Chapter 7

Strategies to Increase Agricultural Productivity and Reduce Land Degradation in Uganda: An Econometric Analysis

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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 1990s (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 chapter 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 on a survey of over 450 households and their farm plots in central and southern Uganda.

Conceptual Framework and Methodology

Empirical Model

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]

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}):

$$y_{hp} = y(C_{hp}, L_{hp}, LM_{hp}, NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, IS_h, X_v, u_{yhp}) \quad (7.1)$$

Soil erosion. Many of the factors determining the value of crop production also are expected to influence land degradation. We use soil erosion as an indicator of land degradation, although this is certainly not the only form of land degradation occurring in Uganda. Because we have not been able to measure erosion on the plots studied in this research, we use predicted erosion based on the revised universal soil loss equation (RUSLE) (Renard et al. 1991). The RUSLE has been calibrated to soil conditions in Uganda by several recent studies (Tukahirwa 1996; Lufafa et al. 2003; Mulebeke 2003; Majaliwa 2003). The RUSLE estimates annual soil loss on the basis of 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 because these are predicted by the model. However, the predictions of RUSLE can be useful in estimating the relationships between underlying socioeconomic and biophysical factors that determine crop choice and land management and hence affect erosion. Considering the factors determining land management decision,[2] and assuming that the error term is additive,[3] we have the following expression for erosion:

$$e_{hp} = e(NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, FC_h, IS_h, L_{fh}, X_v) + u_{ehp} \quad (7.2)$$

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

$$e_{hp} = e^p_{hp} + v_{ehp} \quad (7.3)$$

Then substituting equation (7.3) into (7.2), we have:

$$e^p_{hp} = e(NC_{hp}, T_{hp}, PC_h, HC_h, SC_h, FC_h, IS_h, L_{fh}, X_v) + u_{ehp} - v_{ehp} \quad (7.4)$$

Thus, we can estimate equation (7.2) using equation (7.4), 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 (7.2).

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 agroclimatic potential for perennial crop (banana and coffee) production in Uganda, based on the average length of growing period, rainfall pattern (bimodal versus unimodal), maximum annual temperature, and altitude (Figure 7.1; see color insert). Potential for maize production was also mapped, and this map was found to be very similar. Thus, the zones in Figure 7.1 are representative of agroclimatic potential for the most important crops in Uganda.[4] Seven zones were identified: the high-potential bimodal rainfall area (BH) at moderate elevation near Lake Victoria (the "Lake Victoria crescent"), the medium-potential bimodal rainfall area (BM) at moderate elevation (most of central and western Uganda), the low-potential bimodal rainfall area (BL) at moderate elevation (lower-elevation parts of southwestern Uganda), the high-potential bimodal rainfall southwestern highlands (SWH), the high-potential unimodal rainfall eastern highlands (EH), 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 (unimodel) at moderate elevation (much of northeastern Uganda).

A classification of Uganda into areas of low and high market access, using an index of "potential market integration" based on estimated travel time to the nearest five markets, weighted by their population, is shown in Figure 7.2. Market access in Uganda is highest in the Lake Victoria crescent (especially close to 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.

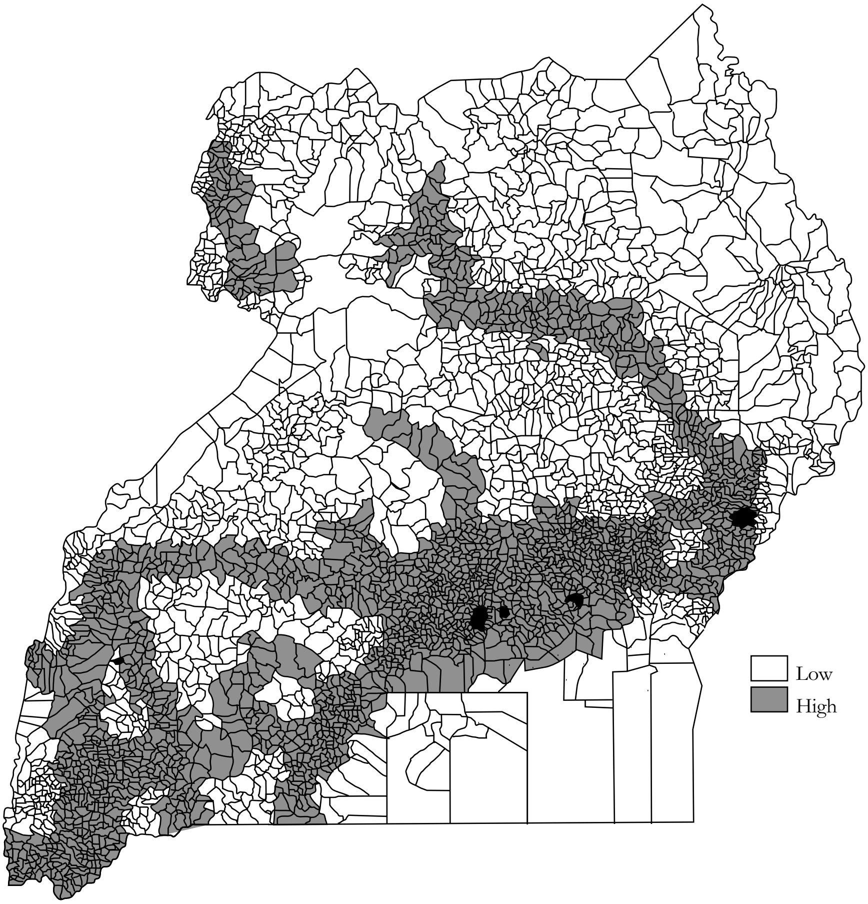
Household-level factors include income strategy (primary income source of the household); ownership of natural and physical capital (area of land, value of livestock and farm equipment); human capital (education, age, and gender of household head); the family labor endowment (size of household and proportion of dependents); financial capital (access to formal or informal credit);[5] and social capital (participation in technical assistance programs [longer-term training and shorter-term extension programs] and in various types of organizations). 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 10 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).

Hypotheses

Hypotheses about the effects of most factors on land management and outcomes were discussed in Chapter 2. Here we focus only on the hypothesized influences of land tenure systems in Uganda, which have not been discussed in any detail in other chapters.

Land tenure. There are four types of land tenure in Uganda: customary, *mailo,* freehold, and leasehold. 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. 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 sub-

Figure 7.2 Classification of market access in Uganda



Source: Ruecker et al. (2003).

ject to approval of clan leaders and family members. Customary landholders are encouraged by the 1998 Land Act to apply for freehold status or to acquire a certificate of customary ownership, both of which are issued by the district land board. However, the process of getting the certificate of customary ownership or a title for freehold is costly and cumbersome, as it involves cadastre expertise. As a result, few customary owners have converted their land to freehold status, and even many owners of freehold land do not have titles. *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. Leasehold land is private or public land leased from the landlord for a specific period of time. Under the leasehold, the landlord grants the tenant exclusive possession of land during the lease period, and in return the tenant pays rent or service under specified terms and conditions that vary widely (Republic of Uganda 1998).

The extent of tenure insecurity among these different tenure systems is debatable. Customary landholders 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 (Place, Ssenteza, and Otsuka 2001), 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 (Place, Ssenteza, and Otsuka 2001), and the 1998 Land Act increases these. Holders of leasehold land generally have long-term leases of public land from the state or individual landlords. 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 (Place, Ssenteza, and Otsuka 2001). Thus, tenure security may be a concern for occupants of leasehold or public land.

Ownership of a formal title may amplify the influence of greater tenure security and complete land rights associated with freehold by providing proof of freehold status. 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 influence of a title, per se, in addition to the land tenure status. We also investigate the effects 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 models were 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 7.3; see color insert).[6] Within the study region, communities (LC1s, 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 7.1 (see color insert) and 7.2, and differences in population density (Pender et al. 2001b). 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 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, 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. The analysis conducted was similar to that discussed in detail in Chapter 5.[7] We used econometric analysis to analyze the determinants of income strategies, participation in programs and organizations, and land management practices and the influences of these factors on crop production and soil erosion. We used instrumental variables (IV) estimation to address the endogeneity of decision variables such as income strategies, participation in programs and organizations, and land management decisions when these are used as explanatory variables (e.g., in the crop production regression).[8] We investigated the robustness of the regression results by comparing the results of ordinary least squares (OLS), instrumental (IV), and reduced form (RF) approaches.[9] We also conducted Hausman (1978) tests comparing the OLS and IV models.

We used a log-log specification for equations (7.1) and (7.4) (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 was not possible to use a simple logarithmic transformation for these variables. Instead, we included a dummy variable for positive asset ownership to allow for an intercept shift for households with zero values for some assets as well as the logarithm of assets for households that have positive asset levels. These transformations reduced problems with nonlinearity and outliers, improving the robustness of the regression results (Mukherjee, White, and Wuyts 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). All parameters were corrected for sampling stratification and sample weights. Estimated standard errors are robust to hetereoskedasticity and clustering (nonindependence) of observations from different plots for the same household. Outliers were detected, and errors corrected where found.[10]

As in Chapter 5, we predicted the effects of changes in selected variables using simulations based on the regression results. This analysis was conducted for the sample as a whole and separately for highland versus lowland subsamples (based on separate regressions for each of these subsamples), to investigate the extent to which responses and effects differ in different regions of Uganda.

Income Strategies and Land Management in Uganda

The primary sources of household income reported by the sample households in the study region include production and sale of agricultural products in general; production and sale of cereals (especially maize, sorghum, and millet), export crops (mainly coffee, but also including cotton, sugar cane, and tobacco), root crops (sweet potatoes, yams, Irish potatoes, and cassava), bananas, legumes, and horticultural crops (fruits and vegetables); livestock production; forestry and fishing activities; off-farm work for wages or salary; brewing beer; and various other nonfarm activities (e.g., petty trade, masonry, carpentry, butchery) (Table 7.1). The most common crops grown include cereals, legumes, root crops, vegetables, coffee, and bananas.

These income strategies and crop choices vary across regions of Uganda. Production of Robusta coffee is primarily in the Lake Victoria crescent region, and Arabica coffee in the eastern highlands around Mt. Elgon and some other highland areas (Pender et al. 2001b). Banana production was historically associated with coffee production in the Lake Victoria region but has been shifting to the southwest in recent years (Gold et al. 1999). Cereal production is important in most regions, and root crop production is particularly important in the northern part of the country (Pender et al. 2001b). Cattle keeping is most important in the lower-rainfall "cattle corridor," which ranges from lower-elevation zones in the southwest through parts of central Uganda to the northeastern Karamoja region (Pender et al.

Table 7.1 Descriptive statistics of variables used in econometric analysis

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

(*continued*)

Table 7.1 (continued)

Variable	Mean	Standard error	Number of observations	Minimum	Maximum
Sex of household head (proportion of households)					
Male	0.895	0.026	451	0	1
Female	0.105	0.026	451	0	1
Participation in organizations (proportion of households)					
Agriculture/environment	0.241	0.032	451	0	1
Credit	0.356	0.032	451	0	1
Poverty reduction	0.107	0.021	451	0	1
Community services	0.464	0.033	451	0	1
Participation in technical assistance (proportion of households)					
Training	0.500	0.034	451	0	1
Extension	0.312	0.032	451	0	1
Availability of credit in village (proportion of households)					
Formal credit	0.260	0.023	451	0	1
Informal credit	0.698	0.024	451	0	1
Plot-level variables					
Crop choice (proportion of plot area)					
Cereals	0.210	0.011	1,436	0	1
Legumes	0.129	0.008	1,436	0	1
Root crops	0.191	0.009	1,436	0	1
Vegetables	0.094	0.005	1,436	0	1
Coffee	0.115	0.010	1,436	0	1
Bananas	0.198	0.011	1,436	0	1
Land management practices (proportion of plots)					
Slash and burn	0.113	0.015	1,785	0	1
Inorganic fertilizer	0.017	0.003	1,786	0	1
Manure/compost	0.176	0.014	1,876	0	1
Incorporation of crop residues	0.251	0.025	1,786	0	1
Crop rotation	0.406	0.020	1,786	0	1
Mulch	0.079	0.010	1,788	0	1
Household residues	0.136	0.011	1,786	0	1
Preharvest labor input (person-hours)	366.549	19.141	1,874	0	10344
Value of crop production (Ush)	188,146	18,606	1,876	0	2.61×10^7
Soil loss (metric tons/hectare per year)	5.758	0.626	1,584	0.02002	127.0776
Altitude (×100 meters above sea level)	13.224	0.383	1,572	10.12	42.09
Distance of parcel (kilometers) to:					
Residence	0.538	0.062	1,854	0	32
All-weather road	2.505	0.195	1,854	0	77
Market	4.494	0.268	1,854	0	37

Table 7.1 (continued)

Variable	Mean	Standard error	Number of observations	Minimum	Maximum
Tenure of plot (proportion of plots)					
Freehold	0.283	0.033	1,861	0	1
Leasehold	0.044	0.014	1,861	0	1
Mailo	0.185	0.027	1,861	0	1
Customary	0.488	0.031	1,861	0	1
Formal title of plot held (proportion of plots)	0.038	0.011	1,861	0	1
How plot acquired (proportion of plots)					
Purchased	0.507	0.032	1,665	0	1
Leased in	0.047	0.013	1,665	0	1
Borrowed	0.035	0.008	1,665	0	1
Inherited	0.404	0.029	1,665	0	1
Encroached common land	0.006	0.005	1,665	0	1
Expect to operate plot in 10 years? (proportion of plots)					
No	0.038	0.009	1,861	0	1
Yes	0.933	0.011	1,861	0	1
Uncertain	0.029	0.007	1,861	0	1
Plot area (acres)	2.352	0.635	1,604	0.1	636

2001b). Cotton used to be an important cash crop in parts of eastern, northern, and western Uganda but has declined over the past few decades because of low world prices, marketing problems, and conflict (You and Chamberlin 2004). Nonfarm activites such as trading, charcoal making, and brick making are generally more common in areas of better market access (Pender et al. 2001b).

The most common land management practices used by farmers in the study villages are crop rotation, incorporation of crop residues, application of household residues, application of manure or compost, use of slash and burn to prepare fields, and application of mulch (Table 7.1).[11] Slash and burn, crop rotation, and incorporation of crop residues are most often associated with extensive annual crop production systems in the east and north (Pender et al. 2001b). Use of manure, compost, and mulch is most often associated with perennial crop systems in the Lake Victoria crescent and the highlands (Pender et al. 2001b). Use of fallow has declined, and use of inorganic and organic sources of soil fertility is still very limited, contributing to perceived declines in soil fertility and crop yields in most areas (Deininger and Okidi 2001; Pender et al. 2001b). Average estimated soil erosion levels are less than 10 tons/hectare per year but are much higher in steeply sloping areas of the highlands.

Results of Econometric Analysis

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 effects of selected interventions.[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 7.2).[13] We do not find statistically significant differences in the value of production among other types of crops.

Crop rotation reduces the value of production significantly, at least in the short run. In the longer term, however, crop rotation may contribute to productivity by helping to restore soil fertility and reducing problems of pests and diseases. We find no statistically significant and robust effects of other land management practices on the 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 an approximately constant return to scale: sum of elasticities = 0.965 (standard error = 0.055), which is not statistically different from 1.000 ($P = 0.52$).

Other factors that significantly affect the value of crop production include agro-ecological zone (highest in the high-potential EH), primary income source of the household (higher for households with primary income from production of legumes, horticultural crops, cereals, export crops, livestock, or nonfarm activities than for general agricultural producers and lowest for households with primary income from forestry or fishing), age of the household head (negative effect), amount of land owned (negative effect), value of livestock owned (positive effect), participation in agricultural extension 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., Berry and Cline 1979; Deolalikar 1981; Carter 1984; Heltberg 1998), indicating that management, labor, or other constraints limit the ability of larger farmers to be as productive as smaller farmers. Because 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 toward smaller farms, whether through

Table 7.2 Determinants of output value and predicted erosion

	ln(Output value) (USh)			ln(Erosion [metric tons/hectare per year])		
Variable[a]	Ordinary least squares	Instrumental variables[b]	Reduced form	Ordinary least squares	Instrumental variables[b]	Reduced form
Crop choice (share of area)						
Legumes	–0.068	0.752				
Root crops	–0.468*	1.553				
Vegetables	0.525	2.523				
Coffee	0.098	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 management	0.158	–1.369				
ln(Preharvest 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		
Nonfarm	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		
Horticultural 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

(*continued*)

Table 7.2 (continued)

	ln(Output value) (USh)			ln(Erosion [metric tons/hectare per year])		
Variable[a]	Ordinary least squares	Instrumental variables[b]	Reduced form	Ordinary least squares	Instrumental variables[b]	Reduced form
Distance (kilometers) 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		
Own equipment	0.010		–0.747	–0.097		
ln(Value of equipment)	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**
Proportion of dependents	–0.266		0.039	0.088		–0.120
Participation in organizations						
Agriculture/environment	–0.168			–0.349**	–0.709***	
Credit	0.129			–0.162	–0.546*	
Poverty reduction	0.229			–0.219*	–0.733	
Community 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

Table 7.2 (continued)

	ln(Output value) (USh)			ln(Erosion [metric tons/hectare per year])		
Variable[a]	Ordinary least squares	Instrumental variables[b]	Reduced form	Ordinary least squares	Instrumental variables[b]	Reduced form
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 10 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
Number of observations	930	920	937	1,295	1,284	1,295
R^2	0.565	0.308	0.456	0.563	0.493	0.541

Note: Least-squares regressions.

A Hausman test failed to reject OLS model for value of crop production (P = 1.000).

***, **, *** mean reported coefficient is statistically significant at 10 percent, 5 percent, and 1 percent level, respectively.**

[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 because of space limitations. Full regression results available on request.

[b]Variables that were jointly statistically insignificant in the OLS regression were excluded from the IV regression.

land reform or the operation of land markets, would be expected to increase productivity in Ugandan agriculture.

The significant influences of income sources, controlling for land quality, crop choice, 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 nonfarm activities earn higher returns from crop production than general agricultural producers or households more dependent on 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 nonfarm 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 effect on value of production in the OLS regression, but the effects are not statistically significant in the IV regression. This could mean that these programs tend to work with people who are more productive anyway (because the IV regression controls for this selection issue), 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 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 influences as a result of the limited number of suitable instrumental variables. Thus, agricultural training and extension programs appear to be having a positive effect on the value of crop production, though we are not certain of this because of limitations in the instrumental variables available. Participation in other organizations did not have a statistically significant influence 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, whereas livestock development and nonfarm development appear to be complementary to increased crop production. The potential effects 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 steeply sloping highlands (SWH and EH zones) and greater in areas of higher population density (though the effect of population density is significant only in the OLS regression). Consistent with the effect of 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 (Grepperud 1996; Pender et al. 2001a). However, this finding is not consistent with optimistic arguments about "more people, less erosion" cited by Tiffen, Mortimore, and Gichuki (1994a) for the Machakos district of Kenya. In that study, the reduction in erosion was influenced by factors other than rural 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 effects 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 caused by a tendency of *mailo* land to be planted with perennial rather than annual crops, however, and may not be related 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 result from 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, credit, land title, and tenure security have a statistically insignificant influence 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; for example, if education were to increase participation in agricultural and environmental organizations, it could indirectly contribute to reducing erosion.

Potential Effects of Selected Interventions

Several interventions may be considered as possible means of increasing agricultural production and reducing land degradation. We focus in this section on factors that are found to have statistically significant and robust influences 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 nongovernmental organizations. We explore the potential effects 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 7.2 as well as indirect effects of such interventions via their effects on households' choice of income sources, participation in programs and organizations, crops planted, land management practices, and labor use. We consider effects for the full sample, as well as those on highland and lowland zones separately, in case there are differential effects.[15]

Population growth of 10 percent is predicted to have a small and statistically insignificant influence on the mean value of crop production, but it would increase predicted erosion by about 2 percent (Table 7.3). The effect of population growth on erosion is mainly in the highland zones (SWH and EH), with small and statistically insignificant effects of population growth on predicted erosion in the lower-elevation zones (Table 7.4). 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 influence on the value of crop production and erosion, considering the entire sample. However, when the highlands and lowlands are considered separately, improved access has differential effects on erosion, with a weakly statistically significant negative effect on erosion (–5 percent) in the lowlands but a significant and robust positive effect on erosion (+5 percent) 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 is found in the lowlands as a result of less intensity of crop production. Whatever the reason, improved road access appears to have different effects 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 influences of education are location-specific but may involve trade-offs between income and agricultural production and sustainability.[16]

Table 7.3 Simulated impacts of changes in selected variables on outcomes

Variable	Scenario	Mean of selected variable		Value of crop production (plot level) (percent change)		Predicted soil erosion (percent change)	
		Before change	After change	Direct effects	Total effects	Direct effects	Total effects
Population density (persons/km^2)	10 percent increase	220	242	+0.1	+0.4	+1.6**	+1.6
Distance to all-weather road (kilometers)	All households next to an all-weather road	2.250	0.000	–2.2^{-}	–0.9	–3.5	–3.2
Primary education (proportion of households)	Universal primary education	0.480	1.000	–8.2^{-}	–7.7	+8.1	+8.2
Postsecondary education (proportion of households)	Higher education for all heads with secondary education	0.078	0.149	–0.1	–0.7	+0.5*	+0.3
Agricultural training (proportion of households)	All households receive training	0.502	1.000	+13.1***	+12.2	+2.5	+2.5
Extension (proportion of households)	All households receive extension	0.311	1.000	+18.5***	+13.7	+11.5	+11.5
Agricultural/environment NGOs (proportion of households)	All households participate	0.241	1.000	–11.8	–8.7	–23.1**$^{---}$	–23.1

Note: Percentage change in mean predicted values. Simulation results for direct effects based on predictions from OLS model regressions reported in Table 7.2. 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 percent level, respectively. Statistical significance of indirect effects not computed.**

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

^{R}Coefficient is of the same sign and statistically significant in the reduced form regression. Because 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 7.4 Simulated impacts of changes in selected variables on outcomes, lowlands versus highlands (total effects)

		Lowlands (BL, BM, BH, and U zones)				Highlands (SWH and EH zones)			
Variable	**Scenario**	**Before**	**After**	**Value of crop production (percent change)**	**Soil erosion (percent change)**	**Before**	**After**	**Value of crop production (percent change)**	**Soil erosion (percent change)**
Population density (persons/km^2)	10 percent increase	207.9	228.7	+1.1	+0.6	308.6	339.5	–5.0**	+2.8**R
Distance to all-weather road (kilometers)	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 (proportion of households)	Universal primary education	0.483	1.000	–11.1**–––	+6.7*	0.462	1.000	+42.1*++	+12.5
Postsecondary education (proportion of households)	Higher education for all heads with secondary education	0.077	0.155	–0.7	–0.5	0.078	0.106	+0.3	+0.4R
Agricultural training (proportion of households)	All households receive training	0.508	1.000	+12.5***+++	+1.9	0.457	1.000	–16.9	+13.3**
Extension (proportion of households)	All households receive extension	0.321	1.000	+10.8***	+14.6	0.227	1.000	+12.0	+33.4***
Agricultural/environment NGOs (proportion of households)	All households participate	0.254	1.000	–10.7**	–19.5***–––	0.154	1.000	+115.9**	–29.4***

Note: Percentage change in mean predicted values. Simulation results for direct effects based on predictions from separate OLS model regressions for highland and lowland subsamples. 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 percent, 5 percent, or 1 percent level, respectively. Statistical significance of indirect effects not computed.**

+, ++, +++ and –, ––, ––– mean direct effect is of the sign shown and statistically significant in the IV regression at 10 percent, 5 percent, or 1 percent level, respectively.

R Coefficient is of the same sign and statistically significant in the reduced form regression. Because participation in agricultural training, extension, and organizations was excluded from the reduced form regressions, the robustness of the total effects for these variables could not be shown

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 percent increase in the value of crop production, while universal participation in extension increases predicted production by 14 percent. The positive influence of these programs are greater in the lowlands. In the highlands, the effects on production are statistically insignificant, and such programs are associated with more soil erosion. Thus, agricultural technical assistance programs appear to have had more beneficial effects in the lowlands.

Trade-offs between environmental and production objectives may result from participation in nongovernmental organizations (NGOs), but this is also location-specific. Universal participation in NGOs focusing on agriculture and environmental issues is predicted to reduce soil erosion in the full sample by 23 percent, with significant effects in both the highlands and lowlands, though with a larger influence in the highlands. However, such participation is predicted to reduce the value of crop production in the 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 effects 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 influence (Shaxson 1988).

Other interventions that may contribute to increased value of crop production, based on the regression results reported in Table 7.2, include promotion of specialized crop production, livestock keeping, and nonfarm 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 influences, 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).

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, Mortimore, and Gichuki 1994a). 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. 2004), 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 may thus produce "win-win" outcomes, helping to both increase agricultural productivity and reduce land degradation.

Agricultural technical assistance programs have important effects 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 influences on production. The effects 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 trade-offs can be adequately considered. Development and promotion of combination technologies that can enhance agricultural productivity and conserve soils and that are suited to local conditions should be a high priority for such programs.

We find little evidence of effects 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 effects. 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 to become much more important.

Land tenure and land title were also found to have limited influences 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. 2004), 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 effects or even have positive effects 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. Asset poverty has mixed effects on agricultural productivity depending on the type of assets considered: smaller farms obtain higher value of crop production per hectare, and 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 effects 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.

Notes

1. This empirical model is derived from a theoretical dynamic household model, which is presented in Nkonya et al. (2004). The empirical model is quite similar to the model presented in Chapter 5, but there are some important differences (e.g., inclusion of annual crop choice in the model and estimation of determinants of erosion). Hence, we present the model in an abbreviated form, focusing only on the outcome variables discussed in this chapter. A complete exposition of the model can be found in Nkonya et al. (2004) and Pender et al. (2004b).

2. These factors are explained fully in Nkonya et al. (2004) and Pender et al. (2004b) and are very similar to the determinants of land management discussed in Chapter 5.

3. In the empirical work we use the logarithm of erosion as the dependent variable; thus the assumption that the error term in equation (7.2) 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.

4. Although soil conditions are also important in determining agricultural potential, no attempt was made to include soils in the classification because of limitations in the available soil data and the high degree of spatial variability in soil quality. Thus, the map in Figure 7.1 does not fully represent "agricultural potential," though it represents agroclimatic zones.

5. Credit access was measured at the village level to address concern about endogeneity of household level use of credit.

6. 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.

7. The analytic approach is described fully in Nkonya et al. (2004).

8. The ethnicity of the household was used as an instrumental variable to predict income strategies and participation in programs and organizations. Other instrumental variables were identified by hypothesis testing: variables that were jointly statistically insignificant in the full version of the models for equations (7.1) and (7.4) were dropped from the regression and used as instrumental variables.

9. The reduced form regressions exclude endogenous decision variables such as income strategies, participation in programs and organizations, and land management practices. The coefficients in these regressions thus reflect total effects of exogenous or predetermined factors on the outcome variables, allowing for indirect impacts that such factors have on the outcomes by affecting the endogenous decision variables as well as direct impacts. The coefficients of exogenous and predetermined factors in the structural OLS and IV regression models reflect only their direct effects on the outcomes, controlling for the endogenous decision variables that are also included in the models. Thus, the coefficients in the reduced form models are not expected to be the same as those in the OLS or IV models because they are reflecting different effects. Nevertheless, it is instructive to investigate robustness of results across all three models.

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 of farmers in Uganda. All remaining households owned less than 100 acres of land, and the average farm size for these was 8.2 acres.

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

12. Other econometric results are presented in Nkonya et al. (2004).

13. Variables that were jointly statistically insignificant in the OLS regression were dropped from the IV regression ($P = 0.57$), and multicollinearity is a problem only for the equipment and livestock variables in the OLS and RF regressions (maximum VIF = 20 for ln[equipment value]). A Hausman test of the OLS versus IV models could not reject the hypothesis of no specification error in the OLS model ($P = 1.000$), which is thus preferred.

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 factor having a statistically significant impact on participation in agricultural training programs is education (higher participation for more educated household heads). These findings do not clearly indicate that participants in technical assistance programs are households that would tend to be more productive in the absence of extension because these factors are found to not have significant direct effects on the value of crop production. Regression results are available on request.

15. As noted previously, separate regressions were run for highland and lowland subsamples but are not reported here to save space. These regression results are available from the authors on request.

16. Influences of education on household income are shown to be positive in Nkonya et al. (2004).