POVERTY-NATURAL RESOURCE MANAGEMENT LINKAGES: EMPIRICAL EVIDENCE FROM UGANDA

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Introduction

Poverty reduction is Uganda's major goal that is emphasized in most government policy statements. Even though the country has shown a strong improvement in per capita income and consumption (Appleton, et al., 2001), the rural poor still perceive that poverty is worsening (Republic of Uganda, 1999). This anomaly is likely due to the skewed income distribution and the broad definition of poverty, which includes more than income. Another concern related to poverty is the serious natural resource and environmental degradation that is likely to exacerbate poverty since the poor depend largely on natural resources like land to sustain their livelihoods (NEMA, 2002).

The severity of land degradation in Uganda is well documented (Zake et al., 1999; Stoorvogel and Smaling 1990; Wortman and Kaizzi, 1998; Pender et al., 2001) and most studies point out that sustainability of most land management practices over long-run is questionable.[1] It is disturbing to note that the negative impact of natural resource degradation is most severe to the poorest. It would therefore be interesting to understand how the poor contribute and respond to natural resource degradation since this would help the government and its development partners to design policy options that would address unsustainable natural resource management.

In this paper, we report some selected results from surveys conducted by the International Food Policy Research Institute (IFPRI) that shows the linkages between poverty and natural resource management (NRM), particularly land management. We do this by examining the factors that determine soil nutrient balances in order to draw policy implications about how to address unsustainable land management practices.

Methodology

Data

A total of 58 households were selected for an intensive soil fertility study aimed at determining the nutrient balances of each household.[2]

The 58 households that collaborated in the on-farm trial were selected from four villages, namely; Nemba/ Kasheshe, Agonyo II, Odwarat and Kongta in Sironko, Soroti, Kumi and Kapchorwa districts respectively. The sites are located in eastern Uganda along a transect which captures variability in soil productivity, land use intensity and agricultural potential. Maize is the dominant crop in the farming systems studied in these sites. The altitude ranges from 1060 meters above sea level (m.a.s.l.) in Odwarat to 1890 m.a.s.l. in Kongta. The mean annual rainfall ranges for each village are 1500-2000 mm at Kongta, 1250-1250 mm at Kasheshe/ Nemba as compared to 1000-1250 mm for Agonyo II and Odwarat sites. Rainfall is much more reliable at Kongta and Nemba/Kasheshe. The farmers' fields were characterized using soil chemical and physical characteristics

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[1] We define sustainable land management as land use practices that ensure land, water and vegetation adequately support land-based production systems for the current and future generations.

[2] Plot level data on nutrient balances are not yet available for the present analysis. Hence our analysis in this paper is limited to the household level.

obtained from soil samples collected from the 0-20 cm depth. The pH, Organic matter, nitrogen (N), extractable phosphorus (P), exchangeable potassium (K) and Calcium (Ca), and texture were measured using the routine soil sample lab analytical method according to Foster (1971).

Using the household and plot level survey, the data on farm management and SWC practices, crop-livestock interaction, crop diversity and other production strategies that affect nutrient flow were used to determine nutrient inflows and outflows for each plot and the farm as a whole. These flows were then used to compute the nutrient balance for each household. The sources of inflows and outflows used in this study are according to de Jager, et al. (1998) and Smaling, et al. (1993). The nutrient inflows are mineral fertilizers, organic inputs from outside the farm, animal feeds and concentrates, grazing outside the farm, purchased food, atmospheric deposition, biological nitrogen fixation, and sedimentation. The major sources of outflows are: harvested crop products, leaching, erosion, animal products, crop residue, exported manure, and gaseous losses.

Model

Our analysis on the determinants of nutrient inflows and outflows focuses on inflows or outflows that the farmer has control over. Those that the farmer cannot influence significantly are not analyzed. The inflows that the farmer can influence substantially are mineral fertilizers, organic inputs from outside the farm, animal feeds and concentrates, external grazing, purchased food, and biologically fixed nitrogen by planting legumes. The nutrient outflows under farmers' control are harvested crop products, erosion, animal products, crop residue, and exported manure. The determinants of the overall nutrient balances for the major macronutrients, namely nitrogen, phosphorus, and potassium, will also be analyzed in order to measure the sustainability of land management practices.

As noted by Nkonya, et al., 2002b, the major factors that affect land management include the village and regional level factors, agricultural potential and market access,[3] human capital, social capital, household assets, namely farm size of livestock herd (measured in tropical livestock units (TLU)), etc. The human capital variables are education and family labor. Contact with extension services was included as the measure of access to technical assistance. The average distance of the farmer's plots to the residence was included as a measure of land fragmentation.

We also included two other variables, namely production strategy (primary activity of household head) and crop diversity (number of crops grown).[4] To minimize the number of variables, we divided the production strategies into only two categories: farm and non-farm activities. Production strategies may have a large impact on land management, which in turn has a large influence on nutrient flow. The crop diversity is

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[3] Since our sample for this analysis is small, we did not include the population density, as we thought its effect would be captured in the farm size variable; i.e. farmers living in densely populated areas would have smaller farms.

[4] Biodiversity is biological diversity, which is manifested by variability in living organisms found in a place at a given time (Mugabe 1998). Biodiversity contributes to nutrient flows. For example, inclusion of legumes in a cereal plot fixes atmospheric nitrogen, reduces nitrate losses, while deep-rooted crops and cover crops reduce nitrate leaching (Keeney 1982; Bruce, et al. 1991).

one of the variables found in other studies to significantly influence nutrient flows (de Jager, et al. 1998; Keeney 1982; Bruce, et al. 1991; Giller, et al. 1997).

We use the same explanatory variables to estimate the determinants of nutrient flows and balances. The models estimated are:

Determinants of nutrient inflows

$In_i = f(\mathbf{x_1 b_1} + e_1)$ ……………………………….(1)

$Out_i = f(\mathbf{x_2 b_2} + e_2)$ ……………………………….(2)

$Nutbal_i = f(\mathbf{x_3 b_3} + e_3)$ ……………………………….(3)

Where: in_i is source i of nutrient inflow, namely chemical fertilizer, organic fertilizer, external grazing, purchased food and biological nitrogen fixation (BNF);

Out_i is channel i of nutrient outflow, namely crop harvest, animals from other farmers grazing in household plots, crop residues exported out of household, soil erosion and animal manure exported;

$Nutbal_i$ is balance of nutrient i, namely nitrogen (N), phosphorus (P), Potassium (K) and total nutrient balance (NPK);

$\mathbf{x_i}$ is column vector of factors that affect nutrient flow and their balances;

$\mathbf{b_i}$ is the associated row vector of coefficients of nutrient flow and balance determinants; and

e_i is the error term of i^{th} nutrient flow or balance.

Explorative analysis of the data was used to detect the distribution of the variables and violation of regression assumptions. Data that were skewed or had heavy tails were transformed to normality, avoiding as much as possible to drop any observations. Family labor, distance from residence to parcel and farm size were positively skewed. A log-transformation normalized their distributions. Heteroscedasticity was also observed in all models, hence feasible generalized least squares (FGLS) was used to estimate asymptotically efficient parameters.

Results

As noted earlier, we examine sustainability of land management by analyzing the nutrient balance, which is the difference between inflows and outflows of the three most important macronutrients, nitrogen (N), phosphorus (P), and potassium (K). The major source of nitrogen inflow is symbiotic N-fixation, which contributed about 26% of the 86 kg ha^{-1} of nitrogen input (Table 1). The large contribution of symbiotic nitrogen fixation is common for households who plant leguminous crops and do not apply inorganic fertilizer. This is the case for most farmers in the study area. Nitrogen fixation depends on soil conditions, climatic conditions and some aspects of farm management such as planting leguminous crops. [5] Atmospheric deposition, which the farmer has no control over, is also an important source of nitrogen in the study area as it contributed an estimated 16 kg of N per ha, which is about quarter of the nitrogen input. Atmospheric deposition is also a major source of phosphorus and potassium inflows. Sedimentation is

[5] Nitrogen fixation by tropical legumes may be limited by lack of nodules, which may be a result of soil acidity or deficiency of P, which is important for nodule formation. Drought can also be a problem as less rainfall leads to less N-fixation (Giller, et al. 1998; Wortman and Kaizzi, 1998). Biological nitrogen fixation can also be limited by altitude and cold temperatures (Kaizzi, et al. 2002).

another important source of nitrogen, especially in areas with extensive rice cultivation in valley bottoms. However, the amount of nitrogen deposited via sedimentation is highly skewed as about half of the 58 farmers under study received less than 10kgN ha^{-1} from sedimentation. This is probably due to non-cultivation of rice in the highlands and the variation in the terrain on mount Elgon sites (Nemba/Kasheshe and Kongta) and the Iteso plains (Odwarat and Agonyo).[6]

Organic fertilizers are not important sources of nutrient inflow for the sample farms. Organic fertilizers contributed only about 2% of total N inflow. There is not much recycling of organic material produced on-farm or biomass transfer. However, biomass transfer through external grazing is the second most important source of both phosphorus and potassium.

The sources of nutrient outflows are crop and animal products sold or given away; crop and animal residues waste sold or given away; leaching of nutrients below the root zone; gaseous losses from the soil, and water and wind erosion. For all three nutrients, crop products are the major outflow, accounting for more than 50% of outflows (Table 2). Leaching is the second most important outflow for nitrogen, while soil erosion is the second most important outflow for phosphorus and potassium. Soil erosion is a major contributor to nutrient losses since much of soil nutrients in tropical agriculture are in the top 5 to 10 cm. of the soil (Keeney, 1982). Our findings on the contribution of soil erosion to nutrient loss are comparable to those of Wortman and Kaizzi (1998), who observed that in the maize farming systems in eastern Uganda, erosion contributes to about 14% of nitrogen; 43% of phosphorus and 27% of potassium outflows.

Only 5% of the sample households had positive total NPK balances, with N and K showing the lowest balances among the three macronutrients (Table 3). The rest of the farmers used land management practices that appear to be unsustainable. N had the lowest percent of households having positive balances. P had the highest percentage of farmers with positive balances and the smallest mean negative balance. About 35% of sampled households had negative K balances, though this does not raise as much concern, since in most SSA soils K is the least limiting among the three macronutrients (Sanchez, et al., 1997; Smaling, et al., 1992; Woodhouse and Rendle, 1983) except for the sandy savanna soils (Ssali, et al., 1986). But K also can become limiting after cultivating the land for some years (Singh and Goma, 1995) and for crops with high K off-take such as root crops and banana, which are common in Uganda (Sanchez, et al., 1997).

If inorganic fertilizer were used to restore the mined nutrients, it would cost an equivalent of a fifth of the household income, which is estimated at US$793/household per year. That is, the economic nutrient depletion ratio (ENDR), which shows the share of farmers' income that is derived from mining soil nutrients, is about one fifth of farmer's income. This implies farmer's income sustainability quotient (FISQ) is only about 80%. If farmers were to practice sustainable land management by producing at zero nutrient balance, their farm income would be reduced to about 80% of the income they realize when they use the current unsustainable land management practices. The cost resulting from soil fertility mining may be computed as share of gross domestic product (GDP) in order to comprehend the cost that it imposes on the entire economy. If the data

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[6] Nemba/Kasheshe is in Mbale, Kongta in Kapchorwa district, Odwarat in Kumi and Agonyo in Soroti.district.

obtained in eastern Uganda are typical of nutrient depletion at national level,[7] nutrient depletion may equal about 9% of the 2000/01 GDP, which was US$3.983 billion (MFPED, 2001).[8] Given that nutrient depletion also is associated with soil quality losses resulting from soil erosion and leaching, this estimate appears reasonable, and is comparable with other studies in Uganda and other countries (Pearce and Warford, 1993; Slade and Weitz, 1991). However, since nutrient depletion is a concealed form of environmental degradation, it sometimes goes unnoticed.[9]

In order to draw policy recommendations to address these unsustainable land management practices, we analyze the factors that determine levels of nutrient inflows, outflows and nutrient balances. Human and financial capital, technical assistance, distance from plot to residence, agricultural potential, market access, crop diversity (biodiversity), farm size and participation in off-farm activities are important determinants of nutrient flows and balances.

Determinants of Nutrient Inflows

For all four major inflows that the farmer has control over--chemical fertilizer, external grazing, purchased food and biological nitrogen fixation (BNF)—more family labor availability reduces nutrient inflows (Table 4).[10] As suggested by results of outflows (Table 5), this is likely due to the ability of households with more family labor to use more intensive and erosive land management practices such as higher tillage or weeding frequency.

The average distance from the farmer's residence to her parcels significantly reduces the inflow from purchased food and BNF. The negative impact of distance to parcel on nutrient inflow from purchased food is a reflection that farmers with distant plots buy less food from the market, possibly because they are poorer than other farmers. Controlling for biodiversity, the reason for the negative relationship between BNF and distance to parcel is not clear.

The inflows from external grazing, purchased food and BNF decrease as one moves from the high agricultural potential zone to the low potential zone (unimodal rainfall).[11] This is perhaps due to the low biomass potential in the unimodal rainfall zone that leads to low quality and quantity of pasture. Farmers living in the low potential zone

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[7] Given that we are using a sample of only 58 households, this may be an unrealistic assumption, and needs to be validated using a bigger sample.

[8] Consider a population of 24 million people in 2000/01, of which 85% live in the rural areas (UBOS, 2001). Assuming an average of 8 persons per household (Nkonya, et al., 2002), there were about 2.5 million rural households in 2000/01, of which 95% had a negative nutrient balance of an average cost of $152.6/household and a total environmental cost of US$362.4 million, which is 9.1% of the 2000/01 GDP of US$3.983 billion.

[9] For example, Slade and Weitz (1991) estimated the annual cost of environmental degradation in Uganda to be $170 to 460 million. They further observed that soil erosion accounted for 85% of the environmental degradation cost while water contamination contributed 10%, biodiversity loss 4% and deforestation 1%.

[10] However the reduction is not significant for the case of chemical fertilizer.

[11] The 58 households included in this study were in the following agricultural potential zones: unimodal rainfall (31), bimodal medium rainfall (12); bimodal high rainfall (1); and eastern highlands (14). To avoid losing degrees of freedom, we categorize the bimodal medium, bimodal high rainfall and eastern highlands zones as the high potential zone and the unimodal rainfall area as the low potential zone.

are more subsistence-oriented households, which buy less food from the market. The negative relationship between agricultural potential and BNF was also expected since dry conditions limit BNF (Giller, et al., 1998).

Ownership of livestock (as measured by tropical livestock units (TLU)) reduces the nutrient inflows from external grazing but increases inflows from purchased foods. It is not clear why livestock ownership is negatively associated with inflow from external grazing since we expected that farmers with large herds of livestock would need supplemental grazing on communal or neighbors' grazing lands. The positive relationship between TLU and nutrient inflow from purchased food is consistent with theory since farmers who own large herds of livestock are wealthier and hence have higher purchasing power and less time for crop production to meet their subsistence needs, hence they depend more on consumption of purchased food.

Access to extension services significantly influences inflows from purchased food and BNF. The positive association between extension contacts and purchased foods may be due to better extension services for farmers growing export crops (such as cotton and coffee). Export crop producers are more likely to buy food than food crop producers because they have more cash and may be less likely to produce enough food for their subsistence needs. The positive association between BNF and extension contact was expected since one of the extension messages is planting leguminous crops to promote BNF.

Education of the household head shows a negative relationship with nutrient inflows from external grazing and BNF. Nkonya, et al., 2002b also show that farmers who have completed primary education are less likely to apply household residues and mulch than those who did not complete primary education. This is consistent with Nkonya et al. (2002a), who noted that education increases farmers' opportunities to be engaged in non-farm activities. Such options may reduce farmers' incentive to invest effort in BNF-enhancing technologies or grazing animals.

Improved market access significantly reduces inflows from external grazing and purchased foods. Due to land shortage in high market access areas, farmers are less likely to feed their animals on other farmers' plots or common grazing areas. This may explain the negative effect of market access on nutrient inflow from external grazing. The likely explanation for the negative impact of market access on nutrient inflows from purchased food is that farmers in high market access areas produce enough crops for their subsistence needs and a marketable surplus. This explanation appears to be supported by the large positive effect of market access on nutrient outflows through crop harvest (Table 5). Farmers in high market access areas therefore appear to be surplus producers hence have less need to buy large quantities of food to supplement their own production. The nutrient inflow from BNF is also higher in high market access than in low market access. Controlling for crop diversity, extension contact, agricultural potential and other factors, this observation may be explained by the better access to phosphorus fertilizers in high market access areas, which improve BNF. It is also possible that there is high demand for leguminous crops in the high market access that gives farmers an incentive to plant more legumes for sale.

Controlling for TLU, farm size and other factors, crop diversity decreases soil nutrient inflows from external grazing but increases inflows from chemical fertilizer. This is likely due to the limited space for external grazing in areas that plant a large number of crops, such as the banana/coffee systems. It is interesting to note that crop diversity increases nutrient inflow from chemical fertilizer. In Uganda, a higher number of crops is probably associated with mixed perennial-annual crop systems that include maize. Producing more crops probably means the farmer is more likely to produce maize and thus more likely to use fertilizer.

We expected that farmers with large farms would have less need to graze their animals on common grazing lands or other farmers' plots. Contrary to our expectation, it is not clear why farm size increases nutrient inflows from external grazing (controlling for livestock ownership). Farm size increases nutrient inflows from purchased food probably because of its wealth effect, which is likely to increase purchased food. Farm size also increases nutrient inflows from BNF perhaps due to the wealth effect that allows farmers to use BNF-enhancing land management practices, such as application of phosphorus fertilizer.

Controlling for market access and other factors, off-farm activities increase nutrient inflows from chemical fertilizer and purchased food but reduces BNF. Farmers having off-farm activities are likely to have higher cash income for buying chemical fertilizer but they are likely to produce less food than their subsistence requirement and hence the need to buy food. The negative association between off-farm activities and BNF may be due to less investment in BNF-enhancing management practices by farmers having off-farm activities due to their higher labor opportunity costs.

Determinants of Soil Nutrient Outflows

After examining the inflows, we now consider the determinants of soil nutrient outflows. Family labor increases nutrient outflows from crop residues, soil erosion and exported animal manure (Table 5). Larger farm households may have greater need to use crop residues as cooking fuel energy or sell them for zero-grazed animals. The positive association between family labor and outflows from soil erosion suggests that households with larger family labor use more labor-intensive and hence more erosive practices such as more tillage or weeding.

Average distance from residence to the farmer's parcels increases nutrient outflows from crop residues and soil erosion. The positive association between distance to parcels and outflow through crop residue may be due to greater theft or grazing of residues by neighbors on distant parcels, since owners are too far away to have effective control on access to such parcels. More nutrient loss through erosion for distant parcels is likely due to use of more erosive practices on distant parcels. For instance, results reported by Nkonya et al., 2002b show that farmers are less likely to be apply manure, compost, mulch or household residues on distant parcels, and are more likely to use slash and burn during land preparation.

Nutrient loss through crop and residue harvest and soil erosion is significantly higher in the low agricultural potential zone than in the high agricultural potential areas. However, controlling for livestock ownership and other factors, nutrient losses through removal of animal manure is less in low potential areas than in high potential areas. The negative association between agricultural potential and nutrient loss through crop harvest was contrary to a priori expectation. This is because high yields are expected in the high potential areas. The negative impact of agricultural potential on nutrient loss through soil erosion is likely due to less vegetation in the low potential areas, which leaves the soils unprotected, hence more erosion.

Farmers in low agricultural potential areas are more likely to experience fuelwood shortage, which forces them to use crop residues for cooking. This may explain the negative relationship between agricultural potential and nutrient losses through crop residues. The positive association of agricultural potential and nutrient loss through animal manure may be explained by the higher probability of applying manure in the high altitude zones, which are of high potential, than in the low altitude areas (Nkonya, et al., 2002b). This implies farmers in the high agricultural potential zones have a market for manure and hence more likely to export than those in the low potential zones.

Livestock ownership significantly reduces nutrient losses through crop harvest, crop residues, soil erosion and exportation of animal manure. However, it slightly increases nutrient losses through animal grazing. Farmers with more animals are likely to depend less on crop production, hence produce less crops and residues for sale. Less crop production for farmers with more livestock may also explain the negative impact of livestock on nutrient losses through soil erosion. This is because in the absence of overstocking, which is not a serious problem in the study villages, crop production is likely to lead to more soil erosion than livestock production.[12] However, nutrient loss through animal grazing increases slightly with TLU since this increases the number of animals to feed on crop residues and the farmer's own pastures.

Contact with extension agents reduces nutrient losses through crop residues, perhaps due to the extension messages that advise farmers not to harvest crop residues in order to reduce soil erosion. However, contact with extension agents increases nutrient losses through soil erosion and exportation of animal manure. The association between nutrient loss through soil erosion and contact with extension may be due to tendency of farmers to adopt one technology at a time (stepwise adoption), as observed by Byerlee and de Polanco (1986). In this case, farmers may adopt more erosive technologies such as higher weeding frequency for cotton, which increase soil vulnerability to erosion, without adopting soil conservation measures.

Education of household head is associated with lower nutrient losses through all four sources of outflow but only losses through crop harvest and exportation of animal manure are statistically significant. The negative association of nutrient loss through crop harvest and level of education of household head suggests that better educated farmers are likely to export less nutrients through crop harvests since they produce less crops for sale. This is consistent with Nkonya et al. (2002b) who showed that better educated farmers use less intensive land management practices, which in turn lead to lower yields.

Better market access increases nutrient loss through crop harvest, crop residues and soil erosion. This was expected since in high market access areas, farmers are likely to produce more crops for sale, hence exporting more nutrients. Farmers in high market access areas are more likely to find a market for their crop residues, which leads to additional nutrient loss through exportation of crop residues and the consequent soil erosion. Controlling for TLU and other factors, the negative association between loss of nutrients through animal manure exportation and market access suggests that labor in the

[12] For instance, Tefera, et al. (2002) observed that croplands are more vulnerable than pastureland to soil erosion than croplands because croplands are repeatedly tilled and left without adequate vegetative cover.

high market access areas is too expensive to use animal manure. Nkonya et al. (2002b) also showed that farmers in the high market access areas use less household waste on their farms.

Crop diversity reduces nutrient loss by reducing soil erosion, as expected,[13] and by reducing exports of crop residue and manure. Farm size increases soil nutrient loss through greater export of crop harvest and residue because larger farms produce larger surpluses for sale. Participation in off-farm activities leads to higher losses of nutrients through crop harvest but reduces nutrient losses through soil erosion. These results support the findings in Table 4 where we observed that off-farm activities enhance use of chemical fertilizer, which in turn increase crop yield and hence nutrient loss through crop harvest. This is also consistent with Nkonya et al. (2002b) who observed that households with wage or salary income as their primary income source were more likely to use slash and burn, which was found to be associated with less erosion.

Determinants of N, P, K and NPK Balances

After studying the determinants of the inflows and outflows, we turn to their net effect and analyze the determinants of nutrient balances of the three major nutrients, namely N, P, K, and their total, NPK. This analysis helps us to understand the overall effects of socio-economic and physical factors on nutrient balances.

The impact of family labor on nutrient balances is mixed. It significantly increases the nutrient balances for N but reduces K and NPK balances (Table 6). This is likely due to its negative effects on most nutrient inflows and positive effect on most outflows. Distance from residence to parcel has a positive impact on N but a negative effect on K. This may be due to a higher level of chemical fertilizer application on distant parcels than those around residence (Table 4). However, it is uncommon for farmers to apply K-rich chemical fertilizers such as muriate of potash or potassium sulphate. K-rich manure and household residues are more likely to be applied on parcels closer to residence, because of the high cost involved in transporting such bulky materials to distant plots. Plots around the homestead benefit from household waste thrown regularly after cleaning the home or animal confinement structures.

Households in the high agricultural potential areas report significantly higher nutrient balances than those in the low potential areas, suggesting that crop production in the high potential areas is more sustainable than in low potential areas. Again this follows from the results reported in Table 6 and Nkonya et al. (2002b) who noted that farmers in the low potential areas experience more loss of nutrients through soil erosion, are less likely to apply chemical fertilizer or adopt BNF-enhancing technologies than those in the high potential areas. Kaizzi, et al.(2002), also observed similar results.

Livestock ownership increased significantly the balances for N, P, K and NPK. The results suggest that farmers with more livestock are likely to apply on-farm produced animal manure to their plots and hence manage their farms more sustainably. Farmers with more livestock also export less nutrients through crop harvest.

We observe a significant negative impact of contact with extension agents on N and NPK balances. This is perhaps due to the stepwise adoption of technologies. To verify this, we ran a version of the regressions for nutrient balances of N, P, K and NPK

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[13] Crop diversity increases soil cover, hence likely to retard soil erosion.

including a quadratic specification of extension contact hours ((ext) and $(ext)^2$) as explanatory variables.[14] We observed a U-shaped relationship of nutrient balances with extension. This relationship was significant for the two most limiting nutrients, namely, N, and P equations. At low number of extension contact hours, as is the case now, farmers are likely to adopt improved crop varieties without soil fertility technologies.[15] Hence initially, there is more soil depletion, which bottoms out and then nutrient balances start increasing with extension contact hours as adoption of soil fertility management technologies increase. The present research suggests that inadequate extension services are likely to contribute to unsustainable land management practices if farmers adopt improved crop varieties without adopting soil fertility management practices that would restore the additional nutrients utilized by the high yielding varieties. This appears to be supported by some field observations. For instance Ssali (pers. Comm. 2002) noted that farmers complained that productivity of plots previously planted with improved varieties decreased substantially.

Controlling for off-farm activities and other factors, farmers having secondary or higher education have higher nutrient balances than those with lower education. This suggests that better education is likely to contribute to more sustainable crop production.

Market access significantly reduces balances of N, P, K and NPK, suggesting that farmers closer to markets mine their soils more than those further away from markets. This observation supports Woelcke, et al. (2002), who noted that commercially oriented farmers in eastern Uganda had worse soil nutrient depletion than subsistence farmers. This implies that improved access to market may induce farmers to practice unsustainable land management for the sake of short-term profit-making objectives, as noted by Angelsen (1999) and Lipton (1987). These findings call into question the assumption of the Plan for Modernization of Agriculture that improvement in infrastructure and markets will solve unsustainable land management problems, at least in the near term.

As expected, crop diversity appears to contribute to more positive (or less negative) nutrient balances, suggesting the need to encourage farmers to plant crops in intercrop systems. It may be the case that intercropping is more common in perennial crop systems, which may have less nutrient depletion problems. This appears to reduce soil erosion (Table 5) and increases probability of application of chemical fertilizers (Table 4). Farm size is negatively related to nutrient balances, implying that larger farmers have higher levels of nutrient depletion than smaller farms. As pointed out earlier, this may be due to the ability of larger farms to produce more marketable crop surplus, which exports soil nutrients off the farm without adequate replenishment. Smaller farms are likely to produce less for sale and are more likely to buy food to supplement their subsistence needs. This reduces soil nutrient depletion by such farmers.

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[14] Results of this regression available upon request. To reduce number of independent variables and problems of multicollinearity, we did not include the quadratic function of extension in the reported set of regressions, but instead included a dummy variable for access to extension.

[15] Among the 58 farmers considered in this paper, 62% did not have extension contact in 2000. Among those who had extension contact, only 25% had more than 4 contact hours in the entire year. Undoubtedly this is a little time for farmers to understand rather complex technologies like soil-fertility practices. PMA (2000) also notes the inadequate extension services in most districts of Uganda. Only 11.4% of households received extension services in 1998 (UBOS, 2002).

Households having a non-farm primary activity are likely to have more sustainable crop production than those with agriculture as a primary activity. As observed earlier, this is likely due to their ability to buy fertilizer and food.

Lastly, we would like to point out the weaknesses of the present paper and to recommend future research in this area. This paper attempted to analyze the factors affecting nutrient balances using only 58 households in a largely maize farming system. The sample of 58 households is small, though it generated quite interesting results. Future studies need to involve a bigger sample of farmers from different farming systems and land tenure systems of the country. This will allow better estimates of the status of nutrient depletion in Uganda.

Conclusions and policy implications

Using nitrogen (N), phosphorus (P) and potassium (K) balances as indicators of sustainability of agricultural production, the present research shows that only 5% of households sampled in the cereal-based farming systems in eastern Uganda practice sustainable land management. This confirms the serious soil nutrient depletion, whose value of replenishment is about 19% of household income. These findings pose a big challenge to policy makers, planners and others who are involved in environmental conservation and developing sustainable agricultural production. This is because buying inorganic fertilizer to replenish mined nutrients appears to be an unaffordable alternative. The findings of the present research confirm the heavy reliance of Ugandan farmers on soil fertility mining to provide for their livelihoods.

Strategies for reducing fertilizer prices need to be sought in order to make it more affordable to the resource-poor farmers. Such strategies include improvement of marketing infrastructure through building and maintaining roads in order to reduce the transportation costs, facilitating input traders by training and offering them credit, waiving some of the taxes levied on input trading businesses, etc. As noted by IFDC (2001), there is also a need to increase the trade relationship between the Ugandan and Kenyan input traders in order to benefit from the economies of scale of the Kenyan fertilizer market. Farmer associations may also help reduce the transaction costs of inputs and outputs. Hence concerted efforts are needed to revive the strong and healthy farmer cooperative unions and associations.

The expensive inorganic fertilizer option needs to be complemented with cultural practices that are affordable, feasible, and compatible with local farming systems. For instance, the present research observed that farmers with more livestock have higher nutrient balances than those with fewer. However, when using organic material to complement inorganic fertilizer, there is a need to weigh the benefits of biomass transfer against the cost of nutrient depletion at the source of organic materials transferred to household crop plots (Palm, et al., 1997). The option of recycling organic material produced on plot is limited by the inadequate production of organic material on plot and competition with other uses. A need to incorporate high-quality legumes such as *Mucuna pruriens* in the farming systems and rhizobial inoculation may greatly improve nutrient balances at a much lower cost (Kaizzi, et al., 2002; Ndakidemi, et al., 2002).

In order to reduce the loss of nutrients through erosion, there is need to promote adoption of soil and water conservation (SWC) methods. In addition to reducing soil erosion, SWC enhances retention of soil organic matter and in some cases includes nitrogen fixing trees and shrubs. Crop biodiversity also appears to retard soil erosion. This suggests that soil fertility technologies developed should also take into account the need for intercropping crops with legumes in order to increase BNF and obtain other benefits of intercropping. As noted by Bekunda, et al. (2002), most fertilizer recommendations are based on mono-crops, while most farmers in Uganda realize the benefits of crop biodiversity and hence intercrop. Hence soil fertility recommendations need to take into account the intercropping practices that farmers normally use.

Emphasis of extension services needs to be directed to both new crop varieties and the fertility problem. Even this may not be a solution in the short term due to the stepwise technology adoption behavior of smallholder farmers. Limited contact with extension agents is likely to lead farmers to adopt high-yielding varieties without fertilizer. This is likely to exacerbate the nutrient mining problem, as observed in this study. This points to the need to increase both the content of extension messages to include a package of seed and fertility-enhancing technologies and to increase contact hours in order to increase the likelihood of adopting both types of technologies.

Our results indicate that farmers in the low agricultural potential areas deplete more soil nutrients than those in high potential areas, as a result of more serious soil erosion and crop residue depletion. This suggests the need to emphasize soil and water conservation practices that would check soil erosion, and a need to discourage farmers from harvesting crop residues.

It appears that non-farm activities contribute to decreasing soil nutrient depletion. Thus, promoting non-farm development may be a “win-win” development strategy, reducing land degradation while helping to improve incomes. In order to increase the competitiveness of non-farm activities, farmers’ skills in making non-farm products need to be increased through training them in polytechnic and vocational schools based in rural areas.

Education also appears to create opportunities for “win-win” outcomes. While education appears to improve soil nutrient balances, our research also shows evidence that better educated farmers are likely to invest less in labor intensive soil-fertility technologies. This suggests the need to introduce agricultural sciences in primary and secondary school curriculum in order to educate future farmers on sustainable crop husbandry practices.

Farmers in high market access areas have lower nutrient balances than those low market access areas. This presents a challenge for both groups of farmers. For the case of farmers in remote areas, they are likely to be faced with high agricultural marketing transaction costs to an extent that it is not remunerative to produce surplus for the market. Such farmers are therefore likely to remain in a vicious cycle of poverty, which poses an enormous challenge to policy makers and development planners. Obviously it is imperative to improve the market access for farmers in remote areas to facilitate their integration in the agricultural market, which is likely to reduce their poverty. Achieving this poses the second challenge whereby, as noted in this study and by Woelcke, et al. (2002), farmers who are more accessible to markets are likely to sell more crops and consequently have lower nutrient balances, which is unsustainable. This challenge may be addressed by promoting increased profitability of soil fertility management technologies by improving the functioning of markets and reducing the input/output price ratio, together with increased extension efforts to persuade farmers to adopt such technologies.

Table 1: Sources of nutrient inflows

Source	Nitrogen Mean Kg ha^{-1}	Nitrogen % of total N inflow	Phosphorus kg ha^{-1}	Phosphorus % of Total P inflow	Potassium Kg ha^{-1}	Potassium % of total K inflow
Mineral fertilizer	7.84	6	3.85	12	0.92	3
Organic fertilizer	1.48	2	0.00	0	0	0
External grazing	8.36	15	0.88	23	8.43	35
Purchased foods	3.62	8	0.32	10	2.08	16
Atmospheric deposition	16.13	20	0.80	42	3.15	36
Symbiotic N-fixation	15.95	26	0.00	0	0	0
Non-symbiotic N-fixation	0.99	4	0.00	0	0	0
Sedimentation	18.16	21	0.43	16	1.31	12
Average total nutrient	85.76		6.22		15.68	

Note: averages for each source are computed from raw data, and not the averages reported in the table. Hence they may not add to exactly 100%.

Table 2: Sources of nitrogen outflows

Outflow channel	Nitrogen Mean	Nitrogen % of Total	Phosphorus Mean	Phosphorus % of Total	Potassium Mean	Potassium % of Total
Crop products	54.01	53	6.79	57	60.32	89
Animal products	0.74	1	0.26	3	0.27	1
Crop residues	1.18	1	0.1	0	0.96	0
Manure	8.33	5	0	0	0	0
Leaching	21.3	24	0	0	0.91	2
Gaseous losses	9.01	8	0	0	0	0
Erosion	10.04	11	9.87	39	3.18	7
Total N outflow	138.11		17.02		65.64	

Table 3: Nutrient Balances in Farm Plots, Eastern Uganda.

	Nitrogen[4]	Phosphorus[4]	Potassium[4]	NPK[4]
% with positive balances	12.07	39.66	34.48	5.17
Mean nutrient balances (kg ha^{-1})	-48.02	-10.80	-51.09	-100.01
Std deviation (kg ha^{-1})	48.20	18.24	82.40	122.79
NDVM (US$)[1]	44.7	11.3	24.3	80.3
Total NDVM (US$) for entire farm[2]	85.00	21.40	46.2	152.6
ENDR (%)[3]	10.7	2.7	5.8	19.2

1. Nutrient deficit market value (NDMV) is the value of nutrients mined per hectare if such nutrients were to be replenished by applying purchased fertilizer (de Pol, 1990).
2. Each household had an average of 1.9 ha.
3. Economic nutrient depletion ratio (ENDR) is an index that shows the share of farmer's income from soil nutrient mining. ENDR = $\frac{NDMV}{GM}$ x 100

   Where GM is the gross margin from agricultural activities per household. Note that de Pol (1990) computes EDNR at per hectare basis. However, this yields the same figure since the numerator and denominator are both multiplied by total crop area. ENDR is the value of mined nutrient for entire farm as % of household income. Household income is estimated to be US$793/year.
4. The cheapest available sources of nutrients are as follows: N = urea (46%N); P = triple super phosphate (45%P) and K = muriate of potash (60%K).

Table 4: FGLS regression of determinants of soil nutrient inflows

Determinant of soil nutrient inflow	Coefficients of source of soil nutrient inflow			
	Chemical fertilizer	External grazing	Purchased food	Ln(biological N fixation)
Ln(family labor)	-0.601	-0.506***	-3.710***	-0.158***
Ln(Distance from residence to parcel)	0.654*	-0.013	-0.767**	-0.0866***
Agricultural potential (Low=1, High=0)	-2.472*	-2.518***	-5.929***	-0.886***
Tropical livestock unit (TLU)[1]	-0.583	-0.241***	4.475***	-0.010
Had extension contact? (yes=1, no=0)	1.451	0.276*	12.820***	0.236***
Education of household head (secondary or higher education=1, otherwise=0)	5.222*	-2.548***	-5.313	-0.352***
Market access (high=1, otherwise=0)	-0.270	-1.387***	-11.261***	0.266***
Crop diversity (# of crops grown)	1.188**	-0.561***	0.219	0.035*
Ln(farm size)	0.620	0.662***	5.302***	0.149***
Off-farm as primary activity of household head? Yes=1, no=0	65.573***	-0.350	10.182***	-0.500***
Constant	-3.003*	7.004***	0.379	3.396***
# of observations (households)	54	54	54	54
Prob > ?^{2}	0.000	0.000	0.000	0.000

Notes: Asterisks denote associated coefficient is significant at: 1% (***); 5% (**) and 10% (*)

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

Table 5: FGLS regression of determinants of soil nutrient outflows

Determinants of soil nutrient outflows	Coefficients for soil nutrient outflows				
	Crop harvest	Animal grazing	Crop residues	Soil erosion	Animal manure exported
Ln(family labor)	10.171	0.066	2.123***	1.689***	1.271**
Ln(Distance from residence to parcel)	1.484	-0.020	0.419***	1.040***	-0.359*
Agricultural potential (Low=1, high=0)	74.602***	-0.113	3.863***	15.053***	-18.289***
Tropical livestock unit (TLU)[1]	-6.917***	0.074*	-0.271***	-1.194***	-1.392***
Had extension contact? (yes=1, no=0)	-5.175	0.209	-1.189**	2.804***	12.651***
Education of household head (secondary or higher education=1, otherwise=0)	-20.313***	-0.026	-0.111	-0.320	-11.890***
Market access (high=1, otherwise=0)	131.321***	0.085	3.755***	28.971***	-20.884***
Crop diversity (# of crops grown)	1.587	0.011	-0.707***	-1.193***	-0.791***
Ln(farm size)	25.201***	0.192	1.770***	0.810	-0.768
Off-farm as primary activity of household head? Yes=1, no=0	49.772***	0.635	0.422	-8.105**	-1.169
Constant	-41.406***	-0.373	-1.774***	1.590	31.566***
# of observations (households)	54	54	54	54	54
Prob > ?^{2}	0.000	0.023	0.000	0.000	0.000

Notes: asterisks denote associated coefficient is significant at: 1% (***); 5% (**) and 10% (*)

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

Table 6: FGLS regression of determinants of soil nutrient balances

Determinant of nutrient balance	Coefficients			
	N balance	P Balance	K Balance	NPK Balance
Ln(family labor)	11.454***	-1.283	-13.456***	-22.837***
Ln(Distance from residence to parcel)	3.980***	0.372	-2.771***	-0.320
Agricultural potential (Low=1, High=0)	21.654***	-15.805***	-101.886***	-50.356***
Tropical livestock unit (TLU)[1]	4.414***	0.838***	3.798***	16.184***
Had extension contact? (yes=1, no=0)	-17.947***	-1.081	23.733***	-25.228**
Education of household head (secondary or higher education=1, otherwise=0)	13.005	4.986	-13.338	37.111**
Market access (high=1, otherwise=0)	-22.527***	-22.192***	-107.988***	-125.400***
Crop diversity (# of crops grown)	-0.163	1.572***	-5.556***	8.825***
Ln(farm size)	6.178**	-2.836***	-9.376**	-28.820***
Off-farm as primary activity of household head? Yes=1, no=0	50.443***	12.097***	-8.547	28.715**
Constant	-74.954***	7.181	139.847***	-31.838***
# of observations (households)	53	39	40	54
Prob > ?[2]	0.000	0.000	0.000	0.000

Notes: asterisks denote associated coefficient is significant at: 1% (***); 5% (**) and 10% (*)

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

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