stage stratified sampling approach was followed, in which each district was treated as a separate stratum. The sample was designed in a manner to enable derivation of reliable estimates of the crop survey characteristics at a district level. It was also designed to ensure representation at national, regional and rural/urban levels. Thus, national representation is still retained even after restricting the sample to rural areas.

This was a multipurpose survey designed with three modules, namely, socio-economic, crop and community. The survey covered 10,696 households in 1,086 communities. Of the sampled households 8,453 were engaged in crop farming both in rural and urban areas. The information for the three modules was collected at the same time and from the same enumeration area, making it easier to match households to their respective communities. Although the UNHS was a nationally representative survey, the analysis is limited to rural crop farming households. The survey covered about 79 percent households with crop farming enterprises, of these 85 percent are used in the analysis after limiting the sample to rural areas and dropping some obvious outliers. In other words, the analysis is limited to 7,140 rural households. In the next sub-section, a description of the variables of interest from these three modules is presented. Since the focus of this paper is on linkages between poverty and land management, efforts are put into relating poverty status[6] to various variables.

Below we discuss the variables and data used in the analysis and their sources. First we consider the dependent variables in equations 1) to 6).

Value of crop production per acre (y_h)

The value of crop production per acre of cropland operated was estimated based on data collected in the UNHS crop module. Total value of production was derived as the product of quantity produced and village level price, aggregated over the two seasons, divided by area cultivated. Area cultivated was derived as the average for both seasons.

[6] The paper borrows from Appleton's (2001) work on poverty estimates based on the UNHS.

Crop choice (C_h)

The analysis uses the share of cropland area under the dominant crop type or crop mix. Using the crop module, it was not possible to estimate the share of crop area under each specific type of crop, due to mixed cropping. Instead, the dominant crop type or crop mixes for each plot was classified based on the plot level data, and used to calculate the share of total crop area under each dominant type. The most common dominant crop types included cereals, matooke (cooking banana), root crops, legumes, coffee, and various mixes (e.g., matooke-coffee, cereals-legumes, legumes-matooke, and legumes-root crops).[7]

Labor intensity (L_h)

Pre-harvest labor use was measured by the number of pre-harvest workers per acre in adult male equivalent (using local wage rates to determine the adult male equivalent of adult females and children), using data from the crop module.

Land management (LM_h)

Land management was indicated by the value of non-labor inputs applied per acre, including organic fertilizer (manure), inorganic fertilizer, pesticides, traditional seeds, improved or hybrid seeds, and other non-labor inputs (costs for soil preparation, etc.), using data from the crop module.

Household Income (I_h)

Household income was measured as income from crop farming, non-crop farming (mainly livestock), non-agricultural enterprises (e.g., trading or brewing), property (e.g., rent from land or buildings, dividends), off-farm employment, and other sources (e.g.,

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[7] Vegetables and fruits were dominant for some households, but only a relatively small number of households. Thus the determinants of this crop choice are not analyzed in this paper.

transfers and remittances). These data are from the household socioeconomic survey module.

Next we consider the explanatory factors in equations 1) to 6):

Natural capital (NC_h)

Natural capital is indicated by the area operated and households' reported land value per acre. These data were taken from the UNHS crop and socioeconomic modules. Land value per acre reflects the quality of land owned by the household, its locational advantages (e.g., land in areas with better access to markets and roads is expected to have higher value) and the scarcity of land (as determined by population density). Since locational and scarcity variables are controlled for in the regressions (X_v), the coefficient of land value per acre in the regressions is assumed to reflect mainly the effects of differences in land quality.

Land Tenure (T_h)

The land tenure of the household is indicated by the share of land held under customary, *mailo* or other tenure (freehold or leasehold), the share of land acquired by various means (purchased, inherited, freely acquired, rented), the proportion of land operated by women, and the average length of time the plots have been held by the household. These data were taken from the UNHS crop module.

Physical capital (PC_h)

The physical capital of each household is indicated by the value of assets owned, including the value of livestock (including poultry), farm equipment, buildings and durable goods. These data were taken from the UNHS socioeconomic module.

Human capital (HC_h)

The human capital of the household is indicated by the household size and share of dependents, the median number of years of education of adult males and females in the household, the gender and age of the household head, and the proportion of adult days lost due to sickness.[8] These data were taken from the UNHS socioeconomic and crop modules.

Social capital (SC_h)

Social capital is proxied by the dominant ethnicity of the village. Uganda has over 50 different ethnic groups. For the purpose of this paper, only the dominant ones by administrative region were considered. These included the Baganda, Basoga, Bagisu, Iteso, Langi, Lugbara, Bakiga, Banyoro, and Banyankole ethnic groups. These data are from the UNHS community module.

Access to information and services (IS_h)

The access to information and services relevant to land management is indicated by whether the household had contact with the agricultural extension service, whether it had access to market information, and whether it had taken any loan in the survey year. These data are from the UNHS crop module.

Village level factors affecting comparative advantage (X_v)

Agro-climatic zones: For the 1999/2000 UNHS, the geographic locations of the respondent households were collected using global positioning system (GPS) units. These data were used to link households to their agricultural potential domain by IFPRI

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[8] An adult is taken as someone older than 15 years of age. The dependency ratio was derived as the number of dependents (aged below 15 & above 65 years) divided by the household members aged between 15-65 years. Household size was taken as a measure of all the usual members (persons living in the household at least six months prior to the survey), normalized in adult equivalents (an 18-30 year old male is taken as the reference person in the adult equivalent measure, following Appleton (2001a)).

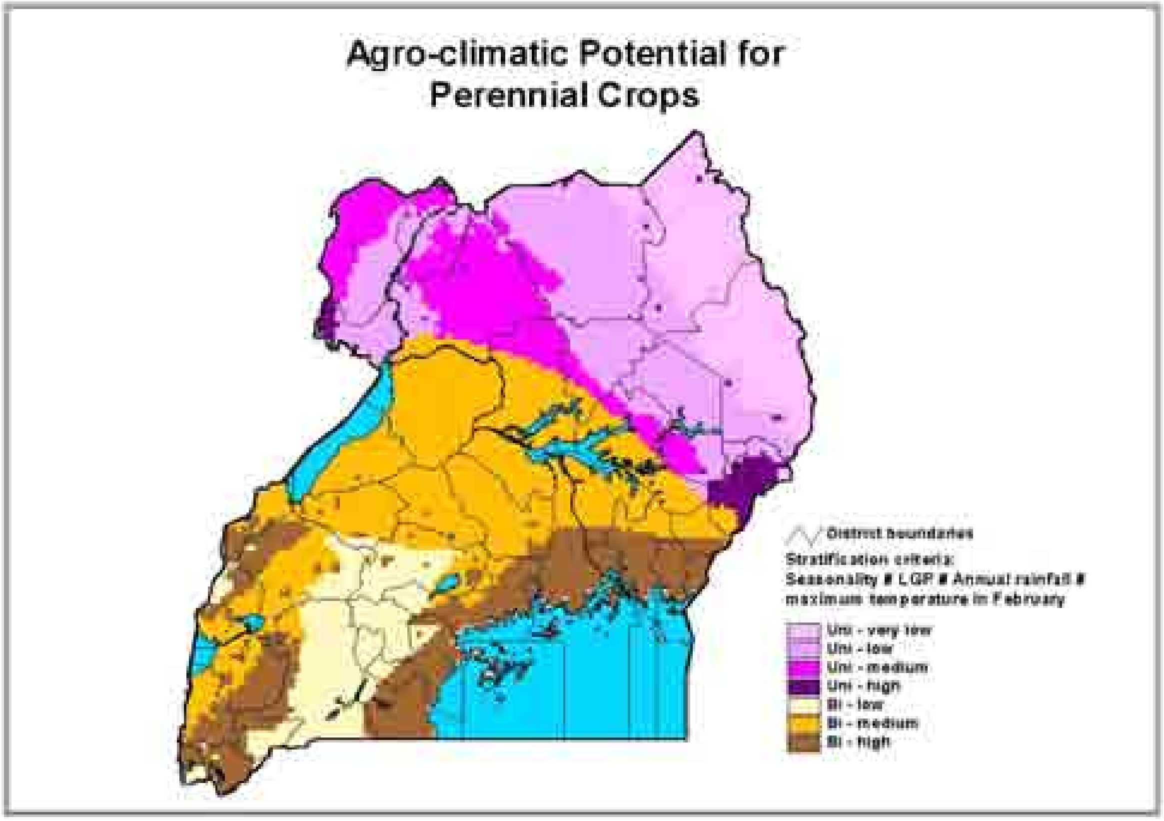
researchers. The agro-ecological zone classification is based on Ruecker et al (2003). This classification was based on the average length of growing period, rainfall pattern, maximum annual temperature and altitude. These zones were broadly categorized into unimodal and bimodal pattern rainfall zones. Within the unimodal class further categorization included very low, low, medium and high rainfall zones; the bimodal class had low, medium and high rainfall zones (Figure 1). The bimodal high rainfall zone covers most of the Lake Victoria crescent and parts of the southwest highlands; the bimodal medium rainfall zone covers most of central and western Uganda; the bimodal low rainfall zone covers most of southwestern Uganda; the unimodal high rainfall zone covers the eastern highlands; the unimodal medium rainfall covers parts of northern and northwestern Uganda; and the unimodal low and very low rainfall zone covers much of northeastern Uganda. For the analysis, we combined the unimodal very low, low and medium rainfall zones, due to limited numbers of households in each of these categories (especially the very low rainfall zone, which includes less than 1 percent of the sample households) and expected similarities in agriculture and land management (especially between the unimodal low and medium rainfall zones).

Market, road and transportation access: The geographic coordinates of the survey households were also 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. 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 and transportation was measured using information from the community survey on the distance of the community to the nearest all-weather road, truck service and minibus/taxi service.

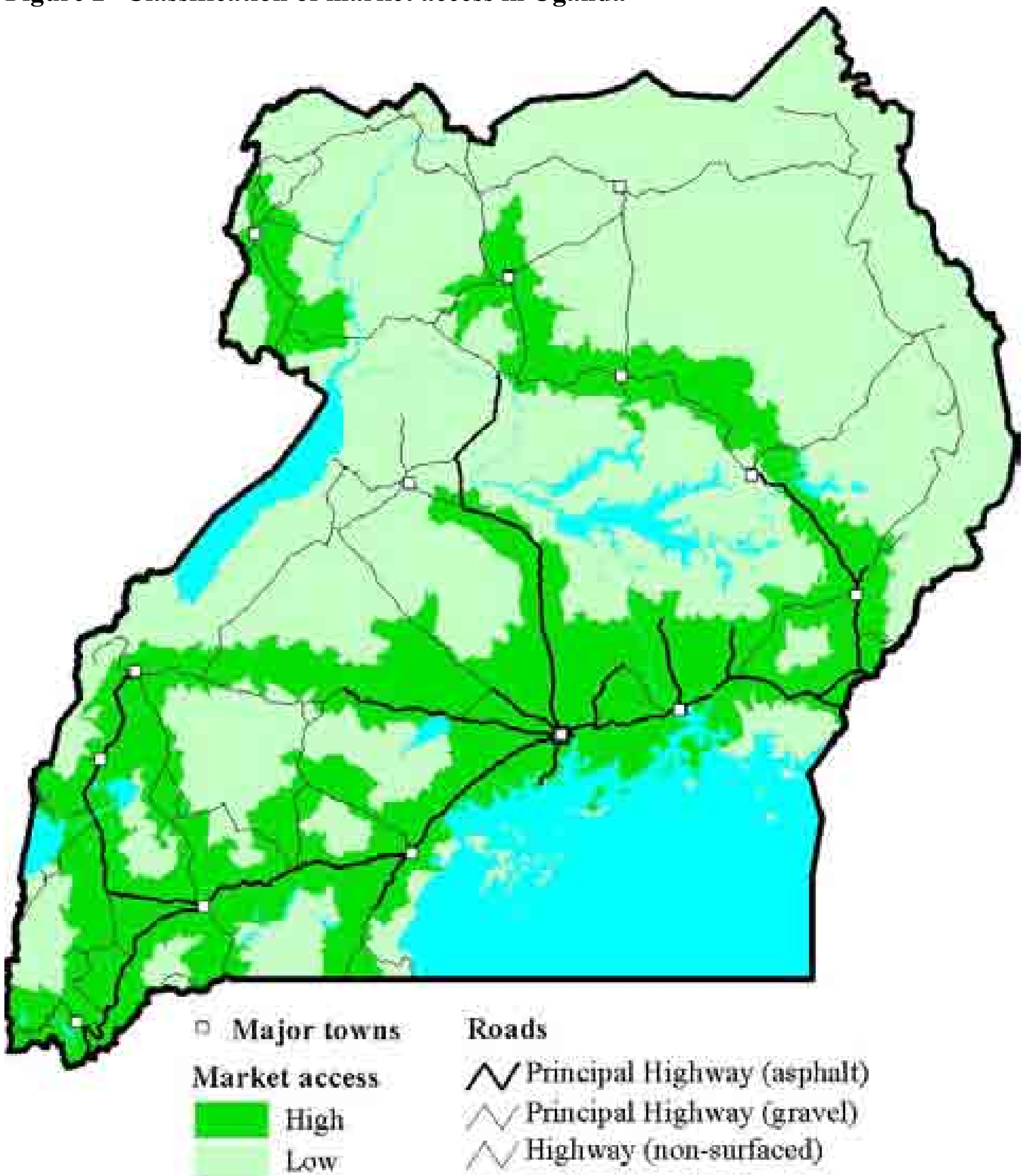
Population density and wage rates: The population density of the parish of which the community was a part was used as an indicator of scarcity of land and other resources relative to the population. These data were provided by Ruecker, et al. (2003), based upon the 1991 Population Census and the National Biomass Study, which provided digitized boundaries of the parishes (used to calculate area of each parish). Local average agricultural wage rates for men and women in the study communities were also included in the analysis, as indicators of the scarcity of and returns to labor. Because of very high collinearity between wage rates of men and women, the wage rate for women was dropped from the analysis.

Figure 1--Agro-climatic zones in Uganda



Source: Ruecker, et al. (2003)

Figure 2--Classification of market access in Uganda



Source: Wood, et. al. (1999)

3. EMPIRICAL RESULTS

DESCRIPTIVE RESULTS

Results by Income Quintile

Descriptive statistics for the variables used in the analysis are reported by income quintile in Table 1. The income quintiles were constructed based on the mean consumption expenditure per adult equivalent. The mean consumption expenditure per adult equivalent was used together with the poverty lines derived by Appleton (2001a) to categorize households into poor and non-poor. Land is the most important asset in rural Uganda. Nearly 50 percent of total assets value was due to land, followed by buildings (24 percent). Livestock accounted for only 11 percent and farm equipment only about 2 percent. Not surprisingly, higher income households have more assets of all kinds.

Table 1--Selected key variables by income group

Income quintile	Share of income by source						Value of production per acre (Ush)	Household size
	Crop farming	Non-crop farming	Non-agricultural activities	Property	Other income	Employment		
Bottom	0.496	0.032	0.099	0.071	0.225	0.077	184,409	6.4
2	0.550	0.028	0.092	0.061	0.188	0.081	220,823	6.2
3	0.545	0.025	0.095	0.068	0.181	0.087	239,623	5.7
4	0.538	0.032	0.109	0.064	0.173	0.083	255,560	5.1
Top	0.496	0.041	0.121	0.071	0.179	0.092	279,343	4.5
All	0.525	0.032	0.103	0.067	0.190	0.084	235,020	5.6

	Dependency ratio	Proportion of adult days lost	Proportion of female adult	*Education*			Age		
				Adult	Male adult	Female adult	Female adult	Male adult	Head
Bottom	0.573	0.087	0.555	2.8	4.0	1.9	35.5	35.8	45.7
2	0.563	0.097	0.549	3.7	4.8	2.7	34.9	36.1	44.7
3	0.537	0.098	0.535	3.9	5.0	3.1	35.2	36.2	44.6
4	0.500	0.112	0.551	4.1	5.2	3.5	35.3	37.0	44.1
Top	0.463	0.132	0.549	4.9	6.1	4.3	36.4	37.7	45.0
All	0.528	0.105	0.548	3.9	5.0	3.1	35.4	36.5	44.8

		Land tenure		Means of land acquisition				
	Mailo	Customary	Others	Purchased	Free	Inherited	Others	Farm size
Bottom	0.358	0.566	0.076	0.204	0.434	0.303	0.145	2.0
2	0.511	0.428	0.062	0.257	0.413	0.291	0.135	2.2
3	0.567	0.355	0.079	0.296	0.371	0.258	0.158	2.5
4	0.590	0.340	0.070	0.301	0.394	0.241	0.169	2.6
Top	0.616	0.296	0.088	0.347	0.359	0.237	0.147	3.1
All	0.525	0.400	0.075	0.280	0.395	0.267	0.151	2.5

Table 2--Selected key variables by income group (continued)

Income quintile	Assets (Ush)							
	Land	Buildings	Durables	Livestock	Equipment	Total assets	Extension	Market information
Bottom	96,707	31,164	9,997	63,434	1,954	203,255	0.078	0.243
2	169,079	49,152	18,538	28,558	3,522	268,848	0.119	0.274
3	383,681	77,568	26,616	39,050	3,443	530,360	0.119	0.300
4	305,968	106,747	37,484	46,443	10,644	507,285	0.149	0.284
Top	639,223	360,872	93,642	92,986	11,175	1,197,897	0.146	0.312
All	314,266	122,879	36,651	54,063	6,066	533,925	0.121	0.282

	Non-labor inputs/Land management investment (Ush per acre)				
	Traditional seeds	Fertilizers/Pesticides	Improved seeds	Other non-labor inputs	Access to loan
Bottom	8,341	406	505	1,228	0.129
2	9,377	946	655	1,563	0.148
3	9,196	1,516	1,036	1,522	0.180
4	10,298	1,784	912	1,641	0.203
Top	9,737	3,213	1,214	2,257	0.214
All	9,389	1,573	864	1,642	0.174

The average cultivated area was about 2.5 acres, a finding consistent with official publications. Differences in average area cultivated per household were observed across the different agro-ecological zones; lowest at 2.0 acres in the unimodal high rainfall zone and highest in unimodal very low rainfall zone (2.6 acres). The non-poor farming households had higher area under cultivation (2.6 acres compared to 2.1 acres for the poor households). In some districts, it is evident from the survey results that households are already experiencing difficulties in increasing the cultivated area. This suggests that the extent to which increasing crop yields can contribute to future agricultural growth and in turn to poverty alleviation will be critical to Uganda's agricultural performance.

The survey results indicate that land tenure system changed little between 1992 and 1999 despite the new Land Act of 1997, which has not yet been fully implemented. In 1999/2000, about 55 percent of total cultivated land was under *mailo* occupancy,[9] followed by 42 percent under customary tenure. Other types of tenure included leasehold, *mailo* ownership, and squatters. The most common means of land acquisition were freely[10] acquired, accounting for almost 40 percent, followed by purchasing (28 percent), inheritance (27 percent) and others (15 percent, mainly cash rental). Across income quintiles some patterns emerge. The share of farm size under *mailo* occupancy tends to be distributed regressively, while the reverse is true for customary tenure. The means of land acquisition also varies with income levels: acquiring land through purchase is more

[9] *Mailo* land refers to freehold land that was distributed in square mile units to the royal family and other elites by the British colonial government, but which is mostly occupied by long-term occupants, who have acquired increasingly secure rights over time (Place, et al. 2001). The rights of *mailo* occupants were codified by the 1998 Land Act, which provided for recognition of freehold status of long-term *mailo* occupants. The Land Act has yet to be fully implemented however.
[10] This is land freely acquired other than through inheritance (i.e., by occupation).

common among richer households while acquisition through inheritance is more common among poorer ones.

On average, household heads were 44 years of age, suggesting that farming households tend to be late in their life cycle. Men are more educated on average, having received about 5 years of formal education compared to 3 years for women. Households with more educated adults tend to have higher incomes, as one would expect. Sickness is an important factor affecting agricultural production; more than 10 percent of adult days were lost on average due to sickness.

Access to agricultural extension, market information and credit is still very low in general. Only 12 percent of households had contact with an extension agent in 1999/2000, while 28 percent had access to market information and 17 percent had taken a loan. Higher income households have better access to these services, however.

Crop farming was the main source of income: it accounted for nearly 53 percent of total household income on average, while non-crop farming accounted for only 3 percent. Non-agricultural enterprises accounted for 10 percent of income, employment income for 8 percent and other income (e.g., property income, transfers, etc.) for 19 percent. In total, non-farm income contributes a substantial proportion (more than 40 percent) to total household income. For all income quintiles, income derived from crop farming dominates followed by income earned from other sources. In addition, the poor and the rich derived more than half of their incomes from crop farming, with disproportionately higher reliance on crops from the poor. By extension different income sources appear to be of differing relevance to the poorer quintiles.

In general, non-poor households invested more in land management practices compared to the poor. For example, households in the top income quintile spent over 4400 USh. per acre on fertilizers, improved seeds and pesticides, compared to only about 900 USh per acre by those in the bottom quintile. The poor also have a lower value of production per acre than the non-poor, consistent with their lower use of inputs.

Differences Across Regions

National and regional averages in 1999/2000 of variables reflecting crop choice, land management, production, income, and the factors expected to affect these variables are compared in Table 2. Most of these variables differ across the regions of the country.[11]

[11] The regions are groupings of districts used by UBOS in analyzing the UNHS data. The central region includes the districts of Kalangala, Kampala, Kiboga, Luwero, Masaka, Mpigi, Mubende, Mukono, Nakasongola, and Rakai. The eastern region includes the districts of Bugiri, Busia, Iganga, Jinja, Kamuli, Kapchorwa, Katakwi, Kumi, Mbale, Pallisa, Soroti, and Tororo. The northern region includes the districts of Adjumani, Apac, Arua, Gulu, Kitgum, Kotido, Lira, Moroto, Moyo, and Nebbi. The western region includes the districts of Bundibugyo, Bushenyi, Hoima, Kabale, Kabarole, Kasese, Kibaale, Kisoro, Masindi, Mbarara, Ntungamo, and Runkungiri.

Table 2--Means and standard errors of variables

Variable	Full Sample		Central Region[a]		Eastern Region[a]		Northern Region[a]		Western Region[a]	
	Mean	Std. error	Mean	Std. error	Mean	Std. error	Mean	Std. error	Mean	Std. error
CROP MIX **(SHARE OF AREA)**										
- CEREALS	0.173***	0.007	0.102[bcd]	0.010	0.227[bf]	0.012	0.229[cg]	0.023	0.145[dfg]	0.006
- MATOOKE	0.109***	0.005	0.152 [bc]	0.009	0.072[bef]	0.006	0.025[ceg]	0.004	0.166[fg]	0.008
- LEGUMES	0.118***	0.004	0.070[bcd]	0.005	0.096[bef]	0.007	0.198[ceg]	0.012	0.131[dfg]	0.007
- ROOT CROPS	0.218***	0.005	0.213[bc]	0.007	0.205[bef]	0.008	0.259[ceg]	0.020	0.205[fg]	0.007
- COFFEE	0.036***	0.002	0.068[bcd]	0.005	0.026[be]	0.003	0.008[ceg]	0.003	0.035[dg]	0.004
- CEREALS/LEGUMES	0.173***	0.006	0.136[bcd]	0.007	0.195[bf]	0.011	0.194[cg]	0.016	0.169[dfg]	0.009
- MATOOKE/COFFEE	0.058***	0.003	0.112[bcd]	0.007	0.058[bef]	0.006	0.009[ceg]	0.003	0.042[dfg]	0.004
- LEGUMES/ROOT CROPS	0.074***	0.004	0.054[bc]	0.006	0.044[bef]	0.006	0.160[ceg]	0.014	0.064[fg]	0.006
- MATOOKE/LEGUMES	0.063***	0.004	0.053[bcd]	0.005	0.069[bef]	0.009	0.014[ceg]	0.004	0.103[dfg]	0.008
INPUTS **(USH/ACRE)**										
LN(LABOR USED/ACRE)	0.639***	0.009	0.587[bc]	0.014	0.685[b]	0.014	0.691[cg]	0.025	0.604[g]	0.015
LN(ORGANIC FERT/ACRE)	0.492***	0.036	1.084[bcd]	0.099	0.246[b]	0.045	0.117[c]	0.041	0.448[d]	0.056
LN(INORGANIC FERT/ACRE)	0.278***	0.040	0.341[c]	0.072	0.268[e]	0.049	0.271[ceg]	0.072	0.231[g]	0.092
LN(PESTICIDE/ACRE)	0.652***	0.037	0.984[bcd]	0.086	0.829[be]	0.072	0.307[ce]	0.054	0.401[d]	0.050
LN(TRAD. SEEDS/ACRE)	5.805***	0.081	6.166[cd]	0.109	6.079[ef]	0.130	4.360[ceg]	0.201	6.226[dfg]	0.118
LN(IMPROVED SEEDS/ACRE)	1.288***	0.069	1.493[bd]	0.117	1.751[bef]	0.151	0.976[eg]	0.123	0.843[dfg]	0.123
LN(OTHER NON-LABOR/ACRE)	1.046***	0.065	0.451[bc]	0.071	1.905[bf]	0.140	1.327[cg]	0.157	0.531[fg]	0.076
LN(VALUE OF PROD./ACRE**)**	11.950***	0.039	12.149[bcd]	0.035	12.013[bef]	0.042	11.186[ceg]	0.146	12.247[dfg]	0.036
LN(INCOME PER CAPITA**)**	13.734***	0.015	13.920[bcd]	0.028	13.675[bef]	0.027	13.321[ceg]	0.040	13.914[dfg]	0.026
NATURAL CAPITAL										
ln(Area farmed)	1.111***	0.008	1.132[cd]	0.015	1.122[ef]	0.015	1.096[ce]	0.023	1.089[df]	0.017
ln(Land value/acre)	12.795***	0.023	12.882[bcd]	0.050	12.740[bef]	0.048	12.082[ceg]	0.090	13.183[dfg]	0.048
LAND TENURE										
ln(Years holding land)	2.534***	0.013	2.492[cd]	0.027	2.477[ef]	0.024	2.646[ce]	0.032	2.561[df]	0.022
Proportion women's land	0.107***	0.004	0.073[bcd]	0.007	0.132[b]	0.010	0.113[c]	0.012	0.109[d]	0.008
How acquired (cf. rented)										
- Share purchased	0.280***	0.007	0.391[bcd]	0.014	0.252[bef]	0.014	0.070[ceg]	0.011	0.351[dfg]	0.015
- Share free land	0.395***	0.007	0.348[bc]	0.012	0.381[bef]	0.014	0.576[ceg]	0.020	0.325[fg]	0.013

Table 2--Means and standard errors of variables (continued)

Variable	Full Sample		Central Region[a]		Eastern Region[a]		Northern Region[a]		Western Region[a]	
	Mean	Std. error	Mean	Std. error	Mean	Std. error	Mean	Std. error	Mean	Std. error
- Share inherited	0.266[***]	0.007	0.182[bcd]	0.013	0.301[be]	0.018	0.344[ceg]	0.025	0.257[dg]	0.014
Land tenure (cf. customary)										
- Share *mailo*	0.525[***]	0.008	0.793[bcd]	0.021	0.492[bef]	0.026	0.093[ceg]	0.018	0.613[dfg]	0.022
- Share other	0.075[***]	0.004	0.087[bcd]	0.007	0.061[b]	0.007	0.087[c]	0.015	0.069[d]	0.006
PHYSICAL CAPITAL										
ln(Value of buildings)	11.364[***]	0.046	11.444[bcd]	0.110	11.258[be]	0.094	10.423[ceg]	0.092	12.078[dg]	0.095
ln(Value of durables)	10.980[***]	0.036	11.500[c]	0.068	10.934[e]	0.080	9.788[ceg]	0.104	11.384[g]	0.055
ln(Value of livestock)	8.183	0.078	7.544	0.154	8.594	0.158	8.157	0.196	8.399	0.160
ln(Value of equipment)	8.829	0.023	9.040	0.037	8.801	0.044	8.475	0.071	8.910	0.040
HUMAN CAPITAL										
ln(No. of adult equivalent)	1.558[***]	0.006	1.534[d]	0.011	1.545[ef]	0.010	1.548[eg]	0.016	1.601[dfg]	0.011
Proportion of dependents	0.528	0.003	0.530	0.006	0.533	0.006	0.520	0.009	0.526	0.006
Female household head	0.250[***]	0.007	0.258[bd]	0.012	0.228[bef]	0.010	0.296[eg]	0.022	0.230[dfg]	0.011
ln(Age of household head)	3.740	0.005	3.741	0.009	3.743	0.009	3.735	0.010	3.739	0.010
Median educ. of males	5.002[**]	0.062	5.120[d]	0.118	5.088[f]	0.104	4.808	0.217	4.939[df]	0.104
Median educ. of females	3.067[***]	0.055	3.658[bcd]	0.128	3.060[be]	0.095	2.033[ceg]	0.143	3.279[dg]	0.100
ln(Prop. days lost to illness)	0.089[**]	0.002	0.081[bc]	0.003	0.094[b]	0.004	0.091[c]	0.005	0.091	0.003
ETHNICITY										
- Baganda	0.104[***]	0.006	0.328[bcd]	0.025	0.027[b]	0.007	0.018[c]	0.008	0.031[d]	0.008
- Basoga	0.078[***]	0.005	0.044[bc]	0.011	0.195[bef]	0.025	0.014[ce]	0.007	0.038[f]	0.011
- Iteso	0.079[***]	0.006	0.032[b]	0.010	0.230[bef]	0.032	0.006[e]	0.005	0.022[f]	0.008
- Bagisu	0.059[***]	0.004	0.042[bc]	0.014	0.139[bef]	0.023	0.013[ce]	0.007	0.027[f]	0.010
- Langi	0.067[***]	0.005	0.011[c]	0.007	0.010[e]	0.007	0.292[ce]	0.039	0.016	0.008
- Lugbara	0.041[***]	0.004	0.016[c]	0.009	0.022[e]	0.008	0.147[ceg]	0.031	0.007[g]	0.003
- Ankole	0.108[***]	0.005	0.085[bcd]	0.016	0.030[bf]	0.009	0.007[cg]	0.006	0.283[dfg]	0.030
- Bakiga	0.097[***]	0.006	0.056[bcd]	0.011	0.048[bef]	0.011	0.022[ceg]	0.010	0.240[dfg]	0.025
- Banyoro	0.032[***]	0.003	0.026[cd]	0.007	0.018[f]	0.006	0.003[cg]	0.002	0.073[dfg]	0.016
ACCESS TO INFORMATION/SERVICES										
Extension service dummy	0.117[***]	0.005	0.094[bc]	0.009	0.142[b]	0.011	0.121[c]	0.015	0.113	0.009
Market information dummy	0.277[***]	0.008	0.367[bcd]	0.017	0.293[bef]	0.019	0.248[ceg]	0.023	0.192[dfg]	0.014
Loan access dummy	0.174[***]	0.005	0.153[bcd]	0.011	0.195[bef]	0.011	0.113[ceg]	0.012	0.218[dfg]	0.011

Table 2--Means and standard errors of variables (continued)

Variable	Full Sample		Central Region[a]		Eastern Region[a]		Northern Region[a]		Western Region[a]	
	Mean	Std. error	Mean	Std. error	Mean	Std. error	Mean	Std. error	Mean	Std. error
Access to markets/transport										
High market access dummy	0.599***	0.017	0.740[bcd]	0.031	0.594[be]	0.035	0.378[ceg]	0.046	0.627[dg]	0.037
Dist. to all weather road (km.)	4.340***	0.515	1.933[bcd]	0.380	3.512[be]	1.108	8.895[ceg]	2.107	4.250[dg]	1.477
Dist. to truck service (km.)	11.250***	0.547	8.187[bc]	0.881	10.885[bef]	1.113	23.240[ceg]	2.810	6.736[fg]	0.871
Dist. to minibus/taxi service	6.074***	0.316	5.001[c]	0.615	5.597[e]	0.848	9.180[ceg]	1.172	5.429[g]	0.513
Land and labor scarcity										
ln(Wage rate of men) (Ush/day)	6.816***	0.016	7.073[bcd]	0.039	6.775[bef]	0.027	6.428[ceg]	0.047	6.894[dfg]	0.022
ln(Population dens.) (#/km^2)	4.812***	0.031	4.841[bcd]	0.064	5.095[bef]	0.052	4.225[ceg]	0.131	4.912[dfg]	0.055
Agro-climatic zone										
- Unimodal v. low/low/medium	0.214	0.010***	0.044[bc]	0.017	0.191[bef]	0.029	0.718[ceg]	0.041	0.038[fg]	0.016
- Unimodal high	0.031	0.004***	0.011[b]	0.006	0.085[bef]	0.019	0.016[e]	0.009	0.004[f]	0.004
- Bimodal low	0.092	0.009***	0.139[bc]	0.022	0.019[bef]	0.007	0.018[ceg]	0.010	0.175[fg]	0.027
- Bimodal medium	0.311	0.013***	0.272[bcd]	0.030	0.379[bef]	0.031	0.185[ceg]	0.034	0.372[dfg]	0.033

*, **, *** mean statistically significant difference across regions at the 10%, 5%, and 1% levels, respectively. Means and standard errors adjusted for sampling weights and robust to heteroskedasticity.

[a] The central region includes the districts of Kalangala, Kampala, Kiboga, Luwero, Masaka, Mpigi, Mubende, Mukono, Nakasongola, and Rakai. The eastern region includes the districts of Bugiri, Busia, Iganga, Jinja, Kamuli, Kapchorwa, Katakwi, Kumi, Mbale, Pallisa, Soroti, and Tororo. The northern region includes the districts of Adjumani, Apac, Arua, Kotido, Lira, Moroto, Moyo, and Nebbi. The western region includes the districts of Bushenyi, Hoima, Kabale, Kabarole, Kibaale, Kisoro, Masindi, Mbarara, Ntungamo, and Runkungiri. The districts of Gulu and Kitgum in the north and Bundibugyo and Kasese in the west were not covered by the UNHS due to insecurity.

[b] means significant difference between central and eastern regions ($p<0.05$)

[c] means significant difference between central and northern regions ($p<0.05$)

[d] means significant difference between central and western regions ($p<0.05$)

[e] means significant difference between eastern and northern regions ($p<0.05$)

[f] means significant difference between eastern and western regions ($p<0.05$)

[g] means significant difference between northern and western regions ($p<0.005$)

The most common crops or crop mixes produced were root crops, cereals, cereals/legumes, legumes and matooke. Root crops were most common in the northern region, though fairly common everywhere. Legumes and legumes/root crops mixes were also most common in the northern region. Cereals and cereals/legumes mixed cropping were most common in the northern and eastern regions. Matooke was most common in the western and central regions, while matooke/coffee was most common in the central region. Matooke/legumes was most common in the western region.

Labor intensity in crop production was greatest in the northern and eastern regions. Average use of organic fertilizer was much greater in the central region than the others, followed by the western region. Use of inorganic fertilizer and pesticides was greatest in the central region. Use of improved seeds and other non-labor inputs was greatest in the eastern region.

The average value of crop production per acre was greatest in the western region, followed by the central region. Household per capita income was also highest in these two regions, but somewhat higher in the central region.

There are also significant differences across regions in average farm size, land value, land tenure, asset ownership, human capital, ethnicity, access to information and services, access to markets, roads and transportation, labor and land scarcity, and agro-climatic conditions (see Table 2 for details). Such differences across regions and households must be accounted for if we are to understand the reasons for differences in cropping choices, input use, production and incomes. That is the purpose of the multivariate econometric analysis discussed in the next section.

Econometric Results

The econometric results are presented in Tables 3 to 10. In this section we discuss the results for each type of dependent variable.

Labor Intensity

The results of OLS and IV estimation of determinants of labor intensity are reported in Table 3.

Table 3--Determinants of Labor Intensity (ln(person-days/ha.))

Ordinary least squares (OLS) and instrumental variables (IV) estimation

Variable	**OLS**	**IV**[a]
NATURAL CAPITAL		
ln(Area farmed)	-0.546***R	-0.578***
ln(Land value/acre)	0.012*R	0.012*
LAND TENURE		
ln(Years holding land)	0.029***R	0.026***
Proportion women's land	-0.145***R	-0.152***
How land acquired (cf. rented)		
- Share purchased	0.039*	0.047*
- Share free land	-0.021	-0.012
- Share inherited	0.041*	0.049**
Land tenure (cf. customary)		
- Share *mailo*	-0.007	-0.016
- Share other	-0.061*	-0.066
PHYSICAL CAPITAL		
ln(Value of buildings)	0.000	-0.001
ln(Value of durables)	-0.006	-0.004
ln(Value of livestock)	0.001	0.001
ln(Value of equipment)	-0.001	-0.003
HUMAN CAPITAL		
ln(Number of adult equivalent)	0.550***R	0.557***
Proportion of dependents	-0.208***R	-0.233***
Female household head	0.040*	0.036
ln(Age of household head)	0.103***R	0.102***
Median education of males	0.004*	0.003
Median education of females	-0.007***R	-0.006**
ln(Prop. days lost due to illness)	-0.121**	-0.094
ETHNICITY		
- Baganda	0.012	0.006
- Basoga	0.038R	0.003
- Iteso	0.056**R	0.060
- Bagisu	0.002	0.006
- Langi	0.137***R	0.122**
- Lugbara	-0.015	-0.033
- Ankole	-0.060***R	-0.047

Table 3--Determinants of Labor Intensity (ln(person-days/ha.)) (continued)

Ordinary least squares (OLS) and instrumental variables (IV) estimation

Variable	**OLS**	**IV[a]**
- Bakiga	-0.090***R	-0.072*
- Banyoro	-0.028	-0.022
ACCESS TO INFORMATION/SERVICES		
Extension service dummy	0.003	0.186
Market information dummy	0.010	0.101
Loan access dummy	0.007	-0.006
Access to markets and transport		
High market access dummy	-0.017	-0.018
Dist. to all weather road (km.)	0.000	0.000
Dist. to truck service (km.)	0.001***R	0.001*
Dist. to minibus/taxi service	0.000	0.001
Land and labor scarcity		
ln(Wage rate of men) (Ush/day)	-0.043***R	-0.040***
ln(Population dens.) (#/km^2)	0.026***R	0.022*
Agro-climatic zone (cf., bimodal high rainfall)		
- Unimodal v. low/low/medium	0.054*R	0.063**
- Unimodal high	0.148***R	0.165***
- Bimodal low	0.045**R	0.052**
- Bimodal medium	-0.028*R	-0.015
Intercept	0.106	0.112
Number of observations	4103	3977
R^2	0.431	
Wu-Hausman test of exogeneity of extension, market information, loan variables		p=0.0001***
Relevance tests of excluded instruments	Extension	p=0.004***
	Market information	p=0.000***
	Loan	p=0.242
Hansen's J test of overidentifying restrictions		p=0.111

[a] Instrumental variables used to predict participation in extension, access to market information and use of a loan include all of the other explanatory variables, plus several community level variables representing distance and time to the most common market, the location of the nearest market, the common transportation modes to the nearest market, availability of formal or informal credit, and the sources of credit.

*, **, *** mean statistical significance at the 10%, 5%, and 1% levels, respectively. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.

[R] means that the coefficient was the same sign and statistically significant at 10% level in an OLS model excluding the potentially endogenous variables (participation in extension, market information, and loan use).

The results of both approaches are quite similar, with most coefficients similar in magnitude, and robust findings of statistical significance across the two OLS specifications and the IV specification in almost all cases. Nevertheless, the OLS model is rejected as inconsistent by the Wu-Hausman test, while the tests of relevance and overidentification support the instrumental variables used in the IV model. We therefore focus on the coefficients that are statistically significant in the IV model.

Larger farms use labor less intensively, suggesting that larger farms face labor constraints limiting their ability and incentive to farm intensively, and that land and labor market imperfections are present (Feder 1985). The role of labor constraints and factor market imperfections is also suggested by the fact that households with a larger labor endowment farm more intensively while a larger share of dependents is associated with less labor intensity. Land farmed by women is farmed less intensively, probably reflecting labor constraints facing women farmers. Similarly, households in which females are more educated farm less intensively, reflecting higher labor opportunity costs as a result of higher education. Households with older heads use labor more intensively, perhaps because more farming experience increases the return to labor invested in agriculture.

Not surprisingly, labor intensity is lower where wage rates are higher. Labor intensity is also higher in more densely populated communities, suggesting that resource scarcity at the community level, even controlling for local wage rates and household land and labor endowments, contributes to intensification. These results are consistent with Boserup's (1965) theory of population-induced intensification.

Land quality (as measured by land value) contributes to higher labor intensity (weakly significant at 10 percent level), probably because the marginal return to labor effort is greater on higher quality land. Households that have held their land for a longer period (controlling for the age of the household head) farm the land more intensively, perhaps due to effects of greater tenure security. Land that was purchased or inherited is farmed more intensively than rented land, possibly for a similar reason.

Labor intensity differs across some ethnic groups, being highest among the Langi and lowest among the Bakiga, controlling for other factors. Labor intensity also differs across agro-climatic zones, being higher in the unimodal rainfall zones and the bimodal low rainfall zone than in the bimodal medium and high rainfall zones. This may reflect production of more labor-intensive crops in these areas.

The determinants of labor intensity differ significantly across the regions of Uganda.[12] Nevertheless, many of the results are qualitatively similar across several regions (Table 4).

[12] A Chow test of equality of all coefficients in the labor intensity regression across the four regions was rejected (p= 0.0000).

Table 4--Determinants of labor intensity by region

Instrumental variables regressions[a]

Variable	Central	Eastern	Northern	Western
NATURAL CAPITAL				
ln(Area farmed)	-0.536***	-0.590***	-0.656***	-0.584***
ln(Land value/acre)	0.014	0.012	0.010	0.021
LAND TENURE				
ln(Years holding land)	0.032	0.012	-0.008	0.027*
Proportion women's land	-0.132	-0.168***	-0.017	-0.188***
How land acquired (cf. rented)				
- Share purchased	-0.092*	0.024	-0.125	0.146***
- Share free land	-0.104**	-0.014	-0.004	0.079
- Share inherited	-0.074	-0.014	0.028	0.148***
Land tenure (cf. customary)				
- Share *mailo*	-0.156*	-0.005	0.127	0.012
- Share other	-0.188**	-0.074	0.066	-0.064
PHYSICAL CAPITAL				
ln(Value of buildings)	0.007	-0.017***	0.003	-0.001
ln(Value of durables)	-0.025***	0.000	-0.007	-0.007
ln(Value of livestock)	0.000	0.001	-0.001	0.001
ln(Value of equipment)	-0.007	0.008	-0.004	-0.006
HUMAN CAPITAL				
ln(Number of adult equivalent)	0.627***	0.564***	0.516***	0.494***
Proportion of dependents	-0.253***	-0.146**	-0.279*	-0.339***
Female household head	0.034	0.102**	-0.062	0.002
ln(Age of household head)	0.121***	0.166***	0.134	0.129***
Median education of males	0.010	0.007	-0.001	-0.005
Median education of females	-0.008*	-0.008	-0.011	-0.004
ln(Prop. days lost due to illness)	-0.286**	0.036	-0.234	-0.095
ETHNICITY				
- Baganda	0.045	-0.147	-0.637	0.049
- Basoga	-0.068	-0.159**	-0.071	-0.053
- Iteso	-0.064	-0.004	0.069	0.175
- Bagisu	0.135*	-0.092	-0.676***	-0.109
- Langi	0.218*	-0.281***	0.168**	0.132
- Lugbara	-0.085	-0.080	-0.036	-0.059
- Ankole	-0.028	0.035	-0.155	-0.031
- Bakiga	-0.073	-0.044	-0.439***	-0.011
- Banyoro	-0.046	0.143	-1.523**	0.004
ACCESS TO INFORMATION/SERVICES				
Extension service dummy	0.064	0.133	-0.386	0.309
Market information dummy	0.217	0.430**	0.112	0.076
Loan access dummy	0.196	-0.095	0.472	0.082
Access to markets and transport				
High market access dummy	-0.071*	-0.007	0.080	0.018
Dist. to all weather road (km.)	0.001	0.000	-0.002*	-0.001***
Dist. to truck service (km.)	0.000	0.001	0.001	0.001
Dist. to minibus/taxi service	0.002	0.001	0.002	0.001
Land and labor scarcity				
ln(Wage rate of men) (Ush/day)	-0.042	-0.043	0.021	0.005
ln(Population dens.) (#/km^2)	-0.006	0.046*	0.030	0.001

Table 4--Determinants of labor intensity by region (continued)

Instrumental variables regressions[a]

Variable	Central	Eastern	Northern	Western
Agro-climatic zone				
- Unimodal v. low/low/medium	-0.031	0.207***	0.052	0.152**
- Unimodal high	0.060	0.251***	0.514***	0.212**
- Bimodal low	0.070	0.093	0.173	0.014
- Bimodal medium	-0.024	0.055	0.050	-0.042
Intercept	0.373	-0.251	-0.079	-0.236
Number of observations	990	1146	565	1303

[a] Instrumental variables used to predict participation in extension, access to market information and use of a loan include all of the other explanatory variables, plus several community level variables representing distance and time to the most common market, the location of the nearest market, the common transportation modes to the nearest market, availability of formal or informal credit, and the sources of credit.

*, **, *** mean statistical significance at the 10%, 5%, and 1% levels, respectively. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.

Labor intensity is decreasing in farm size and proportion of dependents and increasing in household size in all regions, increasing with age of the household head in three of the four regions and decreasing in the proportion of land farmed by women in two of the regions. The effects of other factors on labor intensity, such as access to roads, land tenure and ethnicity, appear to be more location-specific. For example, households with better access to an all-weather road use labor more intensively in the western and northern region (weakly significant at 10 percent level in the northern region), but the impact of road access is insignificant in the other regions.

Overall, these results indicate the importance of land and labor constraints, labor opportunity costs, and land quality in determining the labor intensity of crop production. Poorer communities and households that have smaller land endowments relative to their labor endowment or less educated females tend to farm more intensively. On the other hand, households that are wealthier in terms of land value tend to farm more intensively. Other factors, such as access to information, services, markets and transport were not found to have large impacts on labor intensity.

Land Management/Non-labor Inputs

Determinants of land management practices/use of non-labor inputs—including organic fertilizer, inorganic fertilizer, pesticides, traditional seeds, improved seeds, and other non-labor inputs—are reported in Tables 5a and 5b.

Table 5a--Determinants of non-labor input use and amount used (Ush/acre)
(Maximum likelihood Heckman model)

Variable	Organic Fertilizer Use	Organic Fertilizer Amount	Inorganic Fertilizer Use	Inorganic Fertilizer Amount	Pesticides Use	Pesticides Amount
NATURAL CAPITAL						
ln(Area farmed)	0.452^{***R}	-0.384^{**R}	0.522^{***R}	-0.227^{R}	0.603^{***R}	-0.492^{***R}
ln(Land value/acre)	0.098^{***R}	0.107	0.019	$0.503^{***+++R}$	0.018	0.030
LAND TENURE						
ln(Years holding land)	-0.055	0.050	0.180^{**R}	$-0.651^{***---R}$	-0.027	0.012
Proportion women's land	0.006	-0.716^{**R}	-0.078	-0.929	-0.301^{*R}	-0.027
How land acquired						
- Share purchased	0.047	0.211	-0.749^{***R}	0.466^{R}	-0.109	0.152
- Share free land	0.019	0.085	-0.469^{**R}	0.450	0.006	0.334
- Share inherited	0.256	0.256	-0.571^{***R}	0.447	-0.080	0.254
Land tenure (cf. customary)						
- Share *mailo*	0.284^{**R}	1.041^{***++R}	0.219	-0.381^{R}	0.257^{**R}	0.519^{**R}
- Share other	0.235	0.732^{*R}	0.168	-0.080	0.372^{**R}	0.543^{*R}
PHYSICAL CAPITAL						
ln(Value of buildings)	0.008	0.066^{**+++R}	0.017	-0.010	-0.003	0.017
ln(Value of durables)	0.057	0.127^{*R}	0.030	-0.114^{**---R}	0.070^{*R}	0.186^{***R}
ln(Value of livestock)	0.031^{***R}	-0.011	0.007	0.011	0.008	0.017
ln(Value of equipment)	0.083^{**R}	0.112^{*R}	0.134^{***R}	-0.001	0.102^{***R}	0.076
HUMAN CAPITAL						
ln(No. of adult equivalent)	-0.156	0.152	-0.363^{**R}	-0.012	-0.065	0.302
Proportion of dependents	0.026	-0.154	0.274	0.503	-0.099	-0.737^{*}
Female household head	0.188	-0.287	-0.418^{**R}	0.494	-0.202^{R}	-0.975^{***-R}
ln(Age of household head)	-0.194	-0.597^{*R}	-0.414^{**R}	$1.393^{***+++R}$	-0.333^{**R}	-0.599^{**R}
Median education of males	0.038^{***R}	0.056^{**R}	0.028^{*R}	-0.013	0.016	-0.010
Median education of females	0.012	0.019	0.025^{R}	0.043^{+}	0.012	0.036
ln(Prop. days lost to illness)	0.597^{**R}	0.231	0.302	-1.416^{*-}	-0.143	-1.663^{***---}
ETHNICITY						
- Baganda	1.205^{***R}	0.913^{*R}	0.357	NE	0.335^{**R}	0.327
- Basoga	-0.451^{**R}	-1.623^{***R}	-0.151	NE	0.112	0.036
- Iteso	-0.912^{***R}	-1.936^{**R}	-0.870^{***R}	NE	0.558^{***R}	0.104
- Bagisu	0.199	0.093	0.970^{***}	NE	0.251	0.637
- Langi	-0.190	0.354	-0.952^{**R}	NE	-0.166	-0.618^{*R}
- Lugbara	-0.155	-0.312	0.913^{***R}	NE	0.281	0.446
- Ankole	-0.026	0.154	-0.305	NE	-0.625^{***R}	-0.090
- Bakiga	0.099	-0.073	0.282	NE	-0.604^{***R}	-0.984^{*R}
- Banyoro	0.259	0.841	0.263	NE	-0.205	0.692^{+}
ACCESS TO INFORMATION/SERVICES						
Extension service dummy	0.304^{***}	0.130	0.300^{***}	-0.587^{***-}	0.137	-0.021
Market information dummy	-0.019	0.092	0.215^{**}	0.335	0.115	0.266^{*}

Table 5a--Determinants of non-labor input use and amount used (Ush/acre) (continued)

(Maximum likelihood Heckman model)

	Organic Fertilizer		**Inorganic Fertilizer**		**Pesticides**	
Variable	Use	Amount	Use	Amount	Use	Amount
Loan access dummy	0.128	0.101	0.214**	0.201	0.100	0.057
Access to markets/transport						
High market access dummy	0.218^{**R}	0.471^{*R}	-0.080	-0.218^{R}	0.139*	-0.024
Dist. to all weather road (km.)	-0.011^{*R}	0.026	-0.010^{R}	-0.028^{*-R}	-0.007^{**R}	-0.008
Dist. to truck service (km.)	0.004	0.005	-0.003	-0.003	0.003	0.003
Dist. to minibus/taxi service	0.005	-0.016	0.005	0.010	-0.009^{*R}	-0.003
Land and labor scarcity						
ln(Wage rate of men) (Ush/day)	-0.025	0.076	0.116	0.542^{*+R}	0.013	0.267^{*R}
ln(Population dens.) (#/km^2)	0.168^{**R}	0.116	0.123^{R}	-0.091	0.118^{**R}	-0.055
Agro-climatic zone						
- Unimodal v. low/low/medium	-0.483^{**R}	1.134	0.820^{***R}	1.186^{+++}	0.260^{R}	-0.454
- Unimodal high	-0.347	-0.946	0.217	0.167	0.154	-0.039
- Bimodal low	-0.048	-0.429	-0.672^{**R}	-0.221	-0.112	-0.248
- Bimodal medium	-0.560^{***R}	-0.905^{***R}	-0.431^{***R}	-0.279	0.091	-0.344^{*R}
Intercept	-5.649^{***R}	2.114	-4.595^{***R}	-3.182	-3.808^{***R}	3.828^{*R}
Number of observations	4130		4130		4130	
Number of uncensored obs.	283		141		370	
Test of tobit model restrictions	p=0.0000***		p=0.0000***		p=0.0000***	
Test of independence of first and second stage equations	p=0.0695*		p=0.8758		p=0.0043***	
Wu-Hausman test of exogeneity of extension, market information and loan access	p=0.8406		p=0.0523*		p=0.5208	
Hansen's J Test of overidentifying restrictions in second stage IV models	p=0.2201		p=0.0572*		p=0.0021***	

$^{*, **, ***}$ mean statistical significance at the 10%, 5%, and 1% levels, respectively, in the Heckman model. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.

$^{+, ++, +++ (-, --, ---)}$ mean the coefficient is positive (negative) and statistically significant at the 10%, 5%, and 1% levels, respectively, in an IV estimation of the second stage of the Heckman model, using only observations with positive values of the dependent variable. Instrumental variables used to predict participation in extension, access to market information and use of a loan include all of the other explanatory variables, plus several community level variables representing distance and time to the most common market, the location of the nearest market, the common transportation modes to the nearest market, availability of formal or informal credit, and the sources of credit. The selection bias term (inverse Mills ratio) was dropped from the second stage IV regression for inorganic fertilizer because the test of independence failed to reject independence of the regression model from the selection equation. Dropping this term had little effect on the IV regression results for inorganic fertilizer.

^{R} means that the coefficient was the same sign and statistically significant at 10% level in a Heckman model excluding the potentially endogenous variables (participation in extension, market information, and loan use).

NE – The coefficients of the second stage model for inorganic fertilizer were not fully identified with all of the explanatory variables included. The model was estimated excluding the ethnicity variables in the second stage for this input. These variables were jointly statistically insignificant in the second stage IV regression, with or without the selection correction (p=0.4589 and p=0.5751, respectively).

Table 5b--Determinants of non-labor input use

(Maximum likelihood Heckman model)

Variable	Seeds Use	Seeds Amount	Improved Seeds Use	Improved Seeds Amount	Other non-labor inputs Use	Other non-labor inputs Amount
NATURAL CAPITAL						
ln(Area farmed)	0.210^{***R}	-0.721$^{***---R}$	0.485^{***R}	-0.859^{***--R}	0.566^{***R}	0.041^{++}
ln(Land value/acre)	-0.039	0.081^{***++R}	0.056^{**R}	0.083*	0.012	0.077^{**+++R}
LAND TENURE						
ln(Years holding land)	0.002	0.002	-0.004	0.054	-0.031	0.063
Proportion women's land	0.006	-0.077	-0.098	-0.195	-0.124	-0.136^{---}
How land acquired (cf. rented)						
- Share purchased	0.081	-0.251^{**---R}	-0.146	-0.098	0.085	0.076^{++}
- Share free land	0.165^{*R}	-0.245^{**--R}	-0.113	-0.308^{**R}	0.011	-0.031
- Share inherited	0.149	-0.311$^{***---R}$	-0.184	-0.202	0.029	-0.113
Land tenure (cf. customary)						
- Share *mailo*	0.393^{***R}	-0.168^{**R}	0.252^{***R}	-0.306^{*--R}	-0.093	0.121
- Share other	0.322^{**R}	-0.219	0.068	-0.072	-0.087	0.528^{**R}
PHYSICAL CAPITAL						
ln(Value of buildings)	0.017^{*R}	0.009	0.000	0.006	0.013	0.031^{*++R}
ln(Value of durables)	0.002	0.047^{***++R}	0.022	-0.014^{-}	0.033	0.040^{++}
ln(Value of livestock)	0.009^{*R}	0.005	0.009^{R}	0.002	0.019^{**R}	0.009^{+++}
ln(Value of equipment)	0.012	0.037^{*R}	0.068^{***R}	0.007	-0.016	0.028
HUMAN CAPITAL						
ln(Number of adult equivalent)	-0.032	0.114^{+}	-0.039	0.096^{+}	-0.029	0.079
Proportion of dependents	0.032	-0.083	-0.008	-0.545^{*---R}	0.258	-0.090^{+}
Female household head	-0.034	0.091^{+}	-0.101	-0.241	0.017	-0.154^{---}
log(Age of hh. head)	0.025	-0.058^{-}	-0.425^{***R}	0.070	-0.151	-0.193^{--}
Median education of males	0.026^{***R}	0.002	0.026^{***R}	0.009	0.060^{***R}	0.079$^{***+++R}$
Median education of females	-0.013	0.010	0.027^{**R}	0.006	0.020	0.016^{++}
ln(Prop. days lost due to illness)	0.781^{***R}	-0.250	-0.106	0.114	0.469^{*R}	0.122^{++}
ETHNICITY						
- Baganda	-0.236^{*R}	-0.337^{***R}	-0.060	-0.493^{**R}	-1.695^{***R}	-0.245^{--}
- Basoga	0.609^{***R}	-0.279^{***R}	-0.136	0.318^{+}	0.138	0.092^{++}
- Iteso	0.302^{**R}	-0.201	-0.444^{***R}	0.185^{+}	0.756^{***R}	0.120^{++}
- Bagisu	-0.069	-0.102	0.829^{***R}	-0.565^{**-R}	-0.380^{**R}	-0.532^{**--R}
- Langi	0.148	-0.194	0.040	-0.609^{**--R}	0.354^{**R}	0.046^{++}
- Lugbara	-0.197	0.243	0.412^{**R}	0.214	0.198	0.369^{+++}
- Ankole	-0.070	0.266$^{***+++R}$	-0.900^{***R}	0.012	-0.924^{***R}	0.321^{-}
- Bakiga	0.006	0.529$^{***+++R}$	-0.906^{***R}	0.487^{+}	-1.117^{***R}	0.238^{--}
- Banyoro	-0.240^{*R}	0.239^{R}	-1.023^{***R}	0.621^{+}	-0.383**	-0.481^{---}
ACCESS TO INFORMATION/ SERVICES						
Extension service dummy	0.024	0.026	0.485***	-0.318^{**--}	0.245***	0.030
Market information dummy	0.103*	0.016	0.198***	-0.032	-0.162**	-0.034^{---}
Loan access dummy	-0.091	0.075	0.086	-0.037	0.004	0.043
Access to market and transport						
High market access dummy	0.144^{**R}	-0.009	0.081	-0.354^{***--R}	-0.076	-0.046^{-}
Dist. to all weather road	0.000	0.001	-0.005	0.005^{+}	-0.002	-0.004^{--}
Dist. to truck service	0.000	0.000	-0.002	0.000	0.007^{***R}	0.007^{**+++R}
Dist. to minibus/taxi service	-0.001	0.001	0.001	0.006	-0.003	0.005^{-}
Land and labor scarcity						
ln(Wage rate of men)	0.153^{***R}	0.019	0.043	-0.054^{-}	0.020	0.111^{+++}

Table 5b--Determinants of non-labor input use

(Maximum likelihood Heckman model)

Variable	Seeds: Use	Seeds: Amount	Improved Seeds: Use	Improved Seeds: Amount	Other non-labor inputs: Use	Other non-labor inputs: Amount
ln(Population dens.)	-0.025	0.051	0.072^{*R}	-0.007^{-}	0.203^{***R}	0.034^{++}
Agro-climatic zone						
- Unimodal v. low/low/medium	-0.197*	0.009	0.240^{*R}	-0.321^{--}	0.275**	0.294^{++}
- Unimodal high	-0.098	-0.013	0.713^{***R}	0.193	0.861^{***R}	0.984$^{***+++R}$
- Bimodal low	0.174^{**R}	0.105	-0.111	0.648^{**++R}	-0.439*	0.441^{--}
- Bimodal medium	-0.099	0.096	-0.091	0.016	0.463^{***R}	0.407^{***++R}
Intercept	-1.134^{*R}	7.284$^{***+++R}$	-2.506^{***R}	10.055^{***++R}	-3.800^{***R}	4.376^{***-R}
Number of observations	4130		4130		4130	
Number of uncensored obs.	3001		731		469	
Test of tobit model restrictions	p=0.0000***		p=0.0000***		p=0.0000***	
Test of independence of first and second stage equations	p=0.0000***		p=0.0016***		p=0.0002***	
Wu-Hausman test of exogeneity of extension, market information and loan access	p=0.2053		p=0.0001***		p=0.0140**	
Hansen's J Test of overidentifying restrictions in second stage IV models	p=0.0048***		p=0.0009***		p=0.0001***	

$^{*, **, ***}$ mean statistical significance at the 10%, 5%, and 1% levels, respectively, in the Heckman model. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.

$^{+, ++, +++ (-, --, ---)}$ mean the coefficient is positive (negative) and statistically significant at the 10%, 5%, and 1% levels, respectively, in an IV estimation of the second stage of the Heckman model, using only observations with positive values of the dependent variable. Instrumental variables used to predict participation in extension, access to market information and use of a loan include all of the other explanatory variables, plus several community level variables representing distance and time to the most common market, the location of the nearest market, the common transportation modes to the nearest market, availability of formal or informal credit, and the sources of credit.

^{R} means that the coefficient was the same sign and statistically significant at 10% level in a Heckman model excluding the potentially endogenous variables (participation in extension, market information, and loan use).

In all cases, the tobit model restrictions were strongly rejected, so we report the results of the less restrictive Heckman selection model. The signs and statistical significance of results of the IV estimation of the second stage regressions are also reported in Tables 5a and 5b. In almost all cases (except inorganic fertilizer), the selection and regression equations were found to be non-independent, thus requiring correction for the selection bias in the IV estimation of the second stage regression. For inorganic fertilizer, we excluded the selection correction in the IV estimation of the second stage regression (since this was insignificant), as well as the ethnicity variables, which were found to be jointly statistically insignificant (p=0.46).

In several cases, the IV second stage results corroborate the Heckman model results; however in most cases the IV results are statistically insignificant, reflecting problems in identification of the IV model. This is probably due to the relatively small sample size of most of the second stage regressions (which include only positive observations of the input). The Wu-Hausman test fails to reject exogeneity (at 10 percent level) of the extension, market information and loan variables in three of the regressions (for organic fertilizer, pesticides, and traditional seeds), so the Heckman model (which treats these as exogenous) is preferred in these cases. Although the Wu-Hausman test rejects this model for the other inputs, the overidentification test is also rejected, undermining our confidence in the IV results for those inputs as well. We also report the robustness of the signs and significance of the coefficients in the Heckman models when the potentially endogenous explanatory factors are excluded. The results of the Heckman models are robust to this exclusion in almost all cases, giving us confidence in the Heckman model results, since they are not much affected by the presence of potentially endogenous explanatory variables. We thus discuss only the robust Heckman model results.

Larger farms are more likely to use all land management practices/non-labor inputs. However, the intensity of use of most of these inputs per acre (organic fertilizer, pesticides, seeds, and improved seeds) is lower for larger farms, considering farms that are using such inputs. The net effect of farm size is thus mixed.

Higher land value increases the likelihood of using organic fertilizer and improved seeds, and the intensity of use of inorganic fertilizer, traditional and improved seeds, and other non-labor inputs. As with labor intensity, the marginal return of investing in non-labor inputs appears to be increased by higher land quality.

Land tenure factors have impacts on use of some inputs. The likelihood and amount of organic fertilizer and pesticide use is greater for households who have a larger share of *mailo* land (compared to land under customary tenure). Households with a larger share of land under other tenure (freehold or leasehold) also use more organic fertilizer, pesticides, and other non-labor inputs. Households that have rented a larger share of their land are more likely to use inorganic fertilizer and use more seeds per acre than households that own land acquired through purchase, inheritance, or gift. This suggests that renters substitute non-labor inputs for labor (recall the finding that renters use labor less intensively). Households with a higher proportion of land operated by women use less organic fertilizer and less pesticides, possibly due to labor and cash constraints facing women farmers.

Ownership of physical assets also affects land management. Households with more assets in the form of buildings use more organic fertilizer and other non-labor inputs, and are more likely to use traditional seeds. Households with more durable goods use more organic fertilizer but less inorganic fertilizer, more pesticides and traditional seeds. Households with more livestock are more likely to use organic fertilizer, traditional seeds and other non-labor inputs. Households with more equipment are more likely to use organic fertilizer, inorganic fertilizer, pesticides and improved seeds, and use larger amounts per acre of organic fertilizer and traditional seeds. In general, ownership of physical assets promotes use of non-labor inputs, though the mechanisms by which this occurs are not fully clear. That livestock ownership promotes organic fertilizer use is likely due to the resulting availability of manure. Ownership of buildings, durable goods (such as a cart or a bicycle) and equipment may facilitate storage, transport and application of organic fertilizer. Similarly, durable goods and equipment may facilitate acquisition and use of pesticides and seeds. It is not clear why ownership of durable goods is associated with less use of inorganic fertilizer, however.

Human capital also affects land management. Larger households are less likely to use inorganic fertilizer, perhaps due to cash constraints. Households with a larger share of dependents use less improved seeds, possibly for a similar reason. Female-headed households are less likely to use inorganic fertilizer and pesticides, and use smaller amounts of pesticides per acre than male-headed households, possibly also due to cash constraints or differences in knowledge about these technologies. Older household heads are less likely to use inorganic fertilizer, pesticides, and improved seeds, perhaps also because they are less aware of such modern technologies or more used to using traditional technologies. However, among households that use inorganic fertilizer, older household heads use it more intensively, suggesting that once their knowledge barrier or reluctance to use this technology is overcome, older farmers are willing and able to use inorganic fertilizer intensively. By contrast, older household heads use organic fertilizer less intensively; perhaps because they substitute inorganic fertilizer for it. Older heads also use pesticides less intensively, perhaps because they are better able to control pests using traditional means such as crop rotation.

Households with more educated males are more likely to use several technologies, including organic fertilizer, inorganic fertilizer, traditional seeds, improved seeds, and other non-labor inputs; and they use organic fertilizer and other non-labor inputs more intensively when used. By contrast, female education has limited impact on any of these inputs. Male education thus appears to be a very important factor influencing land management, probably by increasing awareness and ability to use new technologies, and possibly also by increasing households' income and ability to purchase inputs.

Households with more days lost due to illness are more likely to use organic fertilizer, traditional seeds, and other non-labor inputs, but use inorganic fertilizer and pesticides less intensively. Such households may be attempting to compensate for labor and cash constraints by using other traditional inputs to a greater extent.

Access to information and services also appears to affect use of some inputs (though these results are not robust). Households with access to extension were more likely to use organic fertilizer, inorganic fertilizer, improved seeds, or other non-labor inputs. However, among households using these inputs, intensity of use of inorganic fertilizer and improved seeds was lower for households with access to extension, suggesting that extension may be encouraging some farmers to try these inputs, but is not enabling or encouraging farmers to use them at a rate comparable to farmers who have adopted such inputs on their own. Access to market information is also associated with a higher probability of using inorganic fertilizer and improved seeds, but lower probability of using other non-labor inputs. Not surprisingly, use of credit is also associated with greater use of inorganic fertilizer.

Access to markets, roads and transportation has mixed impacts on land management. Households in higher market access areas are more likely to use organic fertilizer and use it more intensively, probably because the returns to using such inputs are higher in these areas. In higher market access areas, households also are more likely to use pesticides and traditional seeds but use less improved seeds. Perhaps this is due to the fact that improved seeds are used mainly for cereals, which are not favored by better market access (see discussion of crop choice below). Households closer to an all-weather road are more likely to use organic fertilizer and pesticides, and use inorganic fertilizer more intensively when they use it. Households closer to minibus or taxi service also are more likely to use pesticides. By contrast, households closer to truck service use less other non-labor inputs. Better access to markets, roads and/or transportation appear to promote use of some inputs, such as fertilizer and pesticides, but reduce use of others, such as improved seeds and other non-labor inputs.

Land and labor scarcity also influence land management. The amounts of inorganic fertilizer and pesticides used per acre are greater in communities where wage rates are higher, possibly because higher wage rates leads to higher off-farm incomes, thus enabling farmers to finance purchase of these inputs. The probability of using traditional seeds is also higher where wage rates are higher, though the reason is not clear. The probability of using organic fertilizer, pesticides, improved seeds and other non-labor inputs is greater in communities with higher population density. This suggests that resource constraints promote intensification of complementary non-labor inputs as well as labor use, consistent with Boserup's (1965) theory.

There are also significant differences in land management across different ethnic groups and different agro-climatic zones. Overall, many factors influence land management practices and use of non-labor inputs, in complex ways. It is difficult to summarize such a complex set of results, though it appears that the value of land and other assets, male education, access to information and services, access to markets, roads and transport, higher wages and population pressure all contribute to intensification of land management in various ways, though not all impacts are uniformly positive or as expected.

Crop Choice

The regression results for determinants of crop choice, using two-limit tobit models, are reported in Table 6.

Table 6--Determinants of Crop Choice (Annuals Only) (share of area)

Interval regressions

Variable	**Cereals**	**Legumes**	**Root Crops**	**Cereals/ Legumes**	**Legumes/ Root crops**
NATURAL CAPITAL					
ln(Area farmed)	0.0081	0.0473***R	-0.0544***R	-0.0204	0.0030
ln(Land value/acre)	-0.0199***R	-0.0033	-0.0111***R	-0.0092	-0.0095
LAND TENURE					
ln(Years holding land)	-0.0160	0.0223**R	-0.0040	-0.0212**R	0.0284*R
Proportion women's land	-0.0284	0.0341	0.0062	-0.0243	0.0216
How land acquired (cf. rented)					
- Share purchased	0.0053	-0.0471**R	-0.0030	-0.0470	-0.0401
- Share free land	-0.0152	-0.0035	-0.0217	-0.0620**R	-0.0121
- Share inherited	0.0019	-0.0058	0.0243	-0.0726***R	-0.0137
Land tenure (cf. customary)					
- Share *mailo*	-0.1112***R	-0.0830***R	-0.0298***R	0.0443**R	-0.0016
- Share other	-0.0992***R	-0.0296	-0.0407**R	0.0844**R	-0.0888
PHYSICAL CAPITAL					
ln(Value of buildings)	0.0015	-0.0024	-0.0015	-0.0037	0.0042
ln(Value of durables)	-0.0088**R	-0.0052	0.0061**R	-0.0065	-0.0004
ln(Value of livestock)	0.0014	-0.0001	-0.0015*R	0.0039***R	0.0066***R
ln(Value of equipment)	0.0042	0.0102**R	-0.0001	0.0065	-0.0041
HUMAN CAPITAL					

Table 6--Determinants of Crop Choice (Annuals Only) (share of area) (continued)

Interval regressions

Variable	Cereals	Legumes	Root Crops	Cereals/ Legumes	Legumes/ Root crops
ln(No. of adult equivalent)	0.0297	0.0116	0.0224*	-0.0223	0.0512
Proportion of dependents	0.0067	-0.0080	-0.0264	-0.0014	-0.0664
Female household head	0.0294	0.0132	-0.0119	-0.0004	-0.0226
ln(Age of household head)	0.0012	-0.0182	0.0052	0.0123	-0.1698^{***R}
Median educ. of males	-0.0009	0.0022	0.0006	0.0090^{***R}	0.0030
Median educ. of females	-0.0038^{*R}	-0.0001	0.0004	-0.0019	0.0001
ln(Prop. days lost to illness)	-0.1344^{***R}	0.0329	-0.0143	-0.0058	0.2174^{**R}
ETHNICITY					
- Baganda	-0.4487^{***R}	-0.0953^{***R}	-0.0039	-0.2243^{***R}	0.0764
- Basoga	-0.0236	-0.1762^{***R}	-0.0424^{**R}	0.1639^{***R}	-0.4959^{***R}
- Iteso	0.2969^{***R}	0.0045	-0.0080	-0.1904^{***R}	-0.4004^{***R}
- Bagisu	-0.1313^{***R}	-0.0698^{*R}	-0.2199^{***R}	-0.0101	-0.2715^{***R}
- Langi	-0.0791^{*R}	0.1086^{***R}	-0.0477*	0.1635^{***R}	0.1106^{*R}
- Lugbara	0.0039	0.0402	-0.0320	-0.0728	0.4519^{***R}
- Ankole	-0.0288	0.0980^{***R}	-0.1148^{***R}	-0.0663^{**R}	-0.2728^{***R}
- Bakiga	0.0083	0.2008^{***R}	0.0182	0.0790^{***R}	-0.1185^{***R}
- Banyoro	-0.3011^{***R}	0.0690^{**R}	0.0783^{***R}	-0.0191	0.0061
ACCESS TO INFORMATION/SERVICES					
Extension service dummy	0.0050	0.0029	0.0114	0.0244	0.0277
Market information dummy	-0.0083	-0.0181	0.0205**	0.0142	-0.0406*
Loan access dummy	-0.0242*	0.0000	0.0068	-0.0065	-0.0020
Access to markets/transport					
High market access dummy	-0.0226	0.0230^{*R}	-0.0269^{***R}	0.0157	-0.0838^{***R}
Dist. to all weather road (km.)	-0.0005	0.0013^{**R}	0.0004	0.0012^{*R}	0.0003
Dist. to truck service (km.)	0.0008^{*R}	0.0005	-0.0003	0.0024^{***R}	-0.0029^{***R}
Dist. to minibus/taxi service	-0.0010	-0.0004	0.0005	0.0006	0.0031^{***R}
Land and labor scarcity					
ln(Wage rate of men) (Ush/day)	-0.0183	0.0103	0.0031	0.0008	0.0064
ln(Population dens.) (#/km^2)	-0.0172	-0.0166^{*R}	0.0004	0.0287^{***R}	0.0187
Agro-climatic zone					
- Unimodal v. low/low/medium	-0.1117^{***R}	0.1205^{***R}	0.0366^{*R}	-0.0545	0.1935^{***R}
- Unimodal high	-0.2292^{***R}	-0.1652^{***R}	-0.1610^{***R}	0.1491^{***R}	-0.1663^{*R}
- Bimodal low	-0.0497^{**R}	0.0084	-0.0328^{**R}	0.0710^{***R}	0.2147^{***R}
- Bimodal medium	-0.0039	-0.0193	0.0103	0.0083	0.0993^{***R}
Intercept	0.7111^{***R}	-0.0418	0.3610^{***R}	0.0587	0.1571
Number of observations	4130	4130	4130	4130	4130
Number left-censored	1902	2263	791	1952	3173
Number right-censored	32	22	22	57	36

$^{*, **, ***}$ mean statistical significance at the 10%, 5%, and 1% levels, respectively. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.

^{R} means that the coefficient was the same sign and statistically significant at 10% level in a Heckman model excluding the potentially endogenous variables (participation in extension, market information, and loan use).

We focus only on determinants of annual crop choice, because perennial crop choice decisions may not have been made in the year of the survey; hence the values of most of the explanatory variables may have been determined after the perennial crop choice and could be endogenous. Unlike the analysis reported in Tables 5a and 5b, we could not implement IV regressions to address the potential endogeneity of the extension, market information and loan use variables, because of the nature of the regression model. However, we still report the robustness of the results to exclusion of the potentially endogenous variables from the model. In almost all cases, the statistically significant results are robust to excluding these variables, indicating that any endogeneity bias is not having a major impact on our conclusions.

Natural capital influences crop choice. Larger farms plant a larger proportion of their area to legumes and less to root crops, possibly because root crops are more for subsistence purposes. Farmers having higher value land grow a smaller proportion of cereals or root crops compared to perennials or perennial/annual crop mixes (which are the excluded categories of crop mixes).

Land tenure also influences crop choice. Households that have held their land for a longer period plant less cereals/legumes and legumes/root crops mixes, and more legumes in pure stands. Perhaps more farming experience leads to more market oriented and specialized legume production. However, legumes are planted less on purchased than rented land, perhaps because legumes can yield sufficient profit in a short term to pay the land rent. Cereals/legumes mixes are planted less on inherited or other gift land than rented land, perhaps for the same reason. Cereals, legumes and root crops (in pure stands) are planted less on *mailo* land than on customary land while cereals/legumes mixed cropping is more common on *mailo* land. Cereals and root crops in pure stands are also less common on other (freehold or leasehold) tenure than on customary, and cereals/legumes more common. The reasons for these associations are not clear.

Asset ownership also influences crop choices. Households owning more durable goods plant less cereals and more root crops. Households with more livestock plant less root crops and more cereals/legumes and legumes/root crop mixes. Households with more equipment plant more legumes in pure stands. The reasons for these associations are also not completely clear. The association of livestock with cereals and legumes rather than root crop production may be because of complementarities between livestock and cereal/legume production (e.g., due to the fodder value of residues of cereals and legumes, and the usefulness of oxen in preparing fields for these row crops). The association of equipment and legume production in pure stands may be related to equipment used to spray legumes with pesticides.

Human capital also influences crop choices. Older household heads are less likely to grow mixed legumes/root crops. Households with more educated males are more likely to grow cereals/legumes, while households with more educated females are less likely to grow cereals in pure stands. The latter result may relate to the labor intensity of cereal production and higher labor opportunity costs of educated women. Such labor considerations may also explain why households with more days lost to illness plant less cereals. These households plant more legumes and root crops, perhaps as a coping mechanism to deal with food security needs by planting less labor demanding crops (such as cassava).

We find few significant impacts of access to information and services on crop choice. Households with access to market information plant more root crops in pure stands and less legumes/root crop mixes. Perhaps such households are specializing more in producing root crops for the market as a result of access to market information.

Market, road and transportation access have mixed impacts on crop production. Households in areas of higher market access plant more legumes in pure stands and less root crops or legumes/root crop mixes. Thus, better market access appears to foster crop specialization. On the other hand, households further from an all-weather road plant more legumes in pure stands and more cereal/legumes in mixed stands. Households further from truck service plant more cereals in pure stands and more cereal/legume mixes, but less legume/root crop mixes. Households further from minibus or taxi service plant more legume/root crop mixes. We do not have a simple explanation for these mixed results.

We do not find a significant impact of local wage rates on crop choice. However, we do find significant impacts of population density, with less planting of legumes in pure stands and more planting of cereals/legumes mixed stands in more densely populated areas. Population pressure appears to foster mixed cropping, perhaps because of subsistence constraints.

Not surprisingly, crop choice is strongly affected by ethnicity, reflecting different food preferences and agricultural experience of different ethnic groups. There are also strong differences across the agro-climatic zones in crop choice.

As for the results on determinants of land management, these results on determinants of crop choice are difficult to summarize. Many factors influence crop choice, especially ethnicity and agro-climatic factors, but natural capital, land tenure, physical capital, access to markets, roads and transportation, and population pressure also influence crop choice in complex ways.

Value of Crop Production per Acre

The OLS and IV estimation results for determinants of value of crop production per acre (reduced form, as in equation (6)) are presented in Table 7.

Table 7--Determinants of value of crop production per acre and income per capita
Ordinary least squares (OLS) and instrumental variables (IV) regressions

Variable	ln(Crop Production (Ush/acre))		ln(income/capita (Ush/person))	
	OLS	IV[a]	OLS	IV[a]
NATURAL CAPITAL				
ln(Area farmed)	-0.527***R	-0.475***	0.396***R	0.446***
ln(Land value/acre)	0.085***R	0.098***	0.086***R	0.087***
LAND TENURE				
ln(Years holding land)	0.013	0.013	-0.028*R	-0.018
Proportion women's land	-0.144***R	-0.035	-0.022	0.023
How land acquired (cf. rented)				
- Share purchased	0.052	0.124	-0.018	0.020
- Share free land	0.022	0.135	-0.037	-0.004
- Share inherited	0.044	0.024	-0.034	-0.0003
Land tenure (cf. customary)				
- Share *mailo*	0.014	-0.043	0.020	0.063
- Share other	-0.140*	-0.027	-0.058	-0.046
PHYSICAL CAPITAL				
ln(Value of buildings)	0.021***R	0.014	0.032***R	0.032***
ln(Value of durables)	0.047***R	0.009	0.073***R	0.068***
ln(Value of livestock)	0.015***R	0.011**	0.004*R	0.003
ln(Value of equipment)	0.030**R	-0.001	0.062***R	0.053***
HUMAN CAPITAL				
ln(Number of adult equivalent)	0.127***R	0.070	0.411***R	0.377***
Proportion of dependents	0.133*R	0.090	-0.017	0.036
Female household head	-0.138**R	-0.102	-0.036	-0.024
ln(Age of household head)	-0.101*R	0.085	-0.012	0.002
Median education of males	0.015***R	0.006	0.025***R	0.022***
Median education of females	0.000	-0.006	0.022***R	0.016***
ln(Prop. days lost due to illness)	0.177*	0.006	-0.056	-0.119
ETHNICITY				
- Baganda	0.165***R	0.189	0.281***R	0.349***
- Basoga	0.309***R	-0.019	-0.043	-0.022
- Iteso	-0.182**	-0.172	-0.334***R	-0.466***
- Bagisu	0.011	0.172	-0.047	-0.023
- Langi	-0.252***R	-0.110	-0.480***R	-0.442***
- Lugbara	0.253**	0.555***	0.182***R	0.154
- Ankole	0.168***R	0.016	0.135***R	0.034
- Bakiga	0.157***R	0.059	0.076**R	-0.023
- Banyoro	0.144*	0.175	0.014	-0.057
ACCESS TO INFORMATION/SERVICES				
Extension service dummy	0.008	-1.035	0.057*	0.013
Market information dummy	0.066**	0.372	-0.031	-0.391
Loan access dummy	0.099***	2.152***	0.042*	0.526

Table 7--Determinants of value of crop production per acre and income per capita
Ordinary least squares (OLS) and instrumental variables (IV) regressions

Variable	ln(Crop Production (Ush/acre))		ln(income/capita (Ush/person))	
Access to markets and transport				
High market access dummy	-0.023	0.025	0.012	0.024
Dist. to all weather road (km.)	-0.002	-0.001	0.002	0.0003
Dist. to truck service (km.)	-0.001	-0.003*	-0.001R	0.0001
Dist. to minibus/taxi service	0.000	0.002	0.002R	0.002
Land and labor scarcity				
ln(Wage rate of men) (Ush/day)	0.070**R	0.100*	0.085***R	0.027**
ln(Population dens.) (#/km^2)	0.034	-0.009	0.012	0.006
Agro-climatic zone				
- Unimodal v. low/low/medium	-0.351***R	-0.369***	0.054	0.048
- Unimodal high	0.213***R	0.343**	0.335***R	0.237*
- Bimodal low	0.085*	0.024	0.066**R	0.051
- Bimodal medium	-0.077**	0.039	-0.021	-0.030
Intercept	9.752***R	9.427***	9.102***R	9.267***
Number of observations	4141	4015	4103	3981
R^2	0.297		0.504	
Wu-Hausman test of exogeneity of extension, market information, loan variables		0.007***		0.000***
Hansen's J test of overidentifying restrictions		0.201		0.072*

[a] Instrumental variables used to predict participation in extension, access to market information and use of a loan include all of the other explanatory variables, plus several community level variables representing distance and time to the most common market, the location of the nearest market, the common transportation modes to the nearest market, availability of formal or informal credit, and the sources of credit.
*, **, *** mean statistical significance at the 10%, 5%, and 1% levels, respectively. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.
R means that the coefficient was the same sign and statistically significant at 10% level in an OLS model excluding the potentially endogenous variables (participation in extension, market information, and loan use).

The Wu-Hausman test rejects the hypothesis of exogeneity of the extension, market information and loan variables, while the IV model passes the test of overidentifying restrictions. Thus, IV is the preferred model. However, the IV model appears to be poorly identified, resulting in many statistically insignificant results (of similar magnitude as in the OLS model). Almost all of the OLS results are robust in both versions of the OLS model (with and without the endogenous explanatory variables). We focus on results of the IV model, but also discuss those that are significant in both versions of the OLS model.

Larger farms have lower crop production per acre. This is consistent with our earlier finding that larger farms use labor less intensively and use several non-labor inputs less intensively (when such inputs are used at all). This finding is also consistent with findings of Nkonya, et al. (2004), who also found such an inverse relationship in Uganda, and with a large body of literature showing an inverse relationship between farm-size and farming intensity and crop production in developing countries (e.g., Lamb 2003; Heltberg 1998; Barrett 1996; Benjamin 1995; Bhalla 1988; Feder 1985; Carter 1984; Berry and Cline 1979; Sen 1975; Bardhan 1973; Chayanov 1966). As mentioned previously, this suggests that land and labor market imperfections limit households' ability to equalize land/labor ratios and yields (Feder 1985). However, other explanations, including insurance market failure (Barrett 1996)), variations in land quality (Sen 1975; Bhalla 1988; Benjamin 1995), and errors in measuring farm size (Lamb 2003) could also be responsible for the inverse relationship. The use of land value per acre as an imperfect proxy for land quality in our regressions suggests that omitted land quality characteristics could be influencing the results. Further research would be necessary to settle this issue definitively.

Not surprisingly, the value of production is higher on higher value farmland, indicating that land values reflect higher soil quality, better climate, or other locational advantages leading to greater profitability of crop production. This is consistent with the fact that several inputs are used more intensively on higher value land.

The value of crop production per acre is higher for households who own more livestock. This is consistent with findings of Nkonya, et al. (2004) and indicates that livestock and crop production are complementary. This is probably in part because of the benefits of manure in increasing soil fertility, but the value of animals for plowing (where used), threshing, and transporting produce also may contribute.

Households with access to credit have significantly higher value of crop production per acre. This indicates that credit access is an important constraint affecting the potential for increased agricultural productivity and modernization in Uganda.

Access to markets and roads have surprisingly limited impacts on the value of crop production in the regression using the full sample.[13] However, we do find significant impacts of these variables in separate regressions for some regions (discussed below). Households that are closer to truck service obtain slightly higher value of crop production (result weakly statistically significant at 10 percent level).

Higher wage rates are also associated with higher value of crop production. This may be because off-farm employment opportunities and income enable households to purchase inputs such as fertilizer and pesticides, as noted previously.

Not surprisingly, agro-climatic conditions affect the value of crop production per acre, which is highest in the high potential unimodal high rainfall zone and lowest in the unimodal very low, low and medium rainfall zones.

Other factors, including land tenure, other assets besides livestock, human capital, access to extension, market information, and ethnicity have limited impacts on crop production per acre in the IV regression, though many of these are significant and robust

[13] Multicollinearity is not a major factor contributing to these insignificant results. The variance inflation factors are 1.35 for the market access variable and 1.08 for the distance to road variable, indicating that multicollinearity had relatively small impacts on the variance of the coefficients.

in the OLS regressions. Among these are the proportion of land operated by women (negative impact), ownership of buildings, durable goods and equipment (positive impacts), household size and proportion of dependents (positive), female-headed household (negative), age of household head (negative), median education of males (positive), and ethnicity (numerous significant effects). These factors also appear to be important in affecting crop production per acre, and their impacts are generally consistent with the impacts of these variables on labor and non-labor input use, as reported previously.

As with labor intensity, the determinants of crop production per acre vary significantly across the regions of Uganda.[14] The results of IV regressions of the determinants of crop production by region are reported in Table 8. Some factors have fairly consistent impacts across the regions.

Table 8--Determinants of Crop Production per Acre by Region (reduced form)
Instrumental variables regressions[a]

Variable	**Central**	**Eastern**	**Northern**	**Western**
NATURAL CAPITAL				
ln(Area farmed)	-0.554***	-0.401***	-0.445***	-0.587***
ln(Land value/acre)	0.094***	0.072***	0.030	0.063**
LAND TENURE				
ln(Years holding land)	0.029	0.010	-0.071	0.096**
Proportion women's land	0.028	-0.100	-0.202	-0.121
How land acquired (cf. rented)				
- Share purchased	-0.035	-0.033	0.041	0.324**
- Share free land	0.028	-0.184*	0.243	0.252**
- Share inherited	0.247	-0.064	0.095	0.205*
Land tenure (cf. customary)				
- Share *mailo*	0.192	0.033	-0.048	-0.142
- Share other	-0.007	0.054	0.004	-0.216
PHYSICAL CAPITAL				
ln(Value of buildings)	0.007	0.025	0.027*	0.024***
ln(Value of durables)	0.021	0.019	0.002	0.043***
ln(Value of livestock)	0.006	0.015***	0.030***	0.011**
ln(Value of equipment)	0.033	0.039	0.013	0.024

[14] Chow test p value = 0.0000.

Table 8--Determinants of Crop Production per Acre by Region (reduced form)

Instrumental variables regressions[a]

Variable	Central	Eastern	Northern	Western
HUMAN CAPITAL				
ln(Number of adult equivalent)	0.021	0.126	0.077	0.091
Proportion of dependents	0.345*	0.215	-0.008	0.161
Female household head	0.070	0.062	-0.813***	-0.124*
ln(Age of household head)	-0.009	0.001	0.087	-0.179*
Median education of males	-0.005	0.017	0.057***	-0.005
Median education of females	-0.008	-0.011	-0.003	0.008
ln(Prop. days lost due to illness)	-0.270	0.022	0.311	0.208
ETHNICITY				
- Baganda	0.172	0.511	1.171	0.029
- Basoga	0.218	0.547**	1.281***	0.236
- Iteso	-0.807**	-0.319*	0.053	-0.716**
- Bagisu	0.099	0.229	-0.036	0.037
- Langi	-0.249	-0.320	-0.105	-0.576***
- Lugbara	0.246	0.515*	0.471*	-0.097
- Ankole	-0.065	-0.429	1.030	0.062
- Bakiga	0.157	0.126	-0.002	0.040
- Banyoro	-0.155	0.588**	4.667***	-0.112
ACCESS TO INFORMATION/SERVICES				
Extension service dummy	0.660	-0.007	-0.894	-0.114
Market information dummy	-0.059	-0.574	-0.256	-0.007
Loan access dummy	1.110**	0.300	0.416	0.834*
Access to markets and transport				
High market access dummy	0.216**	-0.047	-0.139	0.073
Dist. to all weather road (km.)	-0.004	-0.004**	-0.003	-0.005**
Dist. to truck service (km.)	0.005**	0.003	-0.002	-0.007**
Dist. to minibus/taxi service	-0.002	0.002	-0.006	-0.001
Land and labor scarcity				
ln(Wage rate of men) (Ush/day)	0.066	0.113	0.005	0.096
ln(Population dens.) (#/km^2)	-0.058	-0.051	0.251**	-0.121***
Agro-climatic zone				
- Unimodal v. low/low/medium	-0.263	-0.387*	-0.225	0.462**
- Unimodal high	0.473*	-0.017	0.228	0.546**
- Bimodal low	0.035	-0.121	0.234	0.012
- Bimodal medium	-0.002	-0.262	0.113	-0.080
Intercept	9.945***	9.955***	9.530***	10.838***
Number of observations	990	1146	565	1303

[a] Instrumental variables used to predict participation in extension, access to market information and use of a loan include all of the other explanatory variables, plus several community level variables representing distance and time to the most common market, the location of the nearest market, the common transportation modes to the nearest market, availability of formal or informal credit, and the sources of credit.

*, **, *** mean statistical significance at the 10%, 5%, and 1% levels, respectively. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.

For example, there is a statistically significant and quantitatively strong inverse relationship between farm size and crop production per acre in every region. Land value per acre has a positive impact on crop production in three of the four regions, livestock ownership has a positive impact in three regions, female-headed households have lower production in two regions, loan use has a positive impact in two regions, better access to an all-weather road has a positive impact in two regions (Eastern and Western), and several ethnicities have similar qualitative impacts in more than one region. Several other factors, such as land tenure, age of household head, education of males, market access, access to truck service and population density appear to be more region-specific in their impacts. For example, higher market access is associated with significantly higher value of crop production only in the Central Region.

In addition to estimating the determinants of crop production per acre in reduced form, we also estimated the structural model for crop production (equation (1)). For this model, inputs and crop mix were included as endogenous explanatory variables, and several variables included in the reduced form were excluded, based on joint statistical hypothesis tests (i.e., most land tenure variables, several human capital variables, access to extension and market information, and all of the access to market, roads and transport variables). These variables do not affect crop production directly, when controlling for input use and crop mix, though they may affect it indirectly, by affecting these decisions (as reflected in the reduced form models previously discussed). Estimation of the structural model is used to identify the direct impacts of farmers' decisions about input use/land management and crop choice.

The Wu-Hausman test fails to reject exogeneity of the farmer decision variables in equation (1) (Table 9). However, the test of overidentifying restrictions rejects these restrictions in the IV model. This means that both the OLS and IV models may be incorrectly specified (Davidson and MacKinnon 2004). Thus, we are not confident in the results of either model. Nevertheless, we discuss the significant results of the OLS model, but keeping this caveat in mind.

Table 9--Determinants of crop production per acre (structural model) (ln(Ush/ha.))
Ordinary least squares (OLS) and instrumental variables (IV) estimation

Variable	OLS	IV[a]
INPUTS		
LABOR (LN(PERSON-DAYS/ACRE))	0.207***	-0.428
ORGANIC FERTILIZER (LN(USH/ACRE))	-0.007	0.020
INORGANIC FERTILIZER (LN(USH/ACRE))	0.036***	0.048
PESTICIDES (LN(USH/ACRE))	0.004	-0.144
TRADITIONAL SEEDS (LN(USH/ACRE))	0.029***	-0.086
IMPROVED SEEDS (LN(USH/ACRE))	0.018***	0.014
OTHER NON-LABOR INPUTS (LN(USH/ACRE))	0.009**	0.042
CROP MIX **(CF., CEREALS)**		
- MATOOKE	0.311***	1.980
- LEGUMES	-0.206**	-0.110
- ROOT CROPS	0.042	0.483
- COFFEE	0.349***	0.889
- CEREALS/LEGUMES	-0.056	1.747
- MATOOKE/COFFEE	0.459***	2.986
- LEGUMES/ROOT CROPS	0.196**	3.040
- MATOOKE/LEGUMES	0.133**	0.066
NATURAL CAPITAL		
ln(Area farmed)	-0.491***	-0.734
ln(Land value/acre)	0.065***	0.066
LAND TENURE		
Proportion women's land	-0.110**	-0.144
PHYSICAL CAPITAL		
ln(Value of buildings)	0.021***	0.022
ln(Value of durables)	0.044***	0.041*
ln(Value of livestock)	0.014***	0.014*
ln(Value of equipment)	0.024**	0.059
HUMAN CAPITAL		
Female household head	-0.151***	-0.134
ln(Age of household head)	-0.086**	0.146
Median education of males	0.014***	0.010
Proportion of dependents	0.098*	0.170

Table 9--Determinants of crop production per acre (structural model) (ln(Ush/ha.)) (continued)

Ordinary least squares (OLS) and instrumental variables (IV) estimation

Variable	OLS	IV[a]
ETHNICITY		
- Baganda	0.067	-0.032
- Basoga	0.211***	0.304
- Iteso	-0.184**	0.430
- Bagisu	-0.099	0.230
- Langi	-0.322***	-0.438
- Lugbara	0.300***	-0.396
- Ankole	0.176***	0.092
- Bakiga	0.208***	0.124
- Banyoro	0.176**	0.002
ACCESS TO INFORMATION/SERVICES		
Loan access	0.106***	1.029
Agro-climatic zone (cf., bimodal high rainfall)		
- Unimodal v. low/low/medium	-0.366***	-0.420*
- Unimodal high	0.111	-0.351
- Bimodal low	0.034	-0.106
- Bimodal medium	-0.061**	-0.124
Intercept	10.537***	9.684***
Number of observations	5087	3980
R^2	0.335	
Wu-Hausman test of exogeneity of inputs, crop mixes and loan variables		0.7446
Relevance tests of excluded instruments	LABOR	0.0000***
	ORGANIC FERTILIZER	0.0000***
	INORG. FERTILIZER	0.0000***
	PESTICIDES	0.0002***
	TRADITIONAL SEEDS	0.0658*
	IMPROVED SEEDS	0.0000***
	OTHER INPUTS	0.0000***
	MATOOKE	0.0000***
	LEGUMES	0.0000***
	ROOT CROPS	0.0077***
	COFFEE	0.0000***
	CEREALS/LEGUMES	0.0000***
	MATOOKE/COFFEE	0.0001***
	LEGUMES/ROOT CROPS	0.0003***
	MATOOKE/LEGUMES	0.0000***
	LOAN USE	0.0000***
Hansen's J test of overidentifying restrictions		p=0.0001***

[a] Instrumental variables used to predict input use and access to market information all of the other explanatory variables, plus several community level variables representing distance and time to the most common market, the location of the nearest market, the common transportation modes to the nearest market, availability of formal or informal credit, and the sources of credit.

*, **, *** mean statistical significance at the 10%, 5%, and 1% levels, respectively. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.

In the OLS model in Table 9, most inputs have a significant positive impact on crop production, including (in order of magnitude of impact) labor, inorganic fertilizer, traditional seeds, improved seeds, and other non-labor inputs. These results are fairly consistent with those of Deininger and Okidi (2001). The value of crop production also differs substantially across different crop mixes, with coffee and matooke having the highest value, followed by legumes/root crops, matooke/legumes, cereals, and legumes. Place, et al. (2001) also found higher profitability of plots with banana production in central Uganda, as well as coffee and potatoes, compared to cereals.

Crop productivity is declining with the size of the farm, even after controlling for input use and crop choice, indicating a stronger result than the usual finding that yields decline with farm size. This finding suggests that inputs are used more productively (not only more intensively) by smaller farms, perhaps as a result of diminishing returns to scale in crop production and/or indivisible non-marketable production factors such as the farmers' management skill (Nkonya, et al. 2004). Nkonya, et al. (2004), found the same result based on a smaller survey conducted in part of Uganda during 2000. As discussed previously, other explanations may also be responsible for this inverse relationship; further research is needed to test the alternative explanations.

Other factors significantly affecting crop productivity in the OLS regression in Table 9 include the proportion of land operated by women (negative effect), all types of physical assets (positive), female-headed households (negative), age of the household head (negative), education of males (positive), proportion of dependents (positive), loan access (positive), agro-climatic zone (lowest in the unimodal very low/low/medium and bimodal medium rainfall zones), and ethnicity (numerous significant differences). Most of these results are consistent with the results of the reduced form estimation in Table 7.

Household Income per Capita

The determinants of household income per capita are reported in Table 7. The Wu-Hausman test rejects the OLS model, and the IV model weakly passes the test of overidentifying restrictions. The IV model is thus preferred, though we consider the robustness of the findings of the two OLS specifications (with and without the endogenous explanatory variables) and the IV specification. All of the statistically significant coefficients in the IV model are of similar magnitude and significant in both OLS specifications, and most of the significant results in the OLS specifications are significant and similar in magnitude in the IV model. Thus the significant findings of the IV model are robust, and we focus on these.

Not surprisingly, households that farm more land or higher value land, and that own more physical assets, earn higher incomes. Land is the most important contributor to household income, with a 10 percent increase in landholding predicted to increase income by over 4 percent. Both male and female education have positive and similar in magnitude impacts on household income. The positive impacts of education are consistent with findings of Deininger and Okidi (2001) and Appleton (2001b). Interestingly, larger households earn higher income per capita, suggesting economies of scale in household size in terms of income generation. Households in communities where wage rates are higher earn higher incomes per capita, due to the greater value of their labor. Incomes per capita are highest in the high potential unimodal high rainfall zone, controlling for other factors. Incomes differ across ethnic groups, with Baganda households earning higher incomes and Iteso and Langi households earning lower incomes than other ethnic groups. Other factors, including land tenure, other human capital variables, access to markets, roads and transportation, and population density were not found to have statistically significant and robust impacts on household income per capita in the full sample. Access to extension and credit were found to have positive, but quantitatively fairly small and weakly statistically significant impacts on income in the OLS regression that included these variables, but these variables did not have significant impact in the IV regression.

There are significant differences in determinants of household income across the regions of Uganda.[15] Nevertheless, several of the factors have similar impacts across all or most regions (Table 10).

Table 10--Determinants of household income per capita by region

Instrumental variables regressions[a]

Variable	Central	Eastern	Northern	Western
NATURAL CAPITAL				
ln(Area farmed)	0.449***	0.409***	0.286***	0.350***
ln(Land value/acre)	0.128***	0.036	0.034	0.065***
LAND TENURE				
ln(Years holding land)	-0.013	-0.074**	-0.105*	-0.009
Proportion women's land	0.035	0.142	-0.281*	0.049
How land acquired (cf. rented)				
- Share purchased	-0.094	-0.038	-0.077	0.187*
- Share free land	-0.063	-0.081	-0.006	0.118
- Share inherited	-0.038	-0.042	-0.015	0.016
Land tenure (cf. customary)				
- Share *mailo*	0.108	0.084	-0.398**	-0.107
- Share other	0.059	-0.176	-0.190	-0.050
PHYSICAL CAPITAL				
ln(Value of buildings)	0.026***	0.050***	0.019*	0.030***
ln(Value of durables)	0.101***	0.091***	0.016	0.077***
ln(Value of livestock)	-0.005	0.005	-0.003	0.010***
ln(Value of equipment)	0.060***	0.043	0.105***	0.049***
HUMAN CAPITAL				
ln(Number of adult equivalent)	0.421***	0.427***	0.416***	0.400***
Proportion of dependents	0.102	0.083	-0.146	-0.099
Female household head	0.017	-0.261***	-0.108	0.041
ln(Age of household head)	-0.124	0.070	0.223	-0.037
Median education of males	0.019*	0.024***	0.032**	0.016**
Median education of females	0.007	0.029***	0.016	0.007
ln(Prop. days lost due to illness)	-0.081	-0.108	-0.494**	0.229

[15] Chow test p value = 0.0000.

Table 10--Determinants of household income per capita by region (continued)

Instrumental variables regressions[a]

Variable	Central	Eastern	Northern	Western
ETHNICITY				
- Baganda	0.223***	0.466	0.943**	0.346*
- Basoga	-0.240	0.247	-0.041	-0.111
- Iteso	-0.443**	-0.208*	-0.852***	-0.370**
- Bagisu	0.292**	-0.238	0.659**	-0.046
- Langi	-0.330***	-0.807***	-0.399***	-0.292
- Lugbara	0.546*	0.234	0.152*	0.307
- Ankole	0.061	0.230	0.247	0.092
- Bakiga	-0.024	0.145	-0.084	0.014
- Banyoro	-0.037	0.078	0.126	-0.078
ACCESS TO INFORMATION/SERVICES				
Extension service dummy	0.489	0.316	-0.291	0.312
Market information dummy	-0.036	-0.516	-0.249	-0.112
Loan access dummy	0.289	-0.800*	0.789	0.633*
Access to markets and transport				
High market access dummy	0.115*	0.047	-0.022	-0.004
Dist. to all weather road (km.)	-0.009**	0.002	0.000	-0.001
Dist. to truck service (km.)	-0.002	0.004*	-0.004***	-0.002
Dist. to minibus/taxi service	0.008**	-0.005	0.000	0.006*
Land and labor scarcity				
ln(Wage rate of men) (Ush/day)	0.084*	0.084	0.052	0.079
ln(Population dens.) (#/km^2)	-0.046*	0.060	0.041	-0.018
Agro-climatic zone				
- Unimodal v. low/low/medium	-0.187	0.041	-0.130	0.160
- Unimodal high	-0.048	0.364*	-0.170	0.190*
- Bimodal low	0.055	0.220*	-0.210	0.021
- Bimodal medium	-0.025	-0.117	0.084	0.030
Intercept	8.858***	9.169***	10.040***	9.662***
Number of observations	990	1146	565	1303

[a] Instrumental variables used to predict participation in extension, access to market information and use of a loan include all of the other explanatory variables, plus several community level variables representing distance and time to the most common market, the location of the nearest market, the common transportation modes to the nearest market, availability of formal or informal credit, and the sources of credit.

*, **, *** mean statistical significance at the 10%, 5%, and 1% levels, respectively. Coefficients and standard errors adjusted for sampling weights and robust to heteroskedasticity.

Households with more land, buildings, a larger labor endowment, or more educated males earn higher incomes per capita in all regions. Households with more durable goods or farm equipment earn higher incomes in three of the regions. Households with higher value land earn higher incomes in two of the regions. Iteso and Langi households earn lower income than Baganda households in all regions, controlling for other factors. Other factors, such as land tenure, gender, illness, access to credit, and access to markets, roads and transport have more region-specific impacts on income.

These results suggest that efforts to eradicate poverty in rural Uganda should focus on improving access to land, the quality of land, education, off-farm opportunities, and the ability of households to accumulate assets of all kinds. Improving access to technical and market information, credit, markets and transportation can also help, but our results suggest that the impacts of such interventions may be more context-dependent. The low incomes of certain ethnic groups and regions suggests that special efforts are needed to address the problems of poverty among these disadvantaged groups and regions.

SUMMARY OF FINDINGS

In this section, we summarize our econometric findings by main categories of the explanatory variables. We do not discuss all of the econometric results, but instead focus on the impacts of explanatory variables related to poverty (e.g., endowments of different types of capital, access to information, services, markets and infrastructure). The qualitative results are summarized in Table 11.

Table 11. Qualitative Results of the Econometric Analysis (Reduced form results, equations 2)-6))

Factor	Labor Intensity	Land Management/Non-Labor Inputs: Organic Fert.	Inorg. Fert.	Pesticides	Trad. Seeds	Impvd Seeds	Other inputs	Crop Choice: Cereal	Legume	Root Crop	Cereal/ Legume	Legume/ Root Crop	Crop Production per Acre	Income per Capita
NATURAL CAPITAL														
- Land area	-	+/-	+/0	+/-	+/-	+/-	+/0	0	+	-	0	0	-	+
- Land value	+	+/0	0/+	0/0	0/+	+/+	0/+	-	0	-	0	0	+	+
PHYSICAL CAPITAL														
- Buildings	0	0/+	0/0	0/0	+/0	0/0	0/+	0	0	0	0	0	0	+
- Durable goods	0	0/+	0/-	+/+	0/+	0/0	0/0	-	0	+	0	0	0	+
- Livestock	0	+/0	0/0	0/0	+/0	0/0	+/0	0	0	-	+	+	+	0
- Farm equipment	0	+/+	+/0	+/0	0/+	+/0	0/0	0	+	0	0	0	0	+
HUMAN CAPITAL														
- Male education	0	+/+	+/0	0/0	+/0	+/0	+/+	0	0	0	+	0	0	+
- Female education	-	0/0	0/0	0/0	0/0	+/0	0/0	-	0	0	0	0	0	+
- Female head	0	0/0	-/0	0/-	0/0	0/0	0/0	0	0	0	0	0	0	0
- Prop. women's land	-	0/-	0/0	-/0	0/0	0/0	0/0	0	0	0	0	0	0	0
- Household size	+	0/0	-/0	0/0	0/0	0/0	0/0	0	0	+	0	0	0	+
- Prop. of dependents	-	0/0	0/0	0/-	0/0	0/-	0/0	0	0	0	0	0	0	0
- Prop. days lost sick	0	+/0	0/-	0/-	+/0	0/0	+/0	-	0	0	0	+	0	0
ACCESS TO INFO/SERVICES														
- Extension	0	+/0	+/-	0/0	0/0	+/-	+/0	0	0	0	0	0	0	0
- Market information	0	0/0	+/0	0/+	+/0	+/0	-/0	0	0	+	0	-	0	0
- Loan	0	0/0	+/0	0/0	0/0	0/0	0/0	-	0	0	0	-	+	0
ACCESS TO MKTS/ROADS														

Table 11. Qualitative Results of the Econometric Analysis (Reduced form results, equations 2)-6))

Factor	Labor Intensity	Land Management/Non-Labor Inputs						Crop Choice						Crop Production per Acre	Income per Capita
		Organic Fert.	Inorg. Fert.	Pesticides	Trad. Seeds	Impvd Seeds	Other inputs	Cereal	Legume	Root Crop	Cereal/ Legume	Legume/ Root Crop			
- High market access	0	+/+	0/0	+/0	+/0	0/-	0/0	0	+	-	0	-		0	0
- Dist. to all weather rd.	0	-/0	0/-	-/0	0/0	0/0	0/0	0	+	0	+	0		0	0
- Dist. to truck service	+	0/0	0/0	0/0	0/0	0/0	+/+	+	0	0	+	-		-	0
- Dist. to minibus/taxi	0	0/0	0/0	-/0	0/0	0/0	0/0	0	0	0	0	+		0	0
LOCAL FACTOR SCARCITY															
- Wage rate	-	0/0	0/+	0/+	+/0	0/0	0/0	0	0	0	0	0		+	+
- Population density	+	+/0	0/0	+/0	0/0	+/0	+/0	0	-	0	+	0		0	0

+ (-) means positive (negative) and statistically significant at 10% level in preferred specification. +/- means + impact in selection equation, - impact in amount used equation,mixed impacts. 0 means not statistically significant in preferred specification.

NATURAL CAPITAL

The area and value of land held by a household have substantial impacts on labor intensity, land management, value of crop production per acre and income per capita. As expected, households with more land farm with less labor intensity. Larger farms are more likely to use non-labor inputs, but their intensity of use of several inputs (organic fertilizer, pesticides, traditional and improved seeds) is lower among households using such inputs. Largely as a result of lower input intensity, the value of crop production per acre is lower for larger farms. Nevertheless, larger farms earn higher incomes per capita than smaller farms.

Land quality, as reflected by the value of land per acre, contributes to more intensive use of labor and greater use of most inputs and land management practices. Planting of cereals and root crops is less on higher value land compared to higher value perennial crops. Not surprisingly, the value of crop production per acre and household income per capita are higher for households using higher value land. These findings are consistent with our expectations that higher land quality contributes to more intensive use of inputs, adoption of more profitable crops[16], and hence higher value of production and incomes.

PHYSICAL CAPITAL

Household endowments of physical capital (livestock, equipment, buildings and durable goods) have significant impacts on some aspects of land management, crop choice, value of crop production per acre and income per capita. Livestock ownership is

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[16] Nkonya, et al. (2004) found that bananas were more profitable than cereals in their analysis of survey results from most of Uganda (excluding insecure areas of the north).

associated with greater use of organic fertilizer, traditional seeds, and other non-labor inputs, and with higher value of crop production per acre. These impacts may be due to greater ability of livestock owners to finance purchase of inputs as well as greater availability of manure, draught power and transport services that help to increase the value of crop production. Livestock ownership is associated with more planting of cereal/legume and legume/root crop mixes and less planting of root crops in pure stands, perhaps because of advantages of cereals and legume residues as sources of fodder.

Ownership of farm equipment is associated with greater use of most non-labor inputs, including organic and inorganic fertilizer, pesticides, and traditional and improved seeds. This is not surprising since farm equipment is needed to apply most inputs. Ownership of farm equipment is associated with more planting of legumes, and with higher household income per capita.

As one might expect, ownership of buildings has less effect on land management than livestock or equipment. Buildings are associated with more use of organic fertilizer, traditional seeds and other non-labor inputs, perhaps by facilitating storage. Buildings are also associated with higher income per capita, suggesting that buildings are productive investments and not simply consumption goods in rural Uganda.

Ownership of durable goods is associated with less labor intensity, more use of organic fertilizer but less of inorganic fertilizer, and more use of pesticides and traditional seeds. Ownership of some durable goods, such as a bicycle or motorbike, may help farmers to acquire and transport inputs (though the reason for the negative association with inorganic fertilizer use is not clear). Households with more durable goods plant less of their land to cereals and more to root crops, and earn higher income per capita. Some durable goods, such as vehicles, can be productive investments in helping households to take advantage of off-farm income opportunities.

Most types of physical capital are associated with higher household incomes. The largest association is between durable goods and income (each one percent increase in the value of durable goods is associated with a 0.07 percent increase in income per capita). This suggests that most assets are viewed as investments, though this may be due to reverse causality (e.g., households who earn more income are better able to afford durable goods, buildings and other assets). More research is needed (using panel data) to help disentangle such puzzles about the direction of causality.

HUMAN CAPITAL

Human capital also has significant impacts on land management, crop production and incomes. Male education is associated with greater use of organic and inorganic fertilizer, traditional and improved seeds, and other non-labor inputs, more planting of cereals/legumes, and higher income per capita. Female education reduces labor intensity in crop production, increases use of improved seeds, reduces planting of cereals, and also contributes to higher income per capita. Female-headed households use less inorganic fertilizer and pesticides than male-headed households, but are not significantly different in terms of other inputs, crop choice, crop production or income per capita. Households with a greater proportion of land farmed by women use labor less intensively and use less organic fertilizer and pesticides, but also are not significantly different in terms of other inputs, crop choice, production or income. Households with a larger labor endowment use labor more intensively, less inorganic fertilizer, plant more root crops, and earn higher income per capita. Households with a higher share of dependents use labor less intensively, less pesticides and improved seeds, but otherwise are not significantly different than others. Households that have lost more days due to illness use more organic fertilizer and traditional seeds but less inorganic fertilizer, pesticides, and other non-labor inputs, grow less cereals and more legumes/root crops.

In general, human capital variables were found to have limited impact on crop production per acre, though they do influence the mix of inputs used and the crops grown. However, some human capital variables have a strong impact on income per capita (education and household size), probably because of impacts on off-farm income.

ACCESS TO INFORMATION AND SERVICES

Access to extension services is associated with greater adoption of organic and inorganic fertilizer, improved seeds and other non-labor inputs, but less intensive use of inorganic fertilizer and improved seeds among farmers using these inputs. Apparently extension encourages farmers to test such inputs using relatively small amounts. We find statistically insignificant and quantitatively small impacts of extension on the type of crops produced, the value of crop production, and household income. This contrasts with findings of Nkonya, et al. (2004), who found that extension was associated with higher crop production and income, especially in lower elevation regions of central, western and parts of northern and eastern Uganda. The different finding in this study may due to context-specific impacts of extension, which may be averaging out in the larger region of this study. Further study of the impacts of extension in different contexts of Uganda is needed.

Access to market information is positively associated with use of several purchased inputs, including inorganic fertilizer, pesticides, traditional seeds and improved seeds, but with less use of other non-labor inputs. It is also associated with greater planting of root crops in pure stands and less planting of legume/root crops in mixed stands. These results suggest that market information contributes to adoption of modern purchased inputs and more specialized crop production.

Access to credit is associated with greater adoption of inorganic fertilizer, as expected. It is associated with less planting of cereals or legume/root crop mixes, but with higher value of crop production per acre. Credit thus appears to be an important constraint affecting fertilizer use and agricultural productivity in Uganda. This result contrasts with the finding of Nkonya, et al. (2004) of insignificant impact of credit access on crop production. However, they investigated only the effect of access at the village level, and not the effect of household level credit access, as in this study.

ACCESS TO MARKETS, ROADS AND TRANSPORTATION

Better access to markets, as indicated by the areas of relatively high market access shown in Figure 2, is associated with more use of organic fertilizer, pesticides and traditional seeds but, surprisingly, less use of improved seeds. In high access areas, legumes are more common and root crops and legume/root crop mixes are less common. We find statistically insignificant impacts of market access on labor intensity, other inputs, value of crop production and household incomes in the regressions for the full sample. The limited impacts of the market access variable are consistent with results of Nkonya, et al. (2004). However, in separate regressions for each region, we find that in the Central Region, higher market access is associated with significantly higher crop production per acre and income per capita. Differences in market access in the other regions, which have less favorable market access than the Central Region in general, are apparently too limited to have a large impact on production and incomes.

Better access to all-weather roads is associated with more use of organic fertilizer, inorganic fertilizer, and pesticides, and less planting of cereals and cereal/legume mixes. These storable annual crops apparently have less comparative advantage close to roads than higher value perennial or perishable annual crops, as hypothesized by Pender, et al. (2001). Despite these differences, we find no significant difference in the value of crop production per acre or income per capita due to differences in access to roads in the full sample regressions.[17] These findings are also similar to those of Nkonya, et al. (2004). However, in the region specific regressions, we find that better access to an all-weather road is associated with higher value of crop production per acre in the Western and Eastern regions, and with higher income per capita in the Central Region. The association of roads with higher income in the Central Region is consistent with the positive impact of market access on income in this region. The impact of roads is apparently less favorable in the less densely populated and more remote Northern Region, where there are likely fewer vehicles using the roads that are available than in the other more densely populated regions.

Access to transportation services, measured by distance to the nearest truck service or minibus/taxi service, also influences land management. Households closer to truck service use labor less intensively and less other non-labor inputs, plant less cereals or cereal/legumes but more legumes/root crop mixes, and obtain higher value of crop production per hectare. These results suggest that access to truck transportation does not

[17] We investigated alternative specifications of the regression models using distance to the nearest paved road or to the nearest feeder road as measures of road access, and also found insignificant impacts of road access on crop production and income in these specifications. Regression results available upon request.

increase farming intensity, but still increases the value of crop production by promoting production and marketing of higher value crops. Better access to minibus/taxi transport services, by contrast, is associated with more pesticide use, less planting of legume/root crop mixes, and has no significant impact on the value of crop production. Access to this type of transportation may increase ability to purchase some readily transportable inputs, such as pesticides, but does not substantially affect farmers' options for marketing their crops, thus has limited impact on the value of crop production.

FACTOR MARKETS AND FACTOR SCARCITY

As one would expect, higher wage rates were found to reduce the labor intensity of crop production. However, higher wages contribute to greater use of several non-labor inputs, including inorganic fertilizer, pesticides and seeds. Thus, the value of crop production per acre is actually higher where wages are higher, despite lower labor intensity, indicating complementarity between off-farm employment opportunities and agricultural production. Such opportunities also contribute to significantly higher incomes per capita. Promoting such opportunities may therefore be a "win-win" proposition.

Higher population density contributes to more intensive use of labor as well as greater use of organic fertilizer, pesticides, improved seeds and other non-labor inputs, consistent with Boserup's (1965) theory of population-induced intensification. However, this intensification is not associated with higher value of crop production per acre or higher income per capita. Thus, the impacts of population pressure may not be as favorable as hypothesized by Boserup or many of her followers (e.g., Tiffen, et al. 1994), though not as negative as many neo-Malthusian predictions either. This result is similar to the findings of Nkonya, et al. (2004).

Impacts of land management on crop production

In addition to investigating the impacts of various indicators of wealth or poverty on land management, production, and income, we also investigated the impact of non-labor inputs/land management on crop production (and hence indirectly on income and poverty). We found in the OLS model that several inputs/land management practices contribute to higher crop production, including inorganic fertilizer, traditional and improved seeds and other non-labor inputs. The impact of organic fertilizer was quantitatively small, negative, and not statistically significant, suggesting that manure and compost use do not have much near term impact on production in Uganda. This result is similar to findings of Nkonya, et al. (2004) and Woelcke, et al. (2003).

The limited impact of organic fertilizer on crop production may be due in part to the relatively high organic matter content of the soils in much of Uganda (Ssali 2001). It may also be related to the way organic materials are managed. For example, manure is often left in the open and applied after much of the nitrogen content has been lost, thus reducing its effectiveness in enhancing yields (Henry Ssali, personal communication). If the nitrogen to carbon ratio in organic matter is too low, organic material can reduce the availability of nitrogen to crops, potentially reducing yields (Palm, et al. 1997). Such limited or negative near term impacts may be outweighed by the longer-term benefits of organic matter application (e.g., improvement in soil structure and biological activity), however (Reijntjes, et al. 1992). For example, long-term experiments in Kenya have shown that use of inorganic fertilizer along is insufficient to maintain soil productivity over time; maintenance of soil organic matter was found to be essential for this (Nandwa and Bekunda 1998). Thus, even though application of organic materials may yield limited impact on crop production in the near term, it appears to be essential to maintain productivity over the longer term.

The positive impact of inorganic fertilizer use suggests that this form of fertilizer is more likely to have positive near term impact on production, though profitability is still an important consideration affecting fertilizer use. Among the sample households using fertilizer, the average value of fertilizer applied per acre was 10,900 Ush/acre, and the average value of crop production was 314,400 Ush/acre. Given the estimated elasticity of production response to fertilizer reported in Table 9 (0.036), a one percent increase in mean fertilizer use, worth 109 Ush per acre, would increase the predicted value of production by only 113 Ush/acre (314,400 x 0.01 x 0.036). This is a low marginal value/cost ratio (113/109=1.04) for fertilizer, indicating low profitability and explaining why fertilizer use remains low, despite having positive impacts on production.[18] Comparable calculations based on the results reported in Table 9 indicate an estimated marginal value/cost ratio of 1.15 for traditional seeds, 0.83 for improved seeds, and 0.15 for other non-labor inputs. These calculations suggest why use of most non-labor inputs/land management practices (other than traditional seeds) is so low in Ugandan agriculture—because their profitability is low.

It is important to emphasize that these estimates are based on estimated elasticities from the OLS model, which were not robust in the IV estimation. Thus, we do not have strong confidence in these results, though they are suggestive, and the finding of low profitability of these non-labor inputs is consistent with findings of Nkonya, et al. (2004)

[18] A value/cost ratio of 2 is commonly argued as necessary to stimulate significant adoption of inorganic fertilizer.

and Woelcke (2003). However, further research is needed to more fully assess the impacts of land management practices on crop production and income.

4. CONCLUSIONS AND IMPLICATIONS

Poverty has many different dimensions, and the different dimensions of rural poverty have different impacts on land management, agricultural productivity and incomes. These different types of impacts need to be adequately understood if downward spirals of poverty, low productivity and land degradation are to be avoided or reversed.

The impacts of rural poverty on land management depend upon the type of poverty (i.e., what asset or access factor is constrained) and the type of land management considered. We have found that Ugandan households that are poorer in terms of access to land use labor more intensively and are less likely to use several land management practices and inputs, though among households that do use non-labor inputs, land-poor households use many of these inputs more intensively. As a result, land-poor households obtain higher value of crop production per acre, though they have substantially lower incomes than land rich households. Thus, lack of access to land is a key factor affecting intensity of land management and rural poverty.

Households who are poorer in terms of the quality of land that they farm (controlling for farm size) use less labor and most non-labor inputs, and obtain lower crop production and income. To the extent that land quality is declining as a result of soil nutrient depletion and other land degradation problems, which are widespread throughout Uganda, as noted earlier, these results suggest that a downward spiral of land degradation→ declining land quality → lower investment in land management → further land degradation is occurring. Collection of data on land management and land degradation over longer time periods is necessary to assess the extent to which such a downward spiral is occurring, its impacts, and the most effective means to break out of it.

Households that are poorer in terms of ownership of physical assets are less apt to adopt most land management practices and non-labor inputs. Furthermore, households with less livestock obtain lower crop yields, and households with less of other assets obtain lower income. This suggests another negative cycle: low assets → low investment in land management and low income→ continued land degradation and low assets. Land degradation then can cause declining land quality and further declines in land management investment and productivity, as discussed above.

Households who are poorer in terms of males' access to education also invest less in most inputs and land management technologies, and obtain lower incomes. Households in which females lack education use labor more intensively in agriculture and but also obtain lower incomes. These households may be locked into a similar cycle of low education → low investment in land management and low incomes → land degradation and continued low assets as described above.

Households in communities with lower wage rates (and presumably less off-farm employment opportunities) use labor more intensively in agriculture, but use several non-labor inputs less intensively (including fertilizer and pesticides), and obtain lower value of crop production and incomes. Thus lack of off-farm opportunities may contribute to keeping poor households in a poverty and land degradation trap.

Households without access to extension, market information or credit are less apt to use several modern non-labor inputs, likely resulting in lower crop production (demonstrated in the case of lack of credit access). Households with poor access to roads use less organic or inorganic fertilizer, which can contribute to land degradation. Furthermore, we find that poorer road access is associated with lower crop production per acre in two regions and lower incomes in one region. Thus lack of access to infrastructure and services also may prevent households from exiting the poverty-land degradation trap, though the impacts of this are location specific.

Our results suggest that improvement in smallholders' access to land, other assets, education, extension, market information, credit, roads, and off-farm opportunities can help to break the downward cycle of poverty and land degradation, and put farmers on a more sustainable development pathway. Access to land (area and quality), other assets, education and off-farm opportunities appear to be particularly important in addressing poverty directly, while other interventions are likely to have more indirect impacts, as they influence land management, crop choice, and other livelihood decisions. Given the importance of land as the major asset owned by poor rural households in Uganda, investing in land quality maintenance and improvement is a critical need. However, the low apparent returns to investments in organic or inorganic fertilizer and other land management practices suggests that it will be difficult to get farmers to make such investments in the present environment. Improvements in the market environment as well as development of more profitable land management technologies appears essential to address this need.[19]

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[19] Woelcke, et al. (2003) reach a similar conclusion based on their study of technology and policy options for sustainable land management in Iganga district.

Although this study has shed new light on the interrelationships between poverty and land management in Uganda, it faces several shortcomings that should be addressed in future research. In the 1999/2000 UNHS, land management was only crudely characterized by farmers' estimates of the value of non-labor inputs of different types; there is much more to land management than this (e.g., fallow and crop rotation systems, land investments such as terraces and live barriers, use of leguminous cover crops and improved fallows, etc.). These practices vary from one plot to another on the same farm, and are largely influenced by plot level biophysical and locational factors that are not captured in this study, introducing potential omitted variable bias in these analyses. Land quality had to be proxied by households' subjective estimates of land value per acre, which is subject to biases and may be affected by many factors other than land quality. The cross sectional nature of the data limits the ability to control for unobserved fixed factors (such as land quality, differences in climate, etc.) that may have biased the regression results. No indicators of land degradation were included in the UNHS, so we cannot draw direct conclusions about the impacts of poverty and land management on land degradation (though we can infer that land degradation is likely greater where soil fertility inputs are lower). Furthermore, the dynamic relationships among poverty, land management and land degradation cannot be investigated by analyzing a cross-sectional survey. Thus, while many of our results suggest that a downward spiral or poverty-land degradation trap may exist and the factors that influence this, they do not conclusively demonstrate that such spirals or traps are present, nor how effective possible interventions are in helping to prevent or reverse such dynamic spirals. Further research based on panel data, collected at the plot as well as household level, and including information on the broader array of land management practices used and land degradation processes occurring at that level, is needed to adequately address these issues.

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APPENDIX: THEORETICAL DYNAMIC HOUSEHOLD MODEL[20]

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

Consider a household that seeks to maximize its lifetime welfare:

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

where c_t is the value of consumption in year t, $u_t(\ )$ is the single period consumption utility[21] and the expectation (E_0) is taken with respect to uncertain factors influencing future income at the beginning of year t=0. Consumption in year t is given by:

$$2)\ c_t = I_{ct} + I_{lt} + I_{wt} + I_{nt} + p_{Wt}INV_{Wt}$$

where I_{ct} is gross crop income, I_{lt} is gross livestock income, I_{wt} is net wage income, and I_{nt} is income from nonfarm activities in year t.[22] INV_{Wt} is a vector of investments (or disinvestments) in assets during year t, including investments in physical capital (PC_t) (livestock, equipment), human capital (HC_t) (education, experience, training), "natural capital" (NC_t) (assets embodied in natural resources, including land quantity and quality, land rights and tenure, land improving investments), "social capital" (SC_t) (assets embodied in social relationships, such as participation in organizations or networks), and financial

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[20] This appendix is adapted from the theoretical model developed in Nkonya, et al. (2004).

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

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

capital (FC_t) (cash and other liquid assets, access to credit). p_{wt} is the price of marketed assets, or in the case of non-marketed assets (e.g., experience or social capital), we interpret p_{wt} as the cost of acquiring an additional unit of these assets.

Household gross crop income is given by:

3) $I_{ct} = y(C_t, p_{ct}, L_{ct}, LM_t, NC_t, T_t, PC_t, HC_t, SC_t, IS_t, BP_t)A_t$

where y( ) represents the value of production per acre farmed, A_t is the area farmed (part of NC_t), C_t represents the vector of area shares of different annual crops grown by the household[23], p_{ct} is the vector of farm level prices of the different crops, L_{ct} is the amount of labor per acre applied, LM_t is a vector of land management practices (use of mulch, manure, etc.) used, T_t represents tenure characteristics of the land, IS_t represents household access to information and services (e.g., agricultural extension and market information), BP_t are other biophysical factors affecting the quantity of crop production (e.g., rainfall, temperature, etc.), and other variables (NC_t, PC_t, HC_t, SC_t) are as defined previously.[24] The physical, human and social capital of the household are included as possible determinants of crop production because these assets may affect agricultural productivity if there are imperfect factor markets (de Janvry, et al. 1991).

The farm level prices may vary as a result of variations across communities in access to markets and roads (affecting transport costs to markets), agro-ecological conditions (affecting local supply), and population density (affecting local demand and supply). In the presence of transaction costs, prices may also vary across households as a function of

[23] Perennial crops available for harvest in the current year are the result of investment in prior years, and are taken as part of the land investments on the plot (included in NC_t).
[24] The function y( ) is not strictly a production function, since it depends on prices as well as the quantity of production. This form is used because of widespread use of intercropping and multiple cropping in Uganda, and because of the difficulty of determining the allocation of labor and land management practices to specific crops.

household level factors that may affect these transaction costs. For example, households who own transportation equipment (part of PC_t), with more experience in producing cash crops (part of HC_t), who have access to market information (part of IS_t) or who belong to certain ethnic or social groups (part of SC_t) may obtain higher prices for their products as a result of lower transaction costs or better information about markets than other farmers. Since we are interested in the impacts of such underlying factors on production and land management, and because prices for many commodities are not observed for many households, we model prices as a function of these underlying factors and a random factor (u_{ct}):

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

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

We also model biophysical conditions in a given year as dependent upon observable agroecological conditions (a subcomponent of X_{vt}) and random factors (u_{bt}):

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

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

6) $$\begin{aligned} &y'(C_t, L_{ct}, LM_t, NC_t, T_t, PC_t, HC_t, SC_t, IS_t, X_{vt}, u_{yt}) \equiv \\ &y(C_t, p(X_{vt}, PC_t, HC_t, SC_t, IS_t, u_{ct}), L_{ct}, LM_t, NC_t, T_t, PC_t, HC_t, SC_t, IS_t, BP(X_{vt}, u_{bt})) \end{aligned}$$

where u_{yt} is a linear combination of u_{ct} and u_{bt} assuming that the functions p( ) and BP( ) are linear in these terms and that y( ) is a linear function.

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

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

Net wage income is given by:

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

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

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

9) $I_{nt} = I_n(L_{nt}, PC_t, HC_t, SC_t, IS_t, X_{vt}, u_{nt})$

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

10) $L_{ct} + L_{lt} + L_{ot} + L_{nt} \leq L_{ft} + L_{it}$

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

Most forms of capital must be nonnegative:

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

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

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

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

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

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

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

14) $PC_{t+1} = (1 + g)PC_t + INV_{PCt}$

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

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

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

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

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

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

Maximization of 1) subject to the constraints defined by equations 2), 3), and 6) – 16) defines the household optimization problem. If we define the optimized value of 1) ("value function") as V_0 and notice that this is determined by the value of the state variables at the beginning of period 0 (PC_0, HC_0, NC_0, SC_0, FC_0), and by the other exogenous variables in this system that are determined at the beginning of period 0 (X_{v0}, IS_0, L_{f0}), then we have that

$$17)\quad \begin{aligned} &V_0(PC_0, HC_0, NC_0, SC_0, FC_0, IS_0, X_{v0}, L_{f0}) \equiv \\ &\max \ E_0[\sum_{t=0}^{T} u_t(c_t)] \ \ \textit{subject to equations} \ 2),\ 3),\ 6)-16) \end{aligned}$$

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

$$18)\ V_0(W_0, X_{v0}, IS_0, L_{f0}) = \max_{L_0, C_0, LM_0, INV_{W0}} \ E_0[u(c_0)] + E_0V_1(W_1, X_{v1}, IS_1, L_{f1})$$

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

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

$$19)\ C_0{*} = C_0(W_0, X_{v0}, IS_0, L_{f0})$$

$$20)\ L_0{*} = L_0(W_0, X_{v0}, IS_0, L_{f0})$$

$$21)\ LM_0{*} = LM_0(W_0, X_{v0}, IS_0, L_{f0})$$

$$22)\ INV_{W0}{*} = INV_0(W_0, X_{v0}, IS_0, L_{f0})$$

The optimal solutions for crop choice, labor allocation and land management determine the optimized value of production, land degradation, and household income. Substituting equations 19) to 21) into equation 6), we obtain the optimal value of crop production[25]:

$$23)\ \begin{array}{l} y_0{*} = y'(C_0(W_0, X_{v0}, IS_0, L_{f0}), L_{c0}(W_0, X_{v0}, IS_0, L_{f0}), LM_0(W_0, X_{v0}, IS_0, L_{f0}), \\ NC_0, T_0, PC_0, HC_0, SC_0, IS_0, X_{v0}, u_0) \end{array}$$

Equation 23) forms the basis for empirical estimation of the determinants of value of crop production. It will be estimated in structural form, including the impacts of the endogenous variables (C_{p0}, L_{p0}, LM_{p0}). The model will also be estimated in reduced form:

$$24)\ y_0{*} = y''(W_0, X_{v0}, IS_0, L_{f0}, u_0)$$

The reduced form income function is derived by substituting the crop value of production function from equation 24) into crop income equation 3), the labor allocation functions in equation 20) into the other income equations 7)-9), and then summing up total household income[26]:

25)

$$\begin{array}{l} I_0{*} = y''(W_0, X_{v0}, IS_0, u_0)A_0 + I_l(L_{l0}(W_0, X_{v0}, IS_0, L_{f0}), PC_0, NC_0, HC_0, SC_0, IS_0, X_{v0}, u_{l0}) \\ + w_{o0}(X_{v0}, PC_0, HC_0, SC_0, IS_0, u_{wo0})L_{o0}(W_0, X_{v0}, IS_0, L_{f0}) - w_{i0}(X_{v0}, PC_0, HC_0, SC_0, IS_0, u_{wi0})L_{i0}(W_0, X_{v0}, IS_0, L \\ + I_n(L_{n0}, PC_0, HC_0, SC_0, IS_0, X_{v0}, u_{n0}) = I_0(W_0, X_{v0}, IS_0, L_{f0}, u_{I0}) \end{array}$$

Equations 19) – 25) are the basis of the empirical work.

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[25] The terms related to random variations in prices (u_{c0}) and in biophysical factors (u_{v0}) have been combined into a single random variable reflecting random fluctuations in value of crop production (u_0) in equation 22).

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

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