Strategies to Increase Agricultural Productivity and Reduce Land Degradation: Evidence from Uganda

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Abstract

This paper estimates a structural econometric model of household decisions regarding income strategies, participation in programs and organizations, crop choices, land management, and labor use, and their implications for agricultural production and land degradation; based upon a survey of over 450 households and their farm plots in Uganda. The results generally support the Boserupian model of population-induced agricultural intensification, but do not support the "more people-less erosion" hypothesis, with population pressure found to contribute to erosion in the densely populated highlands. Agricultural technical assistance programs have location-specific impacts on agricultural production and land degradation, contributing to higher value of crop production in the lowlands, but to soil erosion in the highlands. By contrast, NGO programs focusing on agriculture and environment are helping to reduce erosion, but have mixed impacts on production. We find little evidence of impact of access to markets, roads and credit, land tenure or title on agricultural intensification and crop production, though road access appears to contribute to land degradation in the highlands. Education increases household incomes, but also reduces crop production in the lowlands. We do not find evidence of a poverty-land degradation trap, while poverty has mixed impacts on agricultural production: smaller farms obtain higher crop production per hectare, while households with fewer livestock have crop production. These findings suggest that development of factor markets can improve agricultural efficiency. Several other factors that contribute to increased value of crop production, without significant impacts on land degradation, include specialized crop production, livestock and nonfarm income strategies, and irrigation. In general, the results imply that the strategies to increase agricultural production and reduce land degradation must be location-specific, and that there are few "win-win" opportunities to simultaneously increase production and reduce land degradation.

Keywords: Agricultural productivity, land degradation, agricultural development strategies, Uganda, farm size-productivity

1. Introduction

Land degradation and low agricultural productivity are severe problems in Uganda. Although Uganda's soils were once considered to be among the most fertile in the tropics (Chenery 1960), problems of soil nutrient depletion, erosion, and other manifestations of land degradation appear to be increasing. The rate of soil nutrient depletion is among the highest in sub-Saharan Africa (Stoorvogel and Smaling 1990), and soil erosion is a serious problem, especially in highland areas (Bagoora 1988). Land degradation contributes to the low and in many cases declining agricultural productivity in Uganda. Farmers yields are typically less than one-third of potential yields found on research stations, and yields of most major crops have been stagnant or declining since the early 1990's (Deininger and Okidi 2001)

Finding ways to reverse these trends is an urgent need in Uganda and many other developing countries. In order to do that, information is needed to help identify strategies that will lead to more productive and sustainable land use. Because of the diverse agro-ecological and socioeconomic conditions in Uganda and the complex set of factors and interactions that influence farmers' land management decisions and their implications for productivity and land degradation, addressing this information need is a formidable challenge. This paper addresses this challenge by developing and estimating a structural econometric model of household decisions regarding income strategies, participation in programs and organizations, crop choices, land management, and labor use, and their implications for agricultural production and land degradation; based upon a survey of over 450 households and their farm plots in central and southern Uganda.

2. Conceptual Framework and Methodology

Empirical Model[1]

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

[1] This empirical model is derived from a theoretical dynamic household model, which is presented in Nkonya, et al. (2003).

Value of Crop Production

For agricultural production, we focus on the value of crop production. We assume that the value of crop production by household h on plot p (y_{hp}) is determined by the vector of shares of area planted to different types of crops (C_{hp}); the amount of labor used (L_{hp}); the vector of land management practices used (LM_{hp}); the "natural capital" of the plot (NC_{hp}) (biophysical characteristics and presence of land investments); the tenure characteristics of the plot (T_{hp}) (land rights category, how plot acquired, tenure security); the household's endowments of physical capital (PC_h) (land, livestock, equipment), human capital (HC_h) (education, age, and gender), and "social capital" (SC_h) (participation in programs and organizations); the household's income strategy (IS_h) (primary income source); village level factors that determine local comparative advantages (X_v) (agro-ecological conditions, access to markets and infrastructure, and population density); and random factors (u_{yhp}):

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

We focus in equation 1) on the value of production 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 and farm level prices of these crops, the inputs and land management practices used in producing them, and the natural conditions of the plot. Since different crops are produced by different households in different locations in Uganda, we do not explicitly include crop prices as determinants of the value of crop production, because this would result in many missing observations for farm level prices, and because farm level prices may be endogenous to production decisions in the context of imperfect markets (de Janvry, et al. 1991). 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 (HC_h, SC_h, IS_h). Household endowments of physical capital (PC_h) can also affect crop production if there are imperfect factor markets. In addition, agroecological conditions (part of

X_v), households' human and social capital and their experience, as reflected by their income strategies, may also influence agricultural productivity, even if these factors have no impact on local prices.

Crop Choice, Labor Use and Land Management

In equation 1), crop choice, labor use and land management are all choices in the current year[2], determined by the natural capital and tenure of the plot; by the household's endowments of physical, human, social, and financial capital and of family labor (L_{fh}) at the beginning of the year; by the household's income strategy; and by agroecological conditions, access to markets and infrastructure, and population density (X_v):

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

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

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

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

Income Strategies and Participation in Programs and Organizations

Because changes in income strategies usually require investments in human and social capital (e.g., development of new skills and investments in developing market connections are needed to shift from subsistence to cash crop production), and because these investments are irreversible (i.e., the costs of these investments cannot be recouped by selling human or social capital), changes in income strategies usually do not occur rapidly, due to the time required for such investments to occur and the "option

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

value" of waiting to invest when investments are irreversible and there is uncertainty about the returns to investment (Dixit and Pindyck 1994). The retarding effect of irreversibility is even more pronounced when credit markets are imperfect and indivisible investments are required, since households may be unable or very slow to self-finance such investments (Fafchamps and Pender 1997). As a result, households may become "locked-in" to a particular income strategy, even when more remunerative strategies could be pursued as a result of profitable investments in human and social capital.

These considerations suggest that there is likely to be a substantial degree of inertia, or "path dependency", in households' choices of income strategies, regardless of how market opportunities may be changing. Furthermore, in the context of imperfect markets and high transaction costs, households' income strategies will depend on their consumption preferences. Thus, we assume that households' current income strategies are determined by fixed cultural factors, reflected by the ethnicity of the household (Eth_h), which may influence consumption preferences and some aspects of social and human capital, as well as by households' endowments of labor, human and natural capital and factors determining local comparative advantages:[3]

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

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

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

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

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

[3] We also could assume that current income strategies depend upon past income strategies, to account for path dependence in such strategies. Investigation of such an empirical model revealed that the income strategies pursued 10 years in the past are very strong predictors of current income strategies, to such an extent that statistical estimation of the multinomial logit model for income strategies was not feasible in this case, because too many outcomes were completely determined. Although this demonstrates the importance of path dependence, this model is of limited usefulness in assessing the importance of other determinants of income strategies.

Land Degradation

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

8) $e_{hp} = e(C_{hp}, L_{hp}, LM_{hp}, NC_{hp}, X_v, u_{ehp})$

Since we have not been able to measure erosion on the plots studied in this research, we use predicted erosion based on the revised universal soil loss equation (RUSLE) (Renard, et al. 1991). The RUSLE has been calibrated to soil conditions in Uganda by several recent studies (Lufafa, et al. 2003; Mulebeke 2003; Majaliwa 2003; Tukahirwa 1996). The RUSLE estimates annual soil loss based upon several factors, including rainfall intensity, soil erodibility, topography (slope, slope length and curvature), land cover and land management practices. The RUSLE model is deterministic, providing deterministic predictions of erosion based on the factors mentioned above. As such, it is not so useful in estimating the statistical relationships between land management practices and actual erosion, as specified in equation 8). However, the predictions of RUSLE can be useful in estimating the relationships between underlying socioeconomic and biophysical factors that determine land management and hence affect erosion. Substituting equations 2) – 4) into equation 8), and assuming that the error term is additive[4], we have the following expression for erosion:

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

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

10) $e_{hp} = e^p{}_{hp} + v_{ehp}$

Then substituting equation 10) into 9), we have:

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

11) $e^{p}{}_{hp} = e'(NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, FC_h, IS_h, L_{fh}, X_v) + u_{ehp} - v_{ehp}$

Thus we can estimate equation 9) using equation 11), as long as the prediction error (v_{ehp}) is not correlated with the explanatory factors. We maintain this as an assumption, recognizing that violation of this assumption would lead to biased estimates of the parameters in equation 9).

Explanatory Variables

The village level explanatory variables (X_v) include the agro-ecological and market access zone, and the population density of the parish (the second lowest administrative unit, consisting of several villages). Ruecker, et al. (2003) classified the agro-climatic potential for perennial crop (banana and coffee) production in Uganda, based upon the average length of growing period, rainfall pattern (bimodal vs. unimodal), maximum annual temperature, and altitude (Figure 1). Potential for maize production was also mapped and the map was found to be very similar. Thus the zones in Figure 1 are representative of agro-climatic potential for the most important crops in Uganda.[5] Seven zones were identified: the high potential bimodal rainfall area at moderate elevation near Lake Victoria (the "Lake Victoria crescent"), the medium potential bimodal rainfall area at moderate elevation (most of central and western Uganda), the low potential bimodal rainfall area at moderate elevation (lower elevation parts of southwestern Uganda), the high potential bimodal rainfall southwestern highlands, the high potential unimodal rainfall eastern highlands, the medium potential unimodal rainfall region at moderate elevation (parts of northern and northwestern Uganda), and the low and very low potential unimodal rainfall region at moderate elevation (much of northeastern Uganda).

A classification of Uganda into areas of low and high access, using an index of "potential market integration" based upon estimated travel time to the nearest five markets, weighted by their population, is shown in Figure 2. Market access in Uganda is highest in the Lake Victoria crescent (especially close to

[5] Although soil conditions are also important in determining agricultural potential, no attempt was made to include soils in the classification, due to limitations in the available soils data and the high degree of spatial variability in soil quality. Thus, the map in Figure 2 does not fully represent "agricultural potential", though it represents agro-climatic zones.

the major urban centers of Kampala and Jinja), in parts of the densely populated highlands, and near to the highway network in the rest of the country.

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

Hypotheses

A large number of hypotheses could be tested concerning the relationships in equations 1) – 11). We focus on the effects of several key factors on the value of crop production and land degradation.

Population Pressure

Population pressure (higher population density) is expected to be associated with higher labor intensity in agriculture, by increasing the availability (hence reducing the costs) of labor relative to land (Boserup 1965). Higher labor intensity of agriculture can take the form of production on more marginal lands, less use of fallow, adoption of more labor-intensive methods of cultivation (e.g., increased hoeing and hand weeding, manuring, composting, mulching), labor-intensive investments in land improvement (e.g., construction of soil bunds, tree planting), and/or adoption of more labor-intensive commodities (e.g., horticultural crops and intensive livestock production) (Pender 2001). This is likely to lead to higher yields and higher value of crop production per hectare, unless greater intensity is offset by land degradation (Ibid., Salehi-Isfahani 1988).

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

Access to Markets and Roads

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

The impacts on land degradation are also ambiguous. By increasing the profitability of agricultural production, greater market access may promote expansion of production into forest areas or other fragile lands (Angelsen 1999), which will increase land degradation. However, if the costs of factors rise as a result of constrained supply, a reduction in agricultural area is possible as productive factors are concentrated on the most profitable lands (Ibid.). Market-driven intensification may also contribute to land degradation by leading to reduced fallowing (Binswanger and McIntire 1987). Improved market access may contribute to increased use of animal draught power for tillage (Ibid.), which will contribute to soil erosion when practiced on sloping lands. On the other hand, market-driven intensification may lead to reduced erosion as a result of the increased incentive to invest in land improvements, given the rising value of land relative to labor (Tiffen, et al. 1994).

Technical Assistance Programs and Organizations

The impacts of participation in programs and organizations will depend upon their focus. Programs and organizations focusing on technical assistance related to agriculture or environment in

Uganda are promoting different types of technologies and land management practices. In some cases (e.g., the Ministry of Agriculture extension program) these programs are promoting increased use of purchased inputs such as improved seeds and fertilizer. In other cases, programs (especially those of non-governmental organizations (NGO's)) are promoting low external input agricultural technologies, such as mulching, composting, leguminous cover crops and agroforestry practices. The net impact of such programs on land management and their ultimate impacts on production and land degradation is an empirical question. Programs focusing more on production inputs may have more impact on production and income in the short run, while programs focusing more on sustainable land management and environment may have more impact on reducing land degradation.

Credit

Access to credit may enable farmers to purchase inputs or acquire physical capital, thus contributing to technology adoption and increased capital and input intensity in agriculture (Feder, et al. 1985). This may promote increased production and marketing of high value crops or intensification of livestock production, and a reduction of subsistence food crop production. If credit availability helps to relax credit constraints, this can reduce the extent to which households discount the future (Pender 1996), possibly leading to more investment in soil and water conservation (Pender and Kerr 1998). Credit may also facilitate labor hiring and thus promote labor intensification. On the other hand, credit availability may enable households to invest in nonfarm activities, and may thus contribute to less intensive management of land and other agricultural resources. Also, by promoting intensification of capital and purchased inputs, credit may reduce labor-intensive land management practices that are substitutes for these. The net impacts on crop production and land degradation are thus ambiguous.

Education

Education may increase households' access to credit as well as their cash income, thus helping to finance purchases of physical capital and purchased inputs. This may help to promote production of high value crops, as well as promoting greater use of such capital and inputs in producing traditional food crops. Education may promote adoption of new technologies by increasing households' access to information and their ability to adapt to new opportunities (Feder, et al. 1985). On the other hand, more educated households may be less likely to invest in inputs or labor-intensive land investments and management practices, since the opportunity costs of their labor and capital may be increased by education. Thus, the net impacts of education on crop production and land degradation are ambiguous.

Poverty

If factor markets (markets for land, labor, and capital) do not operate efficiently, there may be significant differences among households in their agricultural practices and productivity (de Janvry, et al. 1991). In the context of imperfect labor and land markets, agricultural households with less land or a larger family labor endowment per unit of land can be expected to use labor more intensively in agricultural production (Feder et al. 1985). Essentially, the impacts of smaller farm size or larger household labor endowment, controlling for farm size, will be similar to the effects of population density, if imperfections in labor and land markets limit the extent to which differences in labor and land endowments can be overcome through labor or land transactions. The impact of smaller farm size or larger family size on the value of crop production per hectare is likely to be positive if labor and land markets are imperfect, or zero, if these markets function well. As with population pressure, the impact of these factors on land degradation is ambiguous.

If credit is constrained, farmers who own more physical assets such as land, livestock, or equipment may be better able to finance purchase of inputs or investments, and better able to use these assets in agricultural production. The impacts on crop production and land degradation are thus qualitatively similar to the impacts of access to credit discussed above, and are ambiguous for the same reasons.

Land Tenure

The form of tenure on a plot of land can affect land management and productivity for several reasons. If there is insecurity of tenure, the household operating the plot may have less incentive to invest in land improvement (Feder, et al. 1988). This is not necessarily the case, however, if the household can increase tenure security by investing in the land (Besley, 1995; Otsuka and Place, 2001). The form of tenure may also affect households' access to credit (Feder, et al. 1988; Place and Hazell 1993) or the transferability of land, which can affect the ability to use the land efficiently or owners' incentives to invest in land improvement (Pender and Kerr 1999). All of these impacts may affect agricultural productivity and land degradation.

There are four types of land tenure in Uganda: customary, mailo, freehold and leasehold. Customary land is subject to customary laws and regulations, and is the most common form of tenure. Owners of customary land generally have secure rights to use, lease and bequeath this land, but sales are subject to approval of clan leaders and family members. Mailo land is land that was provided by the British colonial government to the Buganda royal family and other nobles in units of square miles ("mailo"), and was regarded as freehold land under colonial law. However, most of this land is occupied by long-term tenants, whose rights have been increasingly protected by the government of Uganda since the end of colonial rule, and the 1998 Land Act provides long-term mailo tenants the right to acquire freehold title to mailo land. Owners of freehold land have complete rights to use, sell, lease, subdivide, mortgage or bequeath this land; formally, this is the most complete and secure form of tenure. Leasehold land is public land leased from the state (usually under long-term leases); in some cases such leases have led to evictions of occupants of the land and conflict (Place, et al. 2001).

The extent of tenure insecurity among these different tenure systems is debatable. Customary tenants have had access to these lands for a long time, though in some areas, the power of traditional authorities has been undermined in the past by actions of the government (Ibid.), which may have contributed to insecurity. The 1998 Land Act seeks to ensure tenure security on customary land by recognizing the jurisdiction of local authorities and customary laws over this land. Mailo tenants generally have strong rights (Ibid.), and the 1998 Land Act increases this. Holders of leasehold land generally have long-term leases of public land from the state. However, in some cases such leases have been provided to elites without regard to other occupants of the land, contributing to risks of insecurity and conflict (Ibid.). Thus, tenure security may be a concern for occupants of leasehold or public land.

Ownership of a formal title may amplify the impacts of greater tenure security and complete land rights associated with freehold, by providing proof of freehold status.[6] In particular, formal title may facilitate access to credit and help to prevent or resolve land disputes (Feder, et al. 1988). Thus, we investigate the impacts of a title, *per se*, in addition to the land tenure status. We also investigate the impacts of households' perception of perceived tenure security, and the means of land acquisition, which may also influence incentives to invest in land management. For example, tenants on rented land are unlikely to invest in soil and water conservation measures if the lease is short term. Owners of purchased land and tenants using cash rental may have more incentive than owners of inherited land to produce cash crops and apply inputs, in order to be able to recoup the costs of their investment. These differences may result in differences in crop production and land degradation.

Data

The above model is estimated using econometric analysis of survey data collected in 107 communities during 1999 to 2001. The study region included most of Uganda, including more densely populated and more secure areas in the southwest, central, eastern and parts of northern Uganda, representing seven of the nine major farming systems of the country (Figure 3).[7] Within the study region, communities (LC1's, the lowest administrative unit, usually a single village) were selected using a stratified random sample, with the stratification based on development domains defined by the different agro-ecological and market access zones shown in Figures 1 and 2, and differences in population density (Pender, et al. 2001). One hundred villages were selected in this way. Additional communities were purposely selected in areas of southwest and central Uganda, where the African Highlands Initiative and the International Center for Tropical Agriculture (CIAT) are conducting research.

A community level survey was conducted with a group of representative people from each selected community to collect information on access to infrastructure and services, local markets and

[6] Not all freehold owners have an actual title to their freehold parcels.
[7] The districts included in the project study area include Kabale, Kisoro, Rukungiri, Bushenyi, Ntungamo, Mbarara, Rakai, Masaka, Sembabule, Kasese, Kabarole, Kibale, Mubende, Kiboga, Luwero, Mpigi, Nakasongola, Mukono, Kamuli, Jinja, Iganga, Bugiri, Busia, Tororo, Pallisa, Kumi, Soroti, Katakwi, Lira, Apac, Mbale, and Kapchorwa.

prices, and other factors. A random sample of 451 households was selected (four households per community in most cases). For each household selected, a household level questionnaire collected information about household endowments of assets, household composition, income and expenditures, and adoption of agricultural and land management technologies. A plot level survey was also conducted to collect information on all of the plots owned or operated by the household, including information about land tenure, plot quality characteristics, land management practices, use of inputs and outputs from the plot in the year 2000. The survey information was supplemented by secondary information collected from the 1991 population census and available geographic information.

Analysis

We use econometric analysis of equations 1) – 6) and 11) to analyze the determinants and impacts of income strategies, participation in programs and organizations and land management practices on crop production and soil erosion. Ideally, we would like to estimate this system using a linear systems approach, such as three-stage least squares, to deal with endogenous explanatory variables and account for correlation of error terms across the different equations. This is not feasible, however, due to the nature of many of the dependent variables. Several of the endogenous variables in this system are limited dependent variables (categorical or censored), for which a linear estimator is not appropriate. C_{hp} are area shares under different crops and thus censored continuous variables (censored below at 0 and above at 1); we use a maximum likelihood Tobit estimator (with left and right censoring) for equation 2). LM_{hp} and SC_h are dichotomous choice variables (whether certain land management practices are used, whether the household participates in different types of programs and organizations); we use probit models to estimate equation 4) and 6). IS_h is a polychotomous choice variable (primary income source); we use a multinomial logit model to estimate equation 5). y_{hp}, L_{hp}, and e_{hp}, are continuous uncensored variables; thus least squares regression can be used for equations 1), 3) and 11).

Inclusion of endogenous explanatory variables in equations 1) – 4) and 11) could result in biased estimates, due to correlation of the error term with the endogenous explanatory variables. We use instrumental variables (IV) or two-stage estimation to address the endogeneity problem.[8] As shown in equations 5) – 6), the ethnicity of the household is used as an instrumental variable to predict income strategies and participation in programs and organizations. These predicted income strategies and participation variables are used as instruments for actual strategies and participation in the IV or two-stage versions of the other equations.[9] In addition, predicted crop choice, labor use and land management practices are used as instruments in estimating equation 1). Other instrumental variables are identified by hypothesis testing: variables that were jointly statistically insignificant in the full version of the models for equations 1), 3) and 11) were dropped from the IV regression and used as instrumental variables.

Identification of the effects of the endogenous variables in the IV models and two-stage models can be difficult unless one has instrumental variables that strongly predict the endogenous explanatory variables. In finite samples, results of estimation with weak instruments can be more biased than ordinary least squares (OLS) (Deaton 1997). We address this concern by controlling for many exogenous explanatory factors in the regressions which could cause endogeneity or omitted variable bias if left out (such as indicators of land quality and agro-ecological conditions), and by investigating the robustness of the regression results to estimation by OLS, IV, and reduced form (RF) approaches. In discussing our findings, we focus on results that are robust across at least two of these three specifications, unless noted otherwise. We also conduct Hausman (1978) tests comparing the OLS and IV models.

For the least squares models with only positive values of the dependent variables (equations 1), 3), and 11)), we use a log-log specification (logarithm of the dependent variable and of all continuous uncensored explanatory variables). Because there are zero values for some household assets (land, livestock, and equipment) for some households, it is not possible to use a simple logarithmic transformation for these variables. Instead, we included a dummy variable for positive asset ownership, to allow for an intercept shift for households with zero values for some assets, as well as the logarithm of

[8] For the limited dependent variable models (equations 2) and 4)) we use a two-stage estimator to obtain unbiased esitamtes, in which predicted values of the endogenous variables are substituted for actual values.
[9] An early example of this approach (using predicted values of categorical variables as instruments in an IV estimation) is provided in Dubin and McFadden (1984).

assets for households that have positive asset levels. These transformations reduced problems with non-linearity and outliers, improving the robustness of the regression results (Mukherjee, et al. 1998).

In all models we tested for multicollinearity, and found it not to be a serious problem (variance inflation factors < 5) for almost all explanatory variables (except for some assets when the logarithmic specification with the intercept shift dummy variables were used) in the OLS and RF regressions. In the two-stage regressions, multicollinearity was more of a problem, as a result of the identification issue already discussed. Since stratified random sampling was used, all parameters were corrected for sampling stratification and sample weights. Estimated standard errors are robust to hetereoskedasticity and clustering (non-independence) of observations from different plots for the same household. Outliers were detected and errors corrected where found.[10]

Predicted Impacts of Selected Variables

In a complex structural model, such as estimated in this study, a change in a particular causal factor may have impacts on outcomes of interest through many different channels, given the many intervening response variables that may be affected. For example, improvements in education may affect agricultural productivity and land degradation directly by affecting farmers' awareness or ability to use technologies that affect these outcomes. But it may also influence these outcomes indirectly by affecting households' choice of income strategy or participation in programs and organizations. Such indirect effects must be accounted for if we are to understand the full effect of causal factors on agricultural production and land degradation.

In studies in which the empirical relationships are linear and involve continuous variables, the predicted total impacts of changes in explanatory variables can be determined using total differentiation of the system (Fan, Hazell and Thorat 1999). In this study, this approach is not practical because of the nonlinear limited dependent variable models estimated. To address this issue, we simulate the predicted responses implied by the estimated econometric relationships under alternative assumptions about the

[10] Two households were dropped from the analysis because they own more than 300 acres of land and are not representative of the vast majority farmers in Uganda. All remaining households owned less than 100 acres of land, and the average farm size for these was 8.2 acres.

values of the explanatory variables for the entire sample, and carry these predicted responses forward to determine their impact on subsequent relationships in the system.[11]

3. Results

In this section we present results of the econometric estimation of determinants of the value of crop production and soil erosion, and simulations of the impacts of selected interventions. We do not report descriptive statistics or the results of estimation of equations 2) – 6) due to space limitations.[12]

Value of Production

The value of crop production is substantially higher on plots where bananas are grown than where cereals and many other types of crops are grown, controlling for labor use, land management, agro-ecological potential and other factors (Table 1).[13] We do not find statistically significant differences in the value of production among other types of crops.

Crop rotation reduces value of production significantly, at least in the short run. In the longer term, however, crop rotation may contribute to productivity by helping to restore soil fertility. We find no statistically significant and robust impacts of other land management practices on value of production, controlling for labor use and other factors.

Not surprisingly, the value of crop production on a plot increases with both plot size and labor use. The elasticities of production value with respect to plot size (0.580 in the OLS regression) and labor (0.385) imply that production is approximately constant returns to scale (sum of elasticities = 0.965 (standard error = 0.055); which is not statistically different from 1.000 (p-value = 0.52)).

Other factors that significantly affect the value of crop production include agro-ecological zone (highest in the high potential EH), primary income source of the household (higher for households with

[11] The method used to predict direct and indirect impacts is explained fully in Nkonya, et al. (2003).
[12] These results are reported in Nkonya, et al. (2003).
[13] As in the regressions for labor intensity, we discuss results that are statistically significant in at least two of the OLS, IV and RF regressions for output value. Also as in the labor regressions, variables that were jointly statistically insignificant in the OLS regression were dropped from the IVregression (p value = 0.57), and multicollinearity is a problem only for the equipment and livestock variables in the OLS and RF regressions (maximum VIF = 20 for ln(equipment value)). A test for no nonlinearity was rejected at the 5% level in the OLS model (implying that nonlinearity exists), but not in the RF model. Additional explanatory variables beyond the full specification of the OLS model were not considered, however. A Hausman test of the OLS vs. IV models could not reject the hypothesis of no specification error in the OLS model (p=1.000), which is thus preferred.

primary income from production of legumes, horticultural crops, cereals, export crops, livestock or non-farm activities than for general agricultural producers, and lowest for households with primary income from forestry or fishing), age of the household head (negative effect), amount of land owned (negative effect), value of livestock owned (positive effect), participation in agricultural extension and training programs (positive effect), and how the plot was acquired (lower for inherited than purchased plots).

The negative effect of farm size on value of crop production is consistent with most of the literature on farm size-productivity effects (e.g., Heltberg 1998; Carter 1984; Deolalikar 1981; Berry and Cline 1979), indicating that management, labor or other constraints limit the ability of larger farmers to be as productive as smaller farmers. Since we find higher value of crop production even controlling for labor input, equipment availability, land quality and other factors, our findings suggest that smaller farmers attain higher total factor productivity, and not only higher land productivity; a finding that is not well established in the literature. This finding implies that reallocation of land towards smaller farms, whether through land reform or the operation of land markets, would be expected to increase productivity in Ugandan agriculture.

The significant impacts of income sources—controlling for land quality, land management, labor use and many other factors—suggest that households pursuing different income strategies acquire skills or have access to information or markets that translate into higher value of production, and indicates the importance of considering income strategies to better understand how to increase agricultural production and incomes in Uganda. Many types of specialized crop producers and households dependent on livestock or non-farm activities earn higher returns from crop production than general agricultural producers or households more dependent upon extractive activities (forestry and fishing), suggesting that there are gains from specialization in crop production, and also that there may be complementarities between livestock or non-farm activities and crop production. However, specialization exposes farmers to increased production and price risks. Thus many farmers may prefer to remain diversified in agricultural production, despite lower expected returns.

Participation in agricultural training and extension programs has a positive and statistically significant impact on value of production in the OLS regression, but the effects are not statistically significant in the IV regression. This could mean that these programs tend to work with people who are more productive anyway (since the IV regression controls for this selection issue), though the coefficients in the IV regression are similar or larger in magnitude (which would not be the case if a selection bias were the only reason for the significant effect), and the regressions predicting participation in these programs do not show clear tendencies in this regard.[14] Insignificance of the coefficients of these variables in the IV regressions may simply be a result of the difficulty of identifying these impacts, due to the limited number of suitable instrumental variables. Thus, agricultural training and extension programs appear to be having a positive impact on the value of crop production, though we are not certain of this due to limitations in the instrumental variables available. Participation in other organizations did not have a statistically significant impact on the value of crop production.

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

Erosion

Erosion varies across the development domains in Uganda. Erosion is highest in the intensively cultivated highlands (SWH and EH zones) and greater in areas of higher population density (though impact of population density significant only in the OLS regression). Consistent with the impact of

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

population density, we find that erosion is higher for larger households, controlling for the amount of land owned by the household.

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

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

Predicted erosion is lower on mailo land than land under freehold tenure (in the OLS and IV regressions). This likely is due to a tendency of mailo land to be planted to perennial rather than annual crops, however, and may not be due to the tenure characteristics of mailo land, *per se*. The fact that there is no statistically significant difference between erosion on mailo and freehold plots in the reduced form regression, in which ethnicity is included in the explanatory factors, suggests that the differences found in the other two models are due to cultural factors leading to different cropping choices in mailo areas.

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

Potential Impacts of Selected Interventions

Several interventions may be considered as possible means of increasing agricultural production and reducing land degradation. We will focus in this section on factors that are found to have statistically significant and robust impacts on at least one of the outcome variables (value of crop production, erosion). Among these are population growth, improved access to all-weather roads, improved access to education, participation in agricultural technical assistance programs, and participation in non-governmental organizations. We explore the potential impacts of such interventions on crop production and erosion using the predicted relationships from the econometric model, considering both the direct effects of such interventions based on the results reported in Table 1, as well as indirect effects of such interventions, via their impacts on households' choice of income sources, participation in programs and organizations, crops planted, land management practices and labor use. We consider impacts for the full sample, as well as for highland and lowland zones separately, in case there are differential impacts.

Population growth of 10% is predicted to have a small and statistically insignificant impact on the mean value of crop production, while it would increase predicted erosion by about 2% (Table 2). The impact of population growth on erosion is mainly in the highland zones (SWH and EH), with small and statistically insignificant impacts of population growth on predicted erosion in the lower elevation zones (Table 3).   This is not surprising, given the steep slopes and dense population in the highland zones, creating substantial land degradation pressure in these areas. This suggests that priority should be given to reducing population pressure in the highlands to help reduce soil erosion.

Improved access to all-weather roads is predicted to have a small and statistically insignificant impact on the value of crop production and erosion, considering the entire sample. However, considering the highlands and lowlands separately, improved access has differential impacts on erosion, with a weakly statistically significant negative impact on erosion (-5%) in the lowlands but a significant and robust positive impact on erosion (+5%) in the highlands. It may be that greater road access reduces labor intensity of land management, which may cause more erosion in the steeply sloping highlands where labor-intensive investments in soil and water conservation measures are critical, but less erosion in the lowlands as a result of less intensity of crop production. Whatever the reason, improved road access appears to have different impacts on land degradation in the lowlands and the highlands.

Universal primary education is predicted to result in an average reduction in value of crop production and an increase in erosion in the full sample, though neither of these results is statistically robust. In the lowlands, education is more strongly associated with both lower value of crop production and higher erosion. In the highlands, by contrast, improved education is predicted to lead to higher crop production. As with population pressure and road access, the impacts of education are location-specific, but may involve trade-offs between income and agricultural production and sustainability.[15]

Agricultural technical assistance, whether through longer-term training programs or short-term extension visits, is predicted to increase the value of crop production significantly. For the full sample, universal participation in agricultural training programs would lead to a predicted 12% increase in the value of crop production, while universal participation in extension increases predicted production by 14%. The positive impacts of these programs are more in the lowlands. In the highlands, the impacts on production statistically insignificant, and such programs are associated with more soil erosion. Thus agricultural technical assistance programs appear to have had more beneficial impacts in the lowlands.

Trade-offs between environmental and production objectives may result from participation in non-government organizations (NGO's), but this is also location-specific. Universal participation in NGO's focusing on agriculture and environmental issues is predicted to reduce soil erosion in the full sample by 23%, with significant impacts in both the highlands and lowlands, though with larger impact in the highlands. However, such participation is predicted to reduce the value of crop production in the

[15] Impacts of education on household income are shown to be positive in Nkonya, et al. (2003).

lowlands, but increase it in the highlands. By emphasizing labor-intensive technologies to conserve soils, such organizations are able to reduce soil erosion, but apparently at the expense of crop production in the near term in the lowlands. Although such near-term losses may be recouped in the longer term, they undoubtedly contribute to the low adoption of conservation practices by most small farmers. In the highlands, the technologies being promoted have more beneficial immediate impacts on production, probably by helping to conserve soil moisture as well as soil. In steeply sloping highland areas, soil moisture is usually a more important constraint on production than in lowland areas, and measures to conserve soil moisture may thus have more immediate impact (Shaxson 1988).

Other interventions that may contribute to increased value of crop production, based on the regression results reported in Table 1, include promotion of specialized crop production, livestock keeping, or non-farm activities as income strategies, investments in irrigation, and improved access of small farmers to land (given the inverse farm size-productivity relationship). Some factors that are commonly thought to be important were found to have mostly insignificant impacts, including access to markets and credit, land tenure and ownership of a title. However, it appears that development of land markets can contribute to more intensive and higher value production (since we find higher value of output on purchased than inherited plots).

4. Conclusions and Implications

The results of this study generally support the Boserupian model of population-induced agricultural intensification, but do not support the optimistic “more people-less erosion” hypothesis (Tiffen, et al. 1994). Households in more densely populated communities and smaller farms were found to be more likely to adopt some labor intensive land management practices (Nkonya, et al. 2003), and smaller farms obtain higher value of crop production per hectare. However, population pressure contributes to soil erosion and lower crop production in the highlands. Efforts to reduce population pressure in the highlands thus may thus produce “win-win” outcomes, helping to both increase agricultural productivity and reduce land degradation.

Agricultural technical assistance programs have important impacts on agricultural production and land degradation, contributing to higher value of crop production (especially in the lowlands), but also to soil erosion in the highlands. By contrast, NGO programs focusing on agriculture and environment are helping to reduce erosion, but have mixed impacts on production. The impacts of technical assistance thus can be very location specific, and involve trade-offs between agricultural production and land degradation. This suggests the importance of a demand-driven community based approach to such programs, in order to ensure that location specific factors and tradeoffs can be adequately considered.

We find little evidence of impact of access to markets, roads and credit on agricultural intensification and crop production, though road access appears to contribute to land degradation in the highlands, again emphasizing the location specificity of impacts. This is not to say that such factors will be unimportant in the longer-term. As agricultural modernization and commercialization proceeds in Uganda, access to markets and credit are likely become much more important.

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

Improving education is critical for increasing household incomes (Nkonya, et al. 2003), but this is not solving problems of low agricultural productivity and land degradation. By increasing household members' income opportunities off the farm, education may reduce small farmers' effort to produce agricultural output or to conserve soil. Such potential trade-offs do not mean that investments in improved education should not be pursued; but other means may be needed to address low productivity and land degradation. Including teaching on principles of sustainable agricultural production in educational curricula might help to minimize negative impacts or even have positive impacts on agricultural production and sustainable land management.

We do not find evidence of a poverty-land degradation trap, given that erosion does not depend significantly on asset ownership. Poverty has mixed impacts on agricultural productivity depending on the type of assets considered: smaller farms obtain higher value of crop production per hectare, while households with fewer livestock obtain lower value of crop production. These findings suggest that development of factor markets (e.g., for land and livestock) can improve agricultural efficiency. Also consistent with this is the finding that owners of purchased land obtain higher value of crop production than owners of inherited land.

Several other factors that contribute to increased value of crop production, without significant impacts on land degradation, include specialized crop production, livestock and nonfarm income strategies, and irrigation. The effect of income strategies on value of crop production suggests the importance of development of human and social capital required to pursue such strategies in increasing households' ability to identify and exploit market opportunities in agriculture. Interventions to promote livelihood diversification as well as investments in irrigation thus can contribute to agricultural growth.

In general, the results imply that the strategies to increase agricultural production and reduce land degradation must be location-specific, and that there are few "win-win" opportunities to simultaneously increase production and reduce land degradation. Interventions must be tailored to local circumstances and trade-offs among different outcomes may often occur. There is no "one-size-fits-all" solution to the complex problems of small farmers in the diverse circumstances of Uganda. Thus, a demand-driven approach to development programs will be crucial.

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Table 1. Determinants of Output Value and Predicted Erosion

(Least Squares Regressions)

Variable[a]	ln(Output Value) (USh)			ln(Erosion (mt/ha/year))		
	Ordinary Least Squares	Instrumental Variables[b]	Reduced Form	Ordinary Least Squares	Instrumental Variables[b]	Reduced Form
Crop Choice (share of area)						
- Legumes	-0.068	0.752				
- Root crops	-0.468*	1.553				
- Vegetables	0.525	2.523				
- Coffee	0.098	1.097				
- Bananas	0.988***	2.090***				
Land Management Practices						
- Slash and burn	-0.048	-0.140				
- Inorganic fertilizer	0.276	0.028				
- Manure and compost	0.103	-1.384*				
- Crop residues	0.043	0.483				
- Crop rotation	-0.201*	-0.892**				
- Mulch	-0.171	-0.152				
- Household residues	-0.093	0.103				
- Pesticides	0.059	0.620				
- Integrated pest mgmt.	0.158	-1.369				
ln(Pre-harvest labor use)	0.385***	0.563**				
Primary income source (cf. general agricultural production)						
- Gifts/donations	0.230	-1.026		-1.189		
- Wages/salary	0.169	0.348		0.007		
- Livestock	0.626**	0.457		-1.006		
- Non-farm	0.549***	0.775***		-0.184		
- Forestry/fishing	-0.732***	-0.720**		0.328		
- Brewing beer	0.279	0.244		0.061		
- Legumes	0.490**	0.600*		0.076		
- Hort. crops	1.676***	1.159***		-0.239		
- Bananas	0.164	0.105		-0.299		
- Cereals	0.484***	0.575**		0.058		
- Root crops	0.117	-0.047		-0.030		
- Export crops	0.483***	0.197		0.168		
Agro-ecological zone (cf. unimodal)						
- BL	0.295	0.149	-0.009	0.611	0.354	0.322
- BM	0.054	-0.033	-0.065	0.151	0.037	0.062
- BH	0.291	0.031	0.303	0.084	-0.187	-0.162
- SWH	0.014	-0.232	-0.505*	1.951***	2.114***	1.510***
- EH	0.672**	0.661	1.008***	1.160***	1.659***	0.940**
Altitude	-0.450**	0.254	-0.289	-2.380*	-2.774*	-2.612
High market access	0.013		0.122	-0.085		-0.109
Distance (km.) to:						
- Residence	-0.093*	0.002	-0.056	0.063		0.067
- All weather road	0.007	0.018*	-0.002	0.016		0.008
- Nearest market	-0.012	-0.015	-0.011	0.011		0.023**
ln(Population density)	0.014		0.001	0.152**	0.004	0.077
Assets						
- Own land	0.305	0.365	0.031	-0.341		
- ln(Area owned)	-0.097*	-0.260**	-0.133**	-0.007		
- Own livestock	-0.828*	-0.437	-1.904***	0.355		
- ln(Value of Livestock)	0.068*	0.062	0.156***	-0.014		

Variable[a]	ln(Output Value) (USh) Ordinary Least Squares	ln(Output Value) (USh) Instrumental Variables[b]	ln(Output Value) (USh) Reduced Form	ln(Erosion (mt/ha/year)) Ordinary Least Squares	ln(Erosion (mt/ha/year)) Instrumental Variables[b]	ln(Erosion (mt/ha/year)) Reduced Form
- Own equipment	0.010		-0.747	-0.097		
- ln(Value of Equipmt.)	0.001		0.060	-0.011		
Education of household head (cf. not completed primary)						
- Primary	-0.155	-0.276*	-0.139	0.146	0.117	0.091
- Secondary	0.129	0.071	0.095	0.441*	0.661*	0.357*
- Higher education	0.117	0.040	-0.087	0.541*	0.541*	0.390
ln(Age of head)	-0.359**	-0.044	-0.615***	-0.271	0.243	-0.200
Female head	-0.152		-0.176	0.469*		0.292
ln(Size of household)	0.011		0.043	0.291**		0.315**
Prop. of dependents	-0.266		0.039	0.088		-0.120
Participation in organizations						
- Agriculture/env.	-0.168			-0.349**	-0.709***	
- Credit	0.129			-0.162	-0.546*	
- Poverty reduction	0.229			-0.219*	-0.733	
- Comm. services	-0.038			-0.182	0.287	
Participation in technical assistance programs						
- Training	0.271***	0.331		0.047	-0.300	
- Extension	0.287***	0.629		0.167	0.551**	
Credit availability in village						
- Formal credit	0.001		0.248	-0.234		
- Informal credit	0.055		0.175	-0.097		
Tenure of plot (cf. freehold)						
- Leasehold	-0.436		-0.273	0.273	0.140	0.551
- Mailo	0.217		0.092	-0.424*	-0.535**	-0.334
- Customary	0.133		0.271*	-0.108	-0.133	-0.003
Formal title to plot	-0.306		0.150	-0.157		-0.295
How plot acquired (cf. purchased)						
- Leased in	-0.138	-0.403	-0.525	-0.636		-0.605
- Borrowed	-0.414	-0.663*	-0.620*	-0.327		-0.230
- Inherited	-0.288***	-0.253*	-0.371***	-0.088		-0.014
- Encroached	-0.331	-1.108**	0.178	-0.061		-0.155
Expect to operate plot in ten years? (cf. no)						
- Yes	-0.008		-0.454	-0.423		-0.267
- Uncertain	0.213		0.040	-0.052		0.133
Area of plot	0.580***	0.648***	0.876***	-0.046	-0.052	-0.023
Investments on plot						
- Irrigation	0.790	2.426**				
- Trenches	-0.009	0.115				
- Grass strips	0.046	0.499				
- Live barriers	-0.330	-0.376				
- Trees	0.030	0.096				
Intercept	11.461***	6.986***	15.905***	6.030	6.417*	6.635
No. of observations	930	920	937	1295	1284	1295
R^2	0.565	0.308	0.456	0.563	0.493	0.541

[a] Coefficients of plot quality variables (slope, position on slope, soil depth, texture, color and perceived fertility) and ethnic groups in reduced form not reported due to space limitations. Full regression results available upon request.
[b] Variables that were jointly statistically insignificant in the OLS regression were excluded from the IV regression. A Hausman test failed to reject OLS model for value of crop production (p=1.000). The test statistic was negative for the labor use regressions, so unable to test hypothesis of exogeneity of explanatory variables in that regression.
*, **, *** mean reported coefficient is statistically significant at 10%, 5%, or 1% level, respectively.

Table 2. Simulated Impacts of Changes in Selected Variables on Outcomes[a]

(percent change in mean predicted values)

Variable	Scenario	Mean of Selected Variable		Value of Crop Production (plot level) (USh)		Predicted Soil Erosion (mt/ha/year)	
		Before change	After change	Direct effects	Total effects	Direct effects	Total effects
Population density (persons/km^2)	10% increase	220	242	+0.1%	+0.4%	+1.6%**	+1.6%
Distance to all-weather road (km.)	All households next to an all-weather road	2.250	0.000	-2.2%$^{-}$	-0.9%	-3.5%	-3.2%
Primary education (prop. of hh)	Universal Primary Education	0.480	1.000	-8.2%$^{-}$	-7.7%	+8.1%	+8.2%
Post-Secondary Education (prop. of hh)	Higher education for all heads with secondary ed.	0.078	0.149	-0.1%	-0.7%	+0.5%*	+0.3%
Agricultural Training (prop. of hh)	All households receive training	0.502	1.000	+13.1%***	+12.2%	+2.5%	+2.5%
Extension (prop. of hh)	All households receive extension	0.311	1.000	+18.5%***	+13.7%	+11.5%	+11.5%
Agricultural/ environment NGOs (prop. of hh)	All households participate	0.241	1.000	-11.8%	-8.7%	-23.1%$^{**---}$	-23.1%

[a] Simulation results for direct effects based upon predictions from OLS and full model regressions reported in Table 1. Results of regressions predicting choices of income sources, crops, land management practices and labor use were used to predict indirect impacts.

$^{*, **, ***}$ mean direct effect is based on a coefficient that is statistically significant in the OLS regression at 10%, 5%, or 1% level, respectively. Statistical significance of indirect effects not computed.

$^{+, ++, +++ \text{ and } -, --, ---}$ mean direct effect in is of the sign shown and statistically significant in the IV regression at 10%, 5% or 1% level respectively.

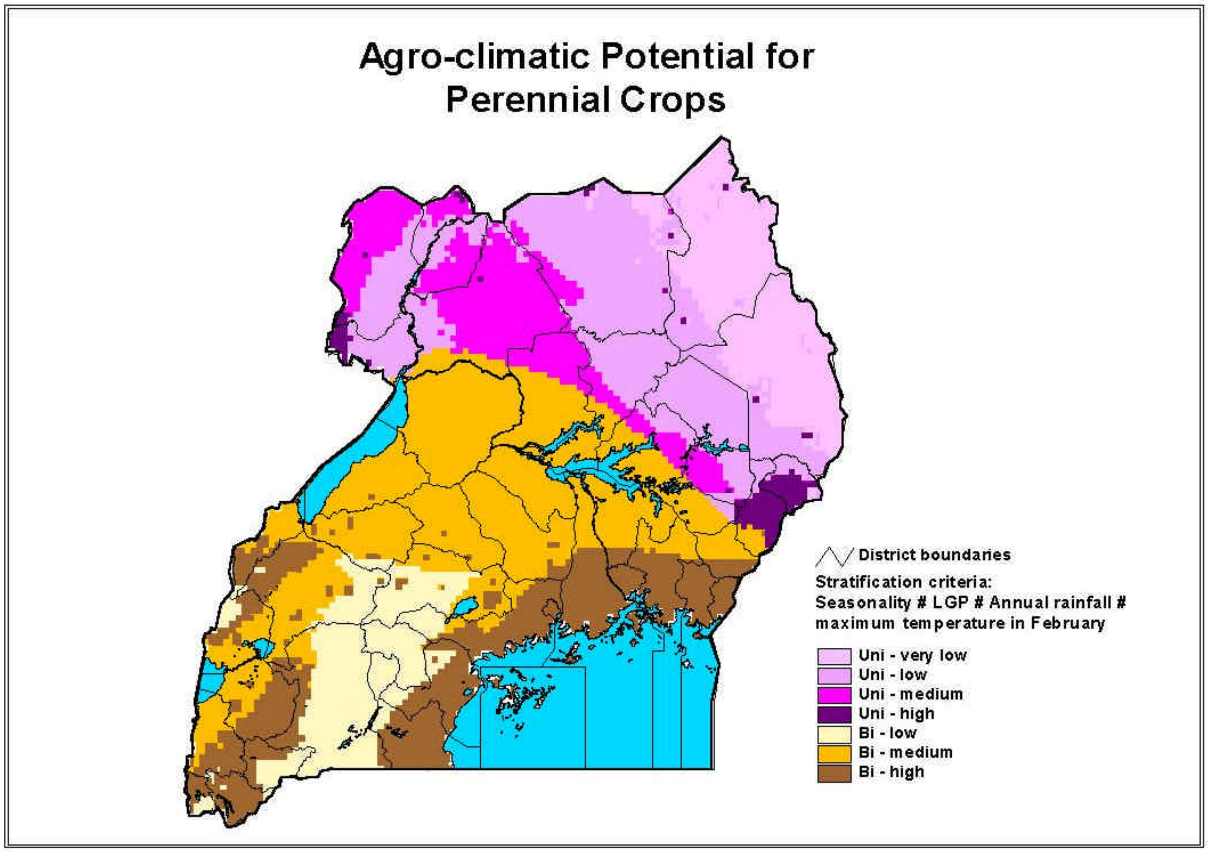
^{R} means that the coefficient is of the same sign and statistically significant in the reduced form regression. Since participation in agricultural training, extension and organizations were excluded from the reduced form regressions, the robustness of the total effects for these variables could not be shown.

Table 3. Simulated Impacts of Changes in Selected Variables on Outcomes, Lowlands vs. Highlands (total effects)[a]
(percent change in mean predicted values)

Variable	Scenario	Lowlands (BL, BM, BH, and U zones)				Highlands (SWH and EH zones)			
		Before	After	Value of Crop Production	Soil Erosion	Before	After	Value of Crop Prod.	Soil Erosion
Population density (persons/km^2)	10% increase	207.9	228.7	+1.1%	+0.6%	308.6	339.5	-5.0%**	+2.8%**R
Distance to all-weather road (km.)	All households next to an all-weather road	2.161	0.000	-0.9%	-5.3%*-	2.915	0.000	-2.9%	+4.5%***+R
Primary education (prop. of hh)	Universal Primary Education	0.483	1.000	-11.1%**---	+6.7%*	0.462	1.000	+42.1%*++	+12.5%
Post-Secondary Education (prop. of hh)	Higher education for all heads with secondary ed.	0.077	0.155	-0.7%	-0.5%	0.078	0.106	+0.3%	+0.4%R
Agricultural Training (prop. of hh)	All households receive training	0.508	1.000	+12.5%***+++	+1.9%	0.457	1.000	-16.9%	+13.3%**
Extension (prop. of hh)	All households receive extension	0.321	1.000	+10.8%***	+14.6%	0.227	1.000	+12.0%	+33.4%***
Agricultural/ environment NGOs (prop. of hh)	All households participate	0.254	1.000	-10.7%**	-19.5%***---	0.154	1.000	+115.9%**	-29.4%***

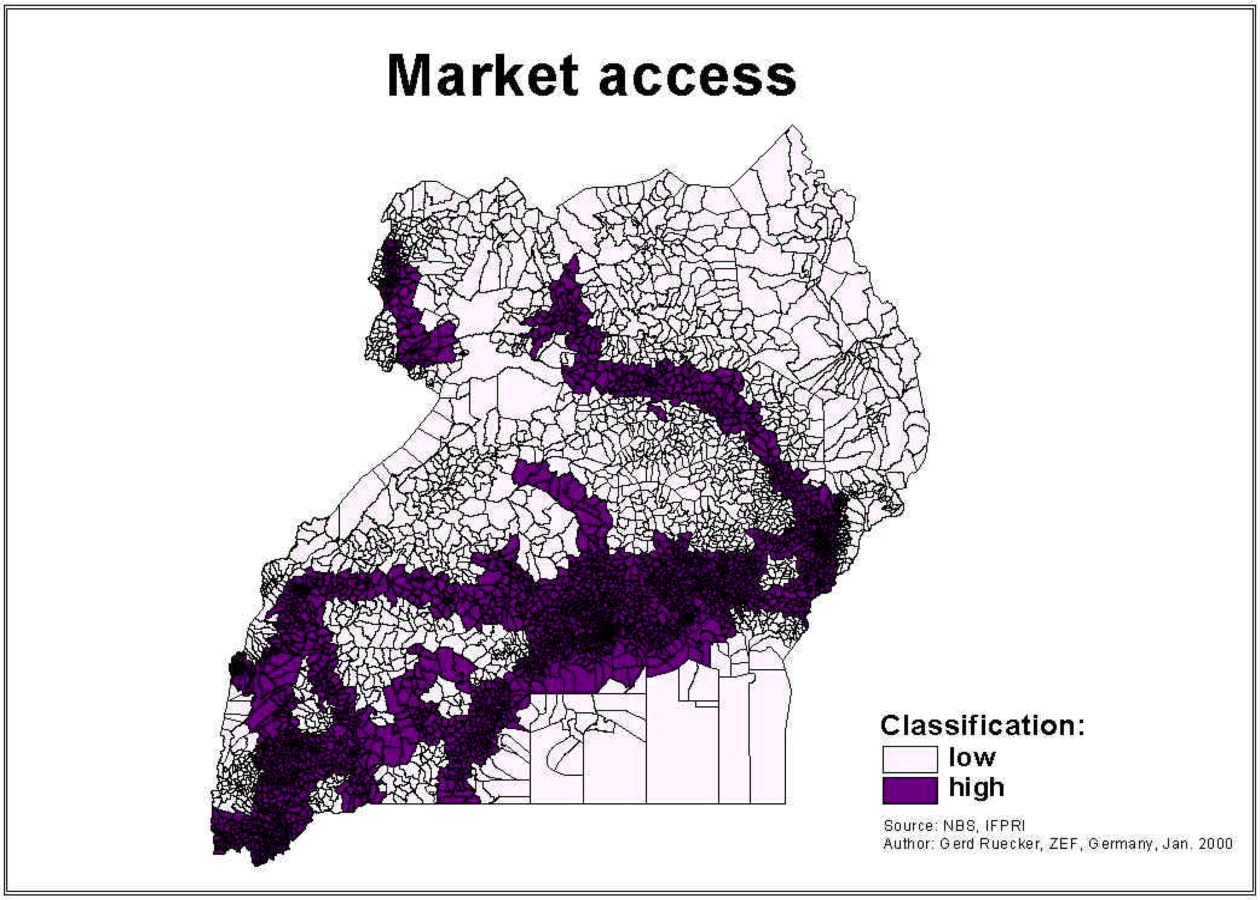
[a] Simulation results for direct effects based upon predictions from OLS and full model regressions reported in Table1. Results of regressions predicting choices of income sources, participation in programs and organizations, crops, land management practices and labor use were used to predict indirect impacts.
*, **, *** mean direct effect is based on a coefficient that is statistically significant in the OLS regression at 10%, 5%, or 1% level, respectively. Statistical significance of indirect effects not computed.
+, ++, +++ and -, --, --- mean direct effect in is of the sign shown and statistically significant in the IV regression at 10%, 5% or 1% level respectively.
R means that the coefficient is of the same sign and statistically significant in the reduced form regression. Since participation in agricultural training, extension and organizations were excluded from the reduced form regressions, the robustness of the total effects for these variables could not be shown

Figure 1. Agro-climatic Potential for Perennial Crops



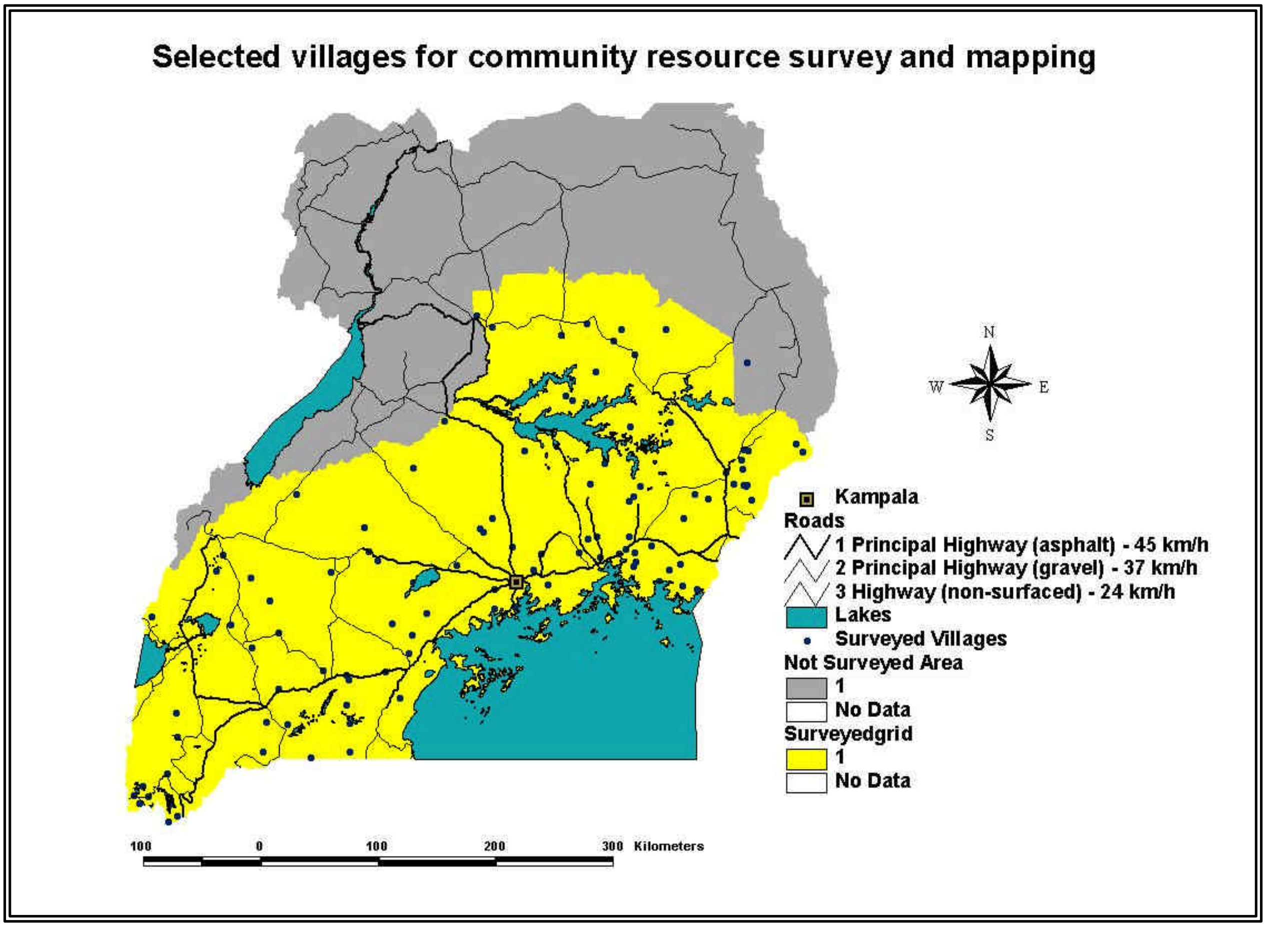
Source: Ruecker, et al. (2003)

Figure 2. Classification of Market Access in Uganda



Source: Ruecker, et al. (2003)

Figure 3. Study Region and Sample Communities



Source: Ruecker, et al. (2003)