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THE INFLUENCE OF ASSET AND ACCESS POVERTY ON CROP PRODUCTION AND LAND DEGRADATION IN UGANDA

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1. Introduction

There is concern that African farmers face a downward spiral of land degradation and poverty (Cleaver and Schreiber, 1994). Land degradation problems are contributing to losses in agricultural productivity and hence contributing to poverty in sub-Saharan Africa (SSA) (Dregne 1990; Smaling, et al. 1993). Conversely, poverty may also contribute to land degradation if poor people lack ability or incentive to invest in conserving and improving their land, resulting in a downward spiral. Little empirical evidence is available concerning the relationships between land degradation and poverty in SSA countries, or the policy, institutional or technological responses that could effectively address these problems.

This study investigates the impacts of poverty on land degradation and agricultural productivity using analysis of data from a recent survey in Uganda. We use Uganda as a case study since the country has been implementing ambitious poverty reduction and agricultural modernization programs, and because land degradation in form of soil nutrient depletion in Uganda is among the highest in SSA (Smaling, et al. 1993), making Uganda a good case study for analyzing these linkages.

2. Empirical Models and Data

Our main objective is to analyze the impacts of different aspects of poverty on land management practices, crop productivity, and measures of land degradation. We are particularly interested in how different types of capital and access constraints (as measures of different types of poverty) influence crop productivity and land degradation. We also investigate the impacts of land management decisions on the value of crop production per acre (hence indirectly on income), thus quantifying some of the linkages from land management to poverty.

As indicators of land degradation, we focus on soil erosion and soil nutrient depletion, which are among the most severe forms of land degradation in Uganda (Nkonya, et al. 2004). We estimate the level of soil erosion using the revised universal soil loss equation (RUSLE) (Renard, et al. 1991), and soil nutrient depletion by computing soil nutrient inflows, outflows and balances (Smaling, et al. 1993).

A large body of research shows that the major determinants of land management include households' endowments of different types of capital, land tenure, and the biophysical and socio-economic environment in which rural households live (e.g., see Reardon and Vosti, 1995; Barrett, et al., 2002; Nkonya, et al., 2004). Due to imperfect or missing markets for these capital goods and services, household land management decisions may differ depending on the levels of their capital endowments. Since there are considerable differences in how farmers manage land depending on the characteristics of specific plots, we analyze crop productivity, soil nutrient flows and balances at plot level.

We assume that the value of crop production per acre by household h on plot p (Y_{hp}) is determined by the following variables: (i) labor use per acre on the plot (L_{hp}); (ii) land management practices and external inputs used (LM_{hp}) on the plot; (iii) the natural capital (quality) of the plot (NC_{hp}), which is measured by the slope of the plot, topsoil depth, stock of soil nutrients (N, P and K) in the top 20 cm. of soil, and prior investments on the plot (soil and water conservation (SWC) structures, agroforestry trees, perennial crops, and other natural resource management (NRM) investments); (iv) the land tenure of the plot (T_{hp}) – i.e. whether the plot is held under customary, freehold/leasehold, or *mailo*[1] tenure; (v) the household's endowments of land and physical capital

[1] In Uganda, there are four types of land tenure systems: (i) customary land tenure, whose rights and access are governed by customary institutions, (ii) freehold tenure; (iii) leasehold tenure (like freehold but limited in duration);

(PC_h), measured as area of land owned, livestock owned (in tropical livestock units (TLU)), and value of farm equipment owned; (vi) human capital (HC_h), measured as the share of female and male household members with different levels of education, the gender of household head, the share of farmland owned by women, household size, and the primary income source of household head (crop production, livestock production, non-farm activities); (vii) access to agricultural technical assistance and credit (AS_h), measured as the number of extension visits received by the household; whether the household participated in the new National Agricultural Advisory Services (NAADS) program, and whether it used formal sector credit; (viii) factors affecting local comparative advantages (X_v), namely agro-ecological zone (Wortmann and Eledu 1999), market access, measured by the potential market integration index (a measure of distance to nearest five markets weighted by their population size (Wood, et al. 1999)), distance of plot to residence and to an all-weather road, population density and the village wage rate;[2] and (ix) e^{v}_{vhp} random factors such as the weather in a given year and location).

The structural model of the value of crop production per acre is thus:

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

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

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

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

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and (iv) *mailo* tenure, which is a freehold system but in which long term occupants enjoy limited rights guaranteed by the Uganda Land Act of 1998. For details of land tenure in Uganda, see Place, et al. (2001).

[2] Some of these factors may have only indirect impacts on crop production, by influencing use of labor and land management practices (e.g., population density and the wage level), though impacts of such variables on farm level prices could result in their having significant impacts even when labor and land management practices are controlled for. We are not able to include crop prices in the model because of the diversity of crops produced in different parts of Uganda, which would result in many missing observations of prices. Thus, we include all of the factors specified (as potential determinants of farm-level prices as well as production) in an unrestricted specification of the structural model, and use hypothesis testing to eliminate those factors that have statistically insignificant impacts.

4) Soil nutrient balances: $\boldsymbol{Nutbal}_{hp} = f(\boldsymbol{NC}_{hp}, \boldsymbol{PC}_{h}, \boldsymbol{T}_{hp}, \boldsymbol{HC}_{h}, \boldsymbol{AS}_{h}, \boldsymbol{X}_{v}, \boldsymbol{e}^{NB}{}_{hp})$

Where

- E_{hp} is estimated erosion on plot p of household h, using the RUSLE; and
- $\mathbf{Nutbal}_{hp}$ is a vector of soil nutrient balances of macronutrients, namely nitrogen (N), phosphorus (P), potassium (K) and total nutrient balance (NPK) from household h on plot p.

All equations are estimated using ordinary least squares (OLS), correcting for sample weights, stratification and clustering (possible non-independence of error terms across plots within a household) at household level. Equation (1) includes endogenous choices that could cause endogeneity bias. The choices are land management practices (including external inputs) and labor input. Variables reflecting participation in agricultural extension or credit programs could also lead to endogeneity bias. To address this problem, we also use instrumental variables (IV) estimation for all equations. We use several community level variables as instrumental variables that are excluded from the regression model.[3] In all cases, we statistically test the assumptions that the excluded instrumental variables are relevant in predicting the endogenous explanatory variables (Bound, et al. 1995). We test the overidentifying restrictions using Hansen's J statistic, which is consistent under heteroskedasticity (Baum, et al. 2002). We also test the consistency of OLS relative to IV using a Durban-Wu-Hausman test (Davidson and MacKinnon 2004). Since OLS estimation is more efficient than IV estimation if the OLS model is consistent, we prefer the OLS model if the Hausman test fails to reject the consistency of OLS. In all cases, the tests support the validity of the excluded instrumental variables (J test insignificant) and their relevance in almost all cases

[2] The instrumental variables used include whether or not a community had enacted a bylaw related to natural resource management and the degree of cropland degradation in a community (which are indicators of awareness of the need for improved land management practices in a community), the number of program and organizations of different types present in a community (indicators of access to extension and credit), and ethnicity (a proxy for social factors that may influence participation in programs, livelihood and land management decisions).

(strongly significant predictors of endogenous variables), while the Hausman tests fail to reject exogeneity of the labor, land management and participation variables in all cases. Nevertheless, we report the OLS, IV and reduced form results for equation (1), and the robustness of the findings in equations (3) and (4) to using IV or reduced form estimation.

Other estimation and data issues considered and addressed included heteroskedasticity, multicollinearity, and outliers. All standard errors are robust to heteroskedasticity. Multicollinearity was not a major problem (maximum variance inflation factor = 7) (Mukherjee, et al. 1998). The distribution of each variable was examined and an appropriate monotonic transformation towards normality was determined using the ladder of power test, because this improves the model specification (Ibid.). For variables taking zero values, the transformation ln(x+1) was used in several cases.

Explanatory variables and hypotheses:

The explanatory variables were all defined earlier. Due to space limitations, we do not discuss hypotheses about the impacts of these different factors. If markets are missing or imperfect, these factors generally have ambiguous theoretical impacts (de Janvry, et al. 1991).

Data:

This study is based on a survey of 851 households conducted during 2003. The sample was a random sub-sample of the households surveyed in the 2002/03 Uganda National Household Survey (UNHS) (UBOS 2003), selected from eight districts representing different agro-ecologies and poverty levels. Data were collected at the plot and household level, and combined with the UNHS data. Soil samples were taken at a depth of 0-20 cm and analyzed in the lab to help estimate the soil nutrient stocks and flows. Additional data for determining nutrient flows were collected in the plot and household survey (e.g., farm management practices). The methods used for estimating nutrient inflows and outflows are according to Smaling, et al., (1993).

3. Results

Extent of soil nutrient depletion

Across all study regions about 1.2% of total N, P and K stocks in the top 20 cm. of soil (the most critical zone for plant nutrient uptake) were depleted on average, including 2% of total N, 0.5% of extractable P and 1% of exchangeable K (Table 1). This indicates the seriousness of the soil nutrient depletion problem in Uganda. If farmers were to buy the cheapest source of nutrients to replenish the nutrients depleted, the cost would average one fifth of household farm income, with the largest depletion cost for nitrogen. These losses vary across different agroecological zones and farming systems, with the most rapid depletion rates (in total and as a percent of soil nutrient stock) in the southwest grasslands zone, where potassium depletion due to intensive banana production is particularly high. The value of nutrient losses relative to farm income is greatest in the northern moist farmlands (equaling one-third of farm income) due to low farm income in this zone.

Determinants of crop production per acre[4]

The factors significantly affecting the value of crop production per acre (at 10% level or less) in the OLS model include inputs of labor (+),and inorganic fertilizer (+), incorporation of crop residues (+),phosphorus stock (+), investments in SWC (+), agroforestry (+) and perennial crops (+), plot size (+), farm size (-), male secondary and post-secondary education (+),household size (+), primary income source (lower for primary livestock producers than primary crop producers), distance of the plot to the residence (-),and participation in the NAADS agricultural extension program (+)(Table 2). Although some of these coefficients were not statistically significant in the IV model due to larger standard errors in that model, all were of the same sign and most were of

[4] Due to the page limit, we do not report econometric results of land management and input use regression equations, nor the coefficients of agroecological zones (which are not critical for the objectives of this paper), the value of equipment, wage rate and population density.

similar magnitude; and since the Hausman test failed to reject the OLS model, that model is preferred because it is more efficient.

As expected, better land quality increases crop productivity. A 1% increase in the P stock in the topsoil is associated with 0.13% higher productivity. Land investments (agroforestry trees, SWC structures and perennial crops) also significantly increase the value of crop production. These findings, together with the positive impacts of fertilizer, support the concern that land degradation is an important constraint to crop production in Uganda. Nevertheless, inorganic fertilizer appears generally unprofitable, earning an estimated marginal value/cost ratio (VCR) of only 0.35, due in part to the high cost of fertilizer relative to output prices. A minimum VCR of at least 1 is necessary for an input to be profitable, and a level of 2 is usually considered necessary for significant adoption of fertilizer in risky environments (CIMMYT, 1988). The low profitability of inorganic fertilizer explains its low adoption in Uganda, and suggests that major improvement in the market environment facing Ugandan farmers is a prerequisite for substantial adoption to occur. Similar findings were reported by Woelcke, et al. (2003) and Pender, et al., (2004).

Although larger plots are more productive, we find an inverse farm size – productivity relationship, as observed in many empirical studies in developing countries (e.g. Heltberg 1998; Lamb 2003). Since we find this relationship while controlling for use of labor, other inputs, land management practices, and observable land quality indicators, our findings imply that smaller farmers are more productive in using inputs, and suggest that improvement in factor markets could increase efficiency and aggregate production (Feder, 1985).

The positive impact of male education on crop productivity may be because higher labor opportunity costs of more educated farmers require them to use labor more productively, and/or because education increases farmers' awareness and ability to use improved production and marketing methods. Larger households obtain higher crop productivity probably because of labor and management constraints affecting smaller households. Livestock-oriented households obtain lower crop productivity than crop-oriented ones, probably because they have less have less experience and/or exert less effort in crop production and marketing.

The positive impact of the new NAADS extension program is consistent with findings of Nkonya, et al. (2004) and Fan, et al. (2004) and supports the government of Uganda's efforts to improve agricultural extension. Analysis of data from the 1999/2000 UNHS showed that the average value of crop production per acre in the sample communities where NAADS was operating, prior to initiation of NAADS (243,000 USh/acre), was not statistically significantly different than the average value of crop production per acre in non-NAADS communities prior to the program (247,000 USh/acre); limiting concern that the positive impact of NAADS was due to bias in program placement. The significant impact of NAADS participation in the IV model also indicates that selection bias is not responsible for the positive estimated impact of NAADS.

The significant positive impact of customary land tenure (compared to freehold and leasehold) on crop productivity suggests that customary land tenure is not a major constraint to crop productivity in Uganda, and may promote higher productivity. Other studies have fount limited impacts of land titles elsewhere in Africa (e.g., Place and Hazell 1993; Platteau 1996).

Determinants of land degradation

Not surprisingly, predicted soil erosion is greater on steeper plots and less where agroforestry and other NRM investments have been made (Table 3). Female primary education is associated with more erosion, though the reasons are not clear. Larger households have significantly higher erosion, probably because of more labor intensive crop production by larger households, consistent with the higher value of crop production per hectare of larger households.

This contradicts the optimistic "more-people, less-erosion" hypothesis (Tiffen, et al. 1994) at the household level, and is consistent with findings of Nkonya, et al. (2004). Erosion is lower for households dependent on livestock activities as their primary source of income than for households dependent upon crop income and for those owning more livestock, probably because livestock-dependent households use the land less intensively, and with greater soil cover on pastures than annually cropped fields. Erosion is greater on *mailo* tenure than freehold and leasehold tenure, though the reasons are not clear.

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

Livestock ownership is associated with more rapid depletion of N. This may be due to feeding crop residues to livestock after harvest, contributing to greater soil nutrient outflows, despite the positive impact of manure on N inflows (which is mainly applied near the homestead).

Human capital endowments have mixed impacts on nutrient balances. Female primary and male post-secondary education are associated with more negative N and P balances respectively. The negative impact of female primary education is related to the association of female primary education with erosion noted earlier. Households with more post-secondary male education are less likely to use short-term SWC practices (results available upon request), probably due to their high opportunity costs of labor. Larger household size is associated with greater P, K and NPK balances even though it is associated with more soil erosion and productivity. This apparent inconsistency may be because larger families are more able to adopt labor intensive soil management practices.

Access to urban markets has insignificant impacts on soil nutrient balances, while better road access is associated with more favorable nutrient balances. The beneficial impacts of road access may be in part because road access is associated with less use of slash and burn (results available upon request), a practice that depletes soil fertility. Consistent with Nkonya, et al. (2005), dependence upon non-farm activities leads to more favorable nutrient balances, probably because such households are less likely to use slash and burn, and more likely to fallow their land (results available upon request).

Participation in extension and credit programs has insignificant impacts on soil nutrient balances, even though participation in extension programs significantly increases use of inorganic fertilizer. The use of inorganic fertilizer is still too uncommon for this to have much effect on average nutrient balances, and is offset by higher yields leading to greater nutrient outflows.

Customary land has more favorable K balances than land under freehold and leasehold tenure, while *mailo* land has more negative balances of N and total NPK than freehold and leasehold land. The association of *mailo* land with banana production may be part of the reason for greater nutrient depletion on *mailo* land; but higher erosion rates on *mailo* land noted earlier also contribute to nutrient depletion. We are not sure why K balances are more favorable on customary than freehold and leasehold land, though this may be due to less banana production on customary than freehold and leasehold land. These results do not support the common belief that land degradation is greater on customary land due to inadequate tenure security on such land.

4. Conclusions and Policy Implications

Land degradation in the form of soil erosion and soil nutrient depletion is a serious problem in Uganda. Our study shows that farmers in our study regions deplete an average of about 1.2% of the nutrient stock stored in the topsoil, and that the cost of replacing the depleted nutrients would average 20% of household farm income. This underscores the reliance of smallholder farmers on soil nutrient mining for their livelihoods and the high costs that would be required to solve this problem. The findings of this study also underscore the great concern that soil nutrient depletion poses since it contributes to declining agricultural productivity. For example, a 1 % decrease in the phosphorus stock leads to a predicted 0.13% reduction in crop productivity, contributing to poverty and food insecurity. Furthermore, soil nutrient depletion may contribute to deforestation and loss of biodiversity since farmers may be forced to abandon nutrient-depleted soils and cultivate more marginal areas such as hillsides and rainforests.

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

Other strategies are likely to involve tradeoffs among different objectives. For example, female education may contribute to improved health, nutrition or other development indicators not analyzed in this research, but also appears to contribute to some indicators of land degradation. The presence of such tradeoffs is not an argument to avoid such strategies; but rather is an argument to recognize and find ways to ameliorate such negative impacts where they may occur. For example, incorporating teaching of principles of sustainable agriculture and natural resource management into educational curricula, as well as in the technical assistance approach of extension and other organizations, is one important way of seeking to address such tradeoffs.

References

Barrett, C.B., F. Place, A. Aboud. 2002. The challenges of stimulating adoption of improved natural resource management practices in African agriculture. In: Barrett, C.B., F. Place, A.A. Aboud (eds). *Natural Resources Management in African Agriculture*. ICRAF and CABI, Nairobi Kenya.

Baum, C. F., M. E. Schaffer, and S. Stillman. 2002. Instrumental variables and GMM: Estimation and testing. Unpublished working paper no. 545, Boston College Department of Economics. http://fmwww.bc.edu/ec-p/WP545.pdf

Bound, J., D.A. Jaeger, and R.M. Baker. 1995. Problems with instrumental variables estimation when the correlation between the instruments and the exogenous explanatory variable is weak. *Journal of the American Statistical Association* 90, 443-450.

Carney, D. 1998. Implementing the sustainable rural livelihoods approach. In: Carney, D. (Ed.), Sustainable Rural Livelihoods: What Contribution Can We Make? Department for International Development, London.

CIMMYT, 1988. *From agronomic data to farmer recommendation: An economics training manual*. Completely revised edition. Mexico DF.

Cleaver, K.M. and G.A. Schreiber. 1994. *Reversing the Spiral: The Population, Agriculture and Environment Nexus in Sub-Saharan Africa.* The World Bank, Washington, D.C.

Davidson, R. and J.G. MacKinnon. 2004. *Econometric Theory and Methods*. Oxford: Oxford University Press.

de Janvry, A., M. Fafchamps, and E. Sadoulet. 1991. Peasant household behavior with missing markets: some paradoxes explained. *Economic Journal* 101.

der Pol, V. F. 1993. Analysis and evaluation options for sustainable agriculture with special reference to southern Mali. In: Van Reuler H., Prins, W.H. (Eds), *The role of plant nutrients for sustainable food crop production in Sub-Saharan Africa*. VKP Leidschendam

Dregne, H.E. 1990. Erosion and soil productivity in Africa. *Journal of Soil and Water Conservation* 45(4): 432-436.

Fan, S., X. Zhang, and N. Rao. 2004. Public spending, growth, and poverty reduction in Uganda. Development Strategy and Governance Division Discussion Paper No. 4, International Food Policy Research Institute, Washington, DC.

Feder, G. 1985. The relation between farm size and farm productivity. *Journal of Development Economics* 18: 297-313.

Heltberg, R. 1998. Rural market imperfections and the farm size-productivity relationship: Evidence from Pakistan. *World Development* 26(10): 1807-1826.

Lamb, R.L. 2003. Inverse productivity: Land quality, labor markets, and measurement error. *Journal of Development Economics*, 71(1):71-95.

Mukherjee, C., H. White, and M. Wuyts. 1998. *Econometric and data analysis for developing countries*. London Routledge.

Nkonya, E., C. Kaizzi, J. Pender. 2005. Determinants of nutrient balances in a maize farming system in eastern Uganda. *Agricultural Systems*, 85(2):155-182.

Nkonya, E., J. Pender, P. Jagger, D. Sserunkuuma, C. Kaizzi and H. Ssali. 2004. Strategies for Sustainable Land Management and Poverty Reduction in Uganda. Research Report No. 133, International Food Policy Research Institute, Washington, D.C.

Otsuka, K. and F. Place. 2001. Issues and theoretical framework. In K. Otsuka and F. Place (eds.), *Land Tenure and Natural Resource Management: A Comparative Study of Agrarian Communities in Asia and Africa*. Baltimore: Johns Hopkins.

Pender, J. 1996. Discount Rates and Credit Constraints: Theory and Evidence from Rural India, *Journal of Development Economics*, 50, 257-296.

Pender, J. 1998. Population growth, agricultural intensification, induced innovation and natural resource sustainability: an application of neoclassical growth theory. *Agricultural Economics* 19, 99-112.

Pender, J., S. Ssewanyana, K. Edward, E. Nkonya. 2004. Linkages between poverty and land management in rural Uganda: evidence from the Uganda National Household Survey, 1999/2000. Environment and Production Technology Division Discussion Paper No. 122, International Food Policy Research Institute, Washington, D.C.

Place, F. and P. Hazell. 1993. Productivity effects of indigenous land tenure systems in sub-Saharan Africa. *American Journal of Agricultural Economics* 75(1): 10-19.

Place, F., J. Ssenteza, and K. Otsuka. 2001. Customary and private land management in Uganda. In K. Otsuka and F. Place (eds.), *Land Tenure and Natural Resource Management: A Comparative Study of Agrarian Communities in Asia and Africa*. Baltimore: Johns Hopkins.

Platteau, J.P. 1996. The evolutionary theory of land rights as applied to sub-Saharan Africa: A critical assessment. *Development and Change* 27:29-86.

Reardon, T. and S. Vosti. 1995. Links between rural poverty and the environment in developing countries: Asset categories and investment poverty. *World Development* 23(9), 1495-1506.

Renard, K.G., G.R. Foster, G.A. Weesies, and J.P. Porter. 1991. RUSLE: Revised Universal Soil Loss Equation. *Journal of Soil and Water Conservation* 46(1): 30-33.

Smaling, E.M.A., Stoorvogel, J.J.and P.N. Windmeijer. 1993. Calculating soil nutrient balances in Africa at different scales. II. District scale. *Fertility Research*. 35, 237-250.

Tiffen, M., M. Mortimore, and F. Gichuki. 1994. *More people – less erosion: Environmental recovery in Kenya.* London, UK: Wiley and Sons.

Wortmann, C. S. and C. A. Eledu 1999. Uganda's Agroecological Zones: A guide for Planners and Policy Makers. Kampala, Uganda: Centro Internacional de Agricultura Tropical (CIAT).

Wortmann, C.S. and C.K. Kaizzi. 1998. Nutrient balances and expected effects of alternative practices in farming systems of Uganda. *Agriculture, Ecosystems and Environment* 71(1-3): 115-130.

Table 1: Severity of soil nutrient depletion and its economic magnitude across agroecological zones

	Agroecological zones[1]						
	NW	NM	ME	SWG	LVCM	SWH	All zones
Nitrogen							
Nutrient balances (kg/ha/year)	-35.55	-53.11	-70.01	-99.22	-82.19	-73.18	70.60
% of plots with positive balances	21.16	19.17	22.58	14.73	14.75	28.40	20.14
N stock (kg/ha)	1944.2	2897.0	6017.3	3842.0	3700.5	4746.1	3695.0
N balance as % of total N stock	1.83	1.83	1.16	2.58	2.22	1.54	1.91
NDMV (US$)/farm[1]	66.17	139.06	106.50	190.41	145.16	75.65	124.80
ENDR[2] (%)	12.0	23.0	6.0	13.0	11.0	6.0	11.0
Phosphorus							
Nutrient balances (kg/ha/year)	-6.29	-4.97	-8.01	-7.33	-9.29	-18.55	-9.98
% of plots with positive balances	25.19	26.11	33.45	26.94	19.32	32.16	26.41
P stock (kg/ha)	1160.2	1412.1	3127.8	1655.2	1828.7	2759.8	1916.5
P balance as % of total P stock	0.54	0.35	0.26	0.44	0.51	0.67	0.52
NDMV (US$)/farm[1]	13.21	14.69	13.75	15.88	18.53	21.62	19.91
ENDR[2] (%)	2.00	2.00	1.00	1.00	1.00	2.00	2.00
Potassium							
Nutrient balances (kg/ha/year)	-31.97	-34.17	-81.25	-172.95	-78.75	-143.70	-94.85
% of plots with positive balances	23.11	30.53	14.42	15.50	14.10	30.70	22.99
K stock (kg/ha)	4207.5	3407.2	11992.6	10888.4	6560.1	18579.9	9618.9
K balance as % of total N stock	0.76	1.00	0.68	1.59	1.20	0.77	0.99
NDMV (US$)/farm[2]	30.71	46.17	63.79	171.30	71.79	76.56	86.54
ENDR[2] (%)	5.56	7.67	3.75	11.29	5.26	6.32	7.78
All Nutrients (N,P,K)							
Nutrient balance (kg/ha)	-73.82	-99.48	-159.27	-279.50	-178.10	-235.53	-178.80
Nutrient balance as % of stock	1.01	1.29	0.75	1.71	1.47	0.90	1.17
% of plots with positive balances	19.14	17.99	20.00	13.18	11.23	26.58	18.05
ENDR[3] (%)	19.94	33.21	10.82	24.90	17.25	14.34	20.80

1 Agroecological zones: NW = North West farmland, NM = Northern Moist farmlands, ME = Mt. Elgon farmlands, SWG = South Western Grass-farmlands, LVCM = Lake Victoria Crescent and Mbarara farmlands, and SWH = South Western Highlands

2. Nutrient Deficit Market Value (NDMV) is the value of nutrients mined per hectare if such nutrients were to be replenished by applying purchased fertilizer (van der Pol, 1993).

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

Table 2: Factors affecting value of crops produced per acre

Variable	Ln(value of crops/acre)		
	OLS full	IV[1]	OLS reduced
Land management practices			
Ln(value of inorganic fertilizer purchased in Ush+1)	0.044**	*0.112*	
Ln(pre-harvest labor used on plot+1)	*0.214****	*0.537***	
Were the crop residues incorporated into plot? Yes=1 no=0	0.313**	*-0.583*	
Natural capital			
Ln(average slope %)	-0.001	0.069	-0.009
Ln(topsoil depth (cm))	0.059	0.017	0.065
Ln(N stock kg/ha)	0.001	-0.072	0.019
Ln(P stock kg/ha)	0.134***	*0.120**	0.129**
Ln(K stock kg/ha)	0.054	*0.067*	0.051
Land investments on plot dummies (yes=1 no=0)			
Practice agroforestry	0.283***	0.401***	0.274***
Have SWC structure?	0.451***	0.571***	0.483***
Perennial as dominant crop grown on plot (cf annual crop)	*0.318****	0.290**	*0.318****
Have other NRM investment?	*0.091*	0.03	*0.125*
Ln(plot area in acres)	*0.258****	*0.567***	*0.077*
Ln(farm area in acres)	*-0.907****	*-1.020****	*-0.876****
Human capital			
Share of female household members with …. (cf no formal education)			
Primary education	0.006	-0.028	0.033
Secondary education	-0.101	-0.206	*-0.115*
Post-secondary education	*0.219*	*0.414*	*0.063*
Share of male household members with …. (cf no formal education)			
Primary education	0.056	-0.022	0.097
Secondary education	0.472***	0.371*	0.517***
Post-secondary education	0.438*	0.307	0.475
Sex of household head. Male = 1, No = female	0.12	-0.019	0.145
Ln(Household size)	0.210*	0.231	0.202
Primary source of income of household head (cf crop production)			
Non-farm	-0.038	0.055	-0.099
Livestock	-0.387*	-0.336	-0.414
Land tenure (cf freehold and leasehold): Customary	0.260**	0.343**	0.403**
Mailo	0.131	0.153	0.079
Access to markets and services			
Ln(Distance from plot to residence in km)	-0.232***	-0.170*	-0.213**
Ln(Distance from plot to all weather road in km)	0.026	0.014	0.044
Potential market integration	*-0.001*	*-0.001*	*0.000*
Ln(Number of extension visits+1)	*0.082*	*0.038*	*0.109*
Participate in NAADS activities? Yes=1, no=0	*0.235****	*0.266***	*0.232***
Household has access to credit? (yes=1 no=0)	*0.195*	*0.283***	*0.155*
Wu-Hausman test of exogeneity of potentially endogenous variables ($P>\chi^2$)		1.000	
Relevance tests of excluded variables ($P>\chi^2$)			
Value of seed		0.000	
Value of inorganic fertilizer		0.0223	
Value of organic fertilizer		0.000	
Pre-harvest labor		0.000	
Crop residue		0.000	
Hansen J test overidentification restrictions ($P>\chi^2$)		0.805	

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

Table 3: Deteminants of soil nutrient balances and erosion

	Ln(N)	Ln(P)	Ln(K)	Ln(NPK)	Ln(erosion)
Natural capital					
Ln(average slope %)	-21.25***[bA]	-4.62***[aA]	-19.14**[a]	-50.34***[aA]	0.73***[aA]
Ln(topsoil depth (cm))	3.22	-1.54	-1.26	8.80	-0.08
Land investment on plot dummies. Yes=1 no=0					
Practice agroforestry?	8.09	2.07[c]	23.11*	36.78**[bC]	-0.27***[aB]
Have SWC structure?	22.49**[bB]	3.31*[b]	10.93	28.33	0.01
Perennial crop (cf annual crop)	-23.94***[aA]	-2.97[bC]	-34.99*[b]	-67.98***[aA]	-0.01
Have other NRM investment?	8.92	-1.42	15.15	40.88[C]	-0.34**[C]
Log(farm area in acres)	-4.87	-1.14[c]	-5.60	-14.54[c]	-0.04[c]
ln(Tropical livestock unit)	-9.49**[a]	-0.30	-1.05	-11.81[c]	-0.11*[bA]
Human capital					
Female education (cf no formal education)					
Primary education	-21.86***[aB]	-3.97**[cB]	-5.65	-35.45	0.20**
Secondary education	-19.43	1.91	-19.92	-29.80	-0.18[C]
Post-secondary education	-14.44	-5.19	-8.61	-33.30	0.27
Male education (cf no formal education)					
Primary education	2.28	-0.23	-6.23	-7.97	-0.04
Secondary education	5.59	0.01	-18.08	-9.01	-0.01
Post-secondary education	-33.08*[b]	-7.31*[c]	-30.71	-65.81	-0.04
Male household head	25.23	2.43	30.27	65.14	0.02
Ln(Household size)	13.81	3.69**[cC]	32.95*[b]	52.86**[b]	0.21*[b]
Share of farm owned by women	22.26	2.39	34.33	52.55	0.02
Primary source of income (cf crop production)					
Non-farm activities	6.77	3.01*[B]	28.18*	33.08	-0.02
Livestock	-14.76	8.65	119.09	24.22	-0.69***[cA]
Access to markets and services					
Ln(Distance to plot in km+1)	13.39**[aB]	2.94**[aB]	16.39*[cC]	30.4894**[bB]	0.06
Potential market integration	0.05	-0.01	-0.04	0.03	0.00
Ln(Distance to road in km+1)	-10.67*[C]	-3.70***[bB]	-32.20***[bA]	-42.66***[bA]	0.10[c]
Ln(Number of extension visits+1)	1.92	-0.83	-1.63[A]	-2.18[B]	-0.01[A]
Participation in NAADS	12.73	3.49	22.61[B]	41.33[C]	-0.05
Household has access to credit	2.09	1.11	-0.22	5.86	0.01
Land tenure of plot (cf freehold and leasehold)					
Customary	13.95	0.08	37.23**[c]	47.19	0.15[C]
Mailo land	-34.79**	0.02	-43.59	-100.6***[cC]	0.56***[b]
Wu-Hausman test ($P>\chi^2$)	1.00	1.00	1.00	1.00	0.95
Relevance tests of excluded variables ($P>\chi^2$)					
Number of extension visits	0.00	0.00	0.00	0.00	0.00
Participation in NAADS	0.00	0.00	0.00	0.00	0.00
Access to credit	0.00	0.00	0.00	0.00	0.00
Hansen J test ($P>\chi^2$)	0.32	0.08	0.21	0.14	0.44

Notes:*, **, *** means the associated coefficient is significant at p<0.1; p<0.05; and p<0.01 respectively.
a, b, c means the associated coefficient is significant at p<0.01; p<0.05; & p<0.1 respectively in the reduced OLS.
A, B, and C means the associated coefficient is significant at p<0.01; p<0.05; & p<0.1 respectively in the IV model.