Determinants of Soil Nutrient Balances and Implications For Addressing Land Degradation and Poverty in Uganda

By

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Introduction

Soil erosion and soil nutrient mining are the leading causes of land degradation in Uganda (NEMA; Zake, et al.). Declining crop yield has manifested the impact of land degradation (Bekunda; Woomer et al.; Wortmann, and Kaizzi). Consequently per capita food production in Uganda has been falling in the past 16 years, despite the expanding crop acreage (Mungyereza; NEMA; UBOS, 2001). This trend has put at stake livelihoods of over 90% of Ugandan farmers.

Soil fertility mining in Uganda is among the highest in Sub-Saharan Africa (SSA), with an estimated average annual nutrient depletion of 70kg of nitrogen (N), phosphorus (P) and potassium (K) (Stoorvogel and Smaling; Wortmann, Kaizzi). The effect of the consequent soil fertility mining is a downward spiral of soil fertility, which makes the current low-external input crop production unsustainable.

A number of studies have measured or developed methods of measuring soil nutrient flow in SSA (Defoer, et al.; de Jager et al., 1998a & 1998b; Smaling, Stoorvogel and Windmeijer; Stoorvogel, Smaling and Windmeijer; Stoorvogel,and Smaling; van den Bosch, et al.; Wortmann, and Kaizzi). In this study, we define soil nutrient flow as the amount of plant nutrients that flow in and out of a system or area. We will refer to the difference between nutrient inflow and outflow as "nutrient balance." Nutrient flow may be measured at different scales, namely, plant, plot, household, water catchment, village, district, national, or higher level (Smaling, Stoorvogel and Windmeijer). Another set of studies has evaluated the impact of land management practices on crop production, profitability and sustainability (Shepherd, and Soule; van der Pol). A third group of studies has analyzed the factors that determine adoption of improved land management practices in general (e.g. Grepperud; Pagiola; Tefera, et al.). A fourth set of studies consists of soil science experiments that analyze the biophysical factors that influence soil nutrient balances or its components (e.g. Bruce, et al.; Defoer, et al.; Giller, et al.,; Ikera, et al.; Keeney; Ndakidemi, et al.; Palm, et al.; Sanchez, et al.). These biological studies do not analyze socio-economic factors that impact nutrient balances.

No study known to the authors has done a combined analysis of physical, biological and socio-economic factors that determine the nutrient flow and balances at household level and this study attempts to fill this gap. The focus of this study on determinants of nutrient balance only, as opposed to land management in general, will help to better understand strategies to address soil nutrient depletion, which is one of the most important land degradation problems in SSA. Therefore, the main objectives of this study are to identify and analyze the socio-economic and biophysical determinants of soil nutrient flow; to discuss the policy implications of the findings; and to suggest policies and strategies that may be used to address the soil nutrient depletion problem.

The model

Factors that are likely to determine soil nutrient flow and balances can be, divided into two major groups: (i) biological and ecological (biophysical) factors, and (ii) socio-economic factors (Harrison and Tisdale). The biophysical factors are, climate, biological, physical and chemical characteristics of the soil, topography, altitude, temperature, and biodiversity (Bruce, et al.; de Jager, et al., 1998a; Giller; Keeney). Biophysical factors determine the agricultural productivity potential of the soil. Biophysical factors influence nutrient balances in many ways. For example 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.; Wortmann and Kaizzi). Topography affects soil erosion, agricultural activities, vegetation, and biological processes (Voortman, et al.).

The socio-economic factors that directly influence soil nutrient flows are: fertility management practices, level of crop-livestock interaction, (De Jager, et al., 1998a; Keeney) and the level of importation and exportation of soil nutrients through crop and livestock product sales and purchases. Other socio-economic factors that are likely to affect soil nutrient balance are household endowment (physical assets, human, financial and social capital); household income activities (sources of income), land tenure, market access, population pressure; and policies and institutions (Boserup; Herweg; Mungyereza; Pender et al.; Sserunkuuma, et al.). The socio-economic factors interact with the biophysical processes, thereby influencing the nutrient flow directly and indirectly. Even though we will analyze and discuss most of these factors, our focus will be on the socio-economic factors since policy intervention may be used to influence them.

Our analysis of the determinants of nutrient flow focuses on inflows and 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 use of mineral fertilizers, organic inputs from outside the farm, off-farm grazing, purchased food, and

BNF. The nutrient outflows under farmers' control are exporting harvested crop products and residues, soil erosion, and exporting animal products and manure. The determinants of these soil nutrient flows will be analyzed using econometric procedures. The determinants of the overall nutrient balances for the major macronutrients, namely nitrogen, phosphorus, and potassium, will also be analyzed.

As discussed earlier, the major determinants of land management and hence soil nutrient balances can be categorized into two major groups, biophysical and socio-economic factors. Since we are using a small sample, we estimate a reduced econometric model in order to have a fair number of degrees of freedom. The biophysical factors will be represented by one variable namely, agricultural potential. The sample households are divided into two agricultural potential zones, namely high potential zone with rainfall above 1500 mm per year, and low potential zone with rainfall below 1500 mm per year. The socio-economic factors will be modeled using the following variables: policies and institutions, which will be represented by market access and access to extension services; human capital (family labor and education), and household physical assets (farm size and distance of parcels from homestead, size of livestock herd - measured in Tropical Livestock Units (TLU). A standard animal with live weight of 250 kg is called TLU (Defoer, et al.). Average TLU for each livestock category is: Cow = 0.9, oxen = 1.5, sheep or goat = 0.20, and calf = 0.25. Other socio-economic factors include primary activity of income household head, and crop diversity, which is the number of crops grown in a given unit area. Large number of crops grown per unit area, as is the case with perennial crop systems in Uganda, is associated with better soil cover, hence less soil erosion.

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

$In_i = f(\mathbf{x_1 b_1} + e_1)$ ……………………………(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 inputs, off-farm grazing, purchased food and BNF;

Out_i is channel i of nutrient outflow, namely exported crop products and residues, exported animal products and manure, excrements of animals while grazing off-farm; and soil erosion;

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

$\mathbf{x_i}$ is column vector of factors that affect nutrient flows 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.

Data:

Fifty eight farmers were randomly selected from four villages in eastern Uganda to collaborate in a soil fertility experiment and a household survey. The biophysical characteristics of farm soils were determined by lab analysis of soil samples collected from a depth of 0-20 cm. The pH, Organic matter, N, extractable P, exchangeable K and Calcium, and texture were measured using the routine soil sample lab analytical method according to Foster.

Information on farm management practices; crop-livestock interaction; crop diversity; and other variables that affect nutrient flow was obtained from the household and plot level surveys. These data were used to determine annual 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 for one year. We will restrict our analysis to the three major macronutrients, i.e. N, P, K. The sources of inflows and outflows used in this study are according to de Jager, et al. (1998a) and Smaling, Stoorvogel and Windmeijer. The nutrient inflows are mineral fertilizers, organic inputs from outside the farm, grazing outside the farm (off-farm grazing), purchased food, atmospheric deposition, biological nitrogen fixation (BNF), and sedimentation.

Contribution of soil nutrient inflow from purchased foods is computed on the assumption that household waste will be disposed on crop plots around or near the homestead. Household waste include human waste, organic residues from in and around the house such as ash from fuelwood and other cooking and heating bio-energy, food leftovers, bran from pounded cereals, peelings, etc. Farmers were asked to explain how they manage household wastes and then their contribution to soil nutrient inflow was computed accordingly. Thus, contribution of household waste to nutrient inflow varied from one household to another.

The major sources of outflows are: exported crop products, leaching, soil erosion, exported animal products, excrements of animals grazing off the farm and exported manure, crop residue, and gaseous losses. Amount of nutrient outflow was computed using the same method as the equivalent inflows. For more details on how soil nutrient inflows and outflows were measured, see Nkonya, et al.

Estimating the economic impact of soil nutrient depletion on agricultural productivity loss would be interesting. However, there are no studies known to authors that have measured agricultural productivity loss due to soil nutrient depletion. We therefore use a simpler measure to estimate this impact. This measure is called the economic nutrient depletion ratio (ENDR) (van der Pol). ENDR is the share of farmers' income derived from mining soil nutrients. Soil nutrient mining is the practice of growing crops with insufficient replacement of nutrients taken up by crops. Mathematically,

$$\text{ENDR} = \frac{NDMV}{GM} \text{ x } 100$$

where: (NDMV) is nutrient deficit market value, which is the value of nutrients mined per hectare if such nutrients were to be replenished by applying fertilizer purchased from the cheapest sources.

GM is the gross margin from agricultural activities per household.

ENDR measures the cost of replenishing nutrient depleted, and not the benefit. The ENDR will also be used as a measure of soil nutrient depletion or level of sustainability of land management practices.

Explorative analysis of the data was used to determine the distribution of the variables and violation of regression assumptions. Data with non-normal error terms or those with 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) method was used to estimate asymptotically efficient parameters.

Results and discussion

***Descriptive statistics*:**

Only 5% of the sampled households had positive total NPK balances (Table 1). The rest of the farmers used land management practices that appear unsustainable for the one-year period considered. However, negative balances are possible over a number of years because plants use nutrients from the available stock of nutrients. If soil nutrients are not replenished, the supply from the available stock will decrease with time. The decline in the nutrient pool will lead to decrease in crop yield, which in turn will reduce the rate of nutrient depletion since there is less outflow through exported crop products. The negative balance over many years is manifesting itself as declining crop yield reported in eastern Uganda (Wortmann and Kaizzi). In more degraded areas, the rate of nutrient depletion may be lower, and eventually reach an equilibrium, but at very low yields, which may not sustain household food needs. However the time for this to appear will depend on the nutrient stock.

Our estimates of nutrient balances are fairly consistent with other studies in Uganda, both using national scale data (Stoorvogel, and Smaling) and another study of household level depletion in the same farming systems and region as our case study, i.e. maize system in eastern Uganda (Wortmann, and Kaizzi).

If inorganic fertilizer were used to restore the mined nutrients, it would cost an equivalent of a fifth of the farm income, which is estimated at US$823/household per year. That is, the ENDR, which shows the share of farm income that is derived from mining soil nutrients, is about one fifth of farm income. This implies that if farmers were to use inorganic fertility such that they produce at zero nutrient balance, their farm income would be reduced to 80%. However, application of fertilizer in the study area leads to substantial yield increase (Kaizzi, et al.). Thus, if weather conditions remain constant, crop yield is likely to increase where fertilizer is applied such that farmers produce at zero nutrient balance. Consequently, farm income will increase if crop market prices remain constant. Hence the large investment required to address soil nutrient depletion may be critical only in the first year if weather and market conditions remain constant.

Econometric results

Determinants of Nutrient Inflows: Human and financial capital; technical assistance; distance from plot to residence; agricultural potential; market access; crop diversity; farm size and participation in non-farm activities are important determinants of nutrient flows and balances. For all four major inflow sources that the farmer has control over--chemical fertilizer, off-farm grazing, purchased food and BNF—more family labor availability reduces nutrient inflows (Table 2).

The average distance from the farmer's residence to her parcels significantly reduces the inflow from purchased food and BNF. These results suggest that farmers with distant plots are likely to be subsistence farmers, buying less food from the market. The negative relationship between BNF and distance to parcel is due to the statistically significant negative relationship between distance from homestead to parcel and the probability to plant leguminous crops, which contribute to BNF.

The inflows from off-farm grazing, purchased food, and BNF decrease as one moves from high to low agricultural potential zone. The negative association between off-farm grazing and agricultural potential is perhaps due to the low biomass potential in the low agricultural potential zone that leads to low quality and quantity of pasture. In the case of negative association between purchased food and agricultural potential, farmers living in the low agricultural potential zone are more subsistence-oriented households due to low crop productivity in such areas - hence lower income and ability to afford buying food. The negative relationship between agricultural potential and BNF was also expected since dry conditions limit BNF (Giller, et al.).

Ownership of livestock (as measured by TLU) reduces the nutrient inflows from off-farm grazing but increases inflows from purchased foods. It is not clear why TLU is negatively associated with inflow from off-farm 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 have less time for crop production to meet their subsistence needs.

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). For example, our data show a positive association between extension contact hours and the probability to grow coffee. There are "subject matter specialists" who are hired by crop authorities to provide extension services specifically for export crops, namely coffee, cotton and tobacco. Certainly this increases the contact with extension agents for export crop farmers. 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 off-farm grazing and BNF. Nkonya, et al., 2004 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 theory that education increases farmers' opportunities to be engaged in non-farm activities. Such options may reduce farmers' incentive to invest efforts in BNF-enhancing technologies or grazing animals. Improved market access significantly reduces inflows from off-farm grazing and purchased foods. Reduced inflow from off-farm grazing may be due to the demand for crop residue and pasture and lack of communal grazing land due to high population pressure in high market access areas.

The likely explanation for the negative impact of market access on nutrient inflows from purchased food is that farmers in high market access areas are surplus producers hence have less need to buy large quantities of food to supplement their own production. This explanation appears to be supported by the large positive effect of market access on nutrient outflows through exported crop products (Table 3). The nutrient inflow from BNF is also higher in high market access than in low market access areas. 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 areas that gives farmers an incentive to plant more legumes for sale. Beans and other pulses are in high demand in urban areas since they are cheap compared to meat - hence major sources of protein for the poor urban population in eastern Africa (CIAT ; Pachico, 1993).

Controlling for TLU, farm size and other factors, crop diversity decreases soil nutrient inflows from off-farm grazing but increases inflows from chemical fertilizer. This is likely due to the limited space for off-farm 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, higher crop diversity is probably associated with mixed perennial-annual crop systems that include maize, which is the most fertilized crop (Nkonya, et al., 2002).

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, farm size increases nutrient inflows from off-farm grazing (controlling for TLU). This may be due to presence of communal grazing lands in low populated areas where farms are larger. 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, non-farm activities increase nutrient inflows from chemical fertilizer and purchased food but reduces BNF. Farmers having non-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 non-farm activities and BNF may be due to less investment in BNF-enhancing management practices by farmers having non-farm activities due to their higher labor opportunity costs.

Determinants of Soil Nutrient Outflows: Family labor increases nutrient outflows from exported crop residues, soil erosion and exported animal excrement and manure (Table 3). Larger farm households may have more labor to harvest and sell crop residues and greater need for cash. The positive association between family labor and outflows from soil erosion suggests that households with larger family labor use more labor-intensive and erosive practices such as more tillage or frequent weeding. This is consistent with Nkonya et al., (2004) who observed a positive association between family size and soil erosion.

The average distance from residence to the farmer's parcels increases nutrient outflows from crop residues and soil erosion. This 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., (2004) show that farmers are less likely to apply manure, compost, mulch or household residues, and are more likely to use slash and burn during land preparation on distant parcels.

Nutrient loss through exportation of crop products and residue 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 exportation of animal manure is less in low potential areas than in high potential areas. The negative association between agricultural potential and nutrient loss through exportation of crop products was contrary to a priori expectation. We expected high yields in the high potential areas, hence likelihood of exporting more agricultural surplus. This observation may be due to tendency of the poor farmers in marginal areas to sell agricultural products and their residues due desperate need for cash.

The negative association between exportation of nutrients through crop residues and agricultural potential may also be explained by fuelwood shortage in low potential areas, which forces farmers to use crop residues for cooking. 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.

The positive association of agricultural potential and nutrient loss through exportation of animal excrement and 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., 2004). 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.

TLU significantly reduces nutrient losses through exportation of crop products and 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. For instance, Tefera, et al. observed that croplands are more vulnerable than pastureland to soil erosion because croplands are repeatedly tilled and left without adequate vegetative cover. However, nutrient loss through animal grazing increases slightly with TLU perhaps because having large TLU increases the probability for a farmer to live in an area where many other farmers raise equally large number of livestock. This in turn increases the probability for neighbors' livestock to feed on farmer's fields.

Contact with extension agents reduces nutrient losses through crop residues, perhaps due to the extension messages that advise farmers not to remove 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. 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 for all four channels of outflow but only losses through exportation of crop products and animal manure are statistically significant. The negative association of nutrient loss through exportation of crop products and level of education of household head suggests that better educated farmers are likely to export less nutrients through crop product exportation since they produce less crops for sale. This is consistent with Nkonya et al. (2004) who showed that better educated farmers use less intensive land management practices, which in turn lead to lower yields. As observed earlier, better-educated farmers also have the opportunity to be engaged in non-farm activities, which compete for labor with agricultural production. This also leads to less crop production and hence less marketable surplus under imperfect labor market condition.

Better market access increases nutrient loss through exportation of crop products and 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 also more likely to find a market in urban areas 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 high market access areas is too expensive to use animal manure. Nkonya et al. (2004) also showed that farmers in the high market access areas use less household waste on their farms.

As expected, crop diversity reduces nutrient loss by reducing soil erosion since it increases soil cover, hence likely to retard soil erosion. Our data show a strong association between crop diversity and the probability to plant perennial crops. This is expected as farmers who grow coffee and banana always plant companion crops such as pulses. The resulting improved soil cover retards erosion in areas with coffee/banana cropping systems. Crop diversity also reduces exports of crop residue and manure. This is due to greater need for using crop residues for mulching and manure for applying on banana/coffee plots, the cropping system that has the highest crop diversity.

Farm size increases soil nutrient loss through greater export of crop products and residue because larger farms produce larger surpluses for sale or giving away. Participation in non-farm activities leads to higher losses of nutrients through crop product exportation but reduces nutrient loss through soil erosion. These results support the findings in Table 2 where we observed that non-farm activities enhance use of chemical fertilizer, which in turn increase crop yield and hence nutrient loss through exportation of crop products. It is also possible that farmers with non-farm income sources are well-off (Barrett, Reardon and Webb) and hence sell more crops that they produce in order to buy food products that they do not produce. Results on association of soil erosion and non-farm income are consistent with Nkonya et al. (2004) 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 since farmers using slash and burn are in areas with better vegetative cover – hence less erosion.

Determinants of N, P, K and NPK Balances: After studying the determinants of the inflows and outflows, we turn to the analysis of 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 overall NPK balances (Table 6). This is due to its negative effect on most nutrient inflows and positive effect on most outflows, as discussed above. 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 2). However, it is uncommon for farmers to apply potassium-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. This follows from the results reported in Table 2 and 3 and Nkonya et al. (2004) 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. also observed similar results.

TLU increased significantly the balances for N, P, K and NPK. As noted in the nutrient flow analysis, farmers with more livestock also export less nutrients through marketed crop surplus and residues, and have less soil erosion (Table 3). Farmers with more livestock also import more food, which increases nutrient inflows (Table 2).

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, whereby the farmers adopt improved crop varieties without applying fertilizer. To verify this, we ran a regressions for nutrient balances of N, P, K and NPK including a quadratic specification of extension contact hours ((ext) and $(ext)^2$) as explanatory variables. 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. 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. Currently, access to extension services is poor. 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. MAAIF and MFPED and UBOS (2002) also note the inadequate extension services in most districts of Uganda. Only 11.4% of households received extension services in 1998. Hence, at low number of extension contact hours, as is the case now, farmers are likely to adopt improved crop varieties without soil fertility technologies.

The present research suggests that inadequate extension services are likely to initially 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 (personal communication, 2002) noted that farmers complained that productivity of plots previously planted with improved varieties decreased substantially. Controlling for non-farm activities and other factors, farmers having secondary or higher education have higher nutrient balances than those with lower education. This follows from the soil nutrient flow results and 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 can be explained by the outflow results (Table 3), which show market access increases nutrient loss through exportation of crop products and residues, and soil erosion. This observation supports Woelcke, et al. 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; and Lipton. These findings call into question the assumption of the Plan for Modernization of Agriculture (PMA) that improvement in infrastructure and markets will not lead to 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 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 3) and increases probability of application of chemical fertilizers (Table 2). 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 from small farms.

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. Though the paper generated interesting results, the sample of 58 households used in this paper is small and it forced authors to estimate reduced econometric equations in order to have reasonable degrees of freedom. 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 in eastern Uganda practice sustainable land management. This confirms the serious soil nutrient depletion, whose value of replenishment is about 20% 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, at least in the short-run. 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. The expensive inorganic fertilizer technology 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.

In order to reduce the loss of nutrients through erosion, efforts to promote adoption of soil and water conservation (SWC) methods need to be increased. Crop diversity 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., most fertilizer recommendations are based on mono-crops, while most farmers in Uganda realize the benefits of crop diversity and hence intercrop. Hence soil fertility recommendations need to take into account the intercropping practices that farmers normally use.

We note in the present research that limited contact with extension agents is likely to lead farmers to initially adopt high-yielding varieties without fertilizer. Hence 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 run due to the stepwise technology adoption behavior of smallholder farmers and limited resources to hire more extension officers. This points to the need for the few extension agents to increase the content of extension messages to include seed and fertility-enhancing technologies. In the long run, more extension agents need to be hired in order to increase contact hours, which in turn will 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 exportation of crop products and residue. 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. The low agricultural potential areas should also be regarded as environmentally fragile, hence targeted for soil and water conservation campaigns.

It appears that non-farm activities contribute to decreasing soil nutrient depletion. Thus, promoting non-farm activities may be a "win-win" development strategy, reducing land degradation while helping to improve incomes. 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 improve soil nutrient balances. However, education also reduces the probability to adopt labor-intensive technologies that improve nutrient balances. 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 in low market access areas. Market improvement should be accompanied with efforts to improve extension and other agricultural services such that it does not lead to more severe nutrient depletion.

Table 1: Nutrient Balances in Farm Plots, Eastern Uganda.

Soil Nutrient	Share of Farmers with positive nutrient balances	Mean nutrient balance	Std deviation of nutrient balance	Economic nutrient depletion ratio (ENDR)
	%	-- Kg per hectare --		%
Nitrogen	12.07	-48.02	48.20	10.70
Phosphorus	39.66	-10.80	18.24	2.70
Potassium	34.48	-51.09	82.40	5.80
NPK	5.17	-100.01	122.79	19.20

Table 2: FGLS regression of determinants of soil nutrient inflows

Determinant of soil nutrient inflow	Coefficients of source of soil nutrient inflow			
	Chemical fertilizer	Off-farm grazing	Purchased food	Ln(BNF)
Ln(family labor)	-0.60	-0.51***	-3.71***	-0.16***
Ln(Distance from residence to parcel)	0.65^z	-0.01	-0.77**	-0.09***
Agricultural potential (Low=1, High=0)	-2.47^z	-2.52***	-5.93***	-0.89***
Tropical livestock unit (TLU)[1]	-0.58	-0.24***	4.48***	-0.01
Had extension contact? (yes=1, no=0)	1.45	0.28*	12.82***	0.24***
Education (secondary or higher education=1, otherwise=0)	5.22^z	-2.55***	-5.31	-0.35***
Market access (high=1, otherwise=0)	-0.27	-1.39***	-11.26***	0.27***
Crop diversity (# of crops grown)	1.19*	-0.56***	0.22	0.04**
Ln(farm size)	0.62	0.66**	5.30***	0.15***
Primary activity (non-farm=1, otherwise=0	65.57***	-0.35	10.18***	-0.50**
Constant	-3.00^z	7.00***	0.38	3.40**
# of observations (households)	54	54	54	54
Prob > χ^2	0.000	0.000	0.000	0.000

Notes: Asterisks denote associated coefficient is significant at: P<0.05 (*); P<0.01 (**) and P<0.001 (***)
^{z} Implies associated coefficient is significant at P<0.100

Table 3: FGLS regression of determinants of soil nutrient outflows

Determinants of soil nutrient outflows	Coefficients for soil nutrient outflows				
	Exported crop products	Exported crop residues	Off-farm animal excrement	Animal manure exported	Soil erosion
Ln(family labor)	10.17	2.12***	0.07	1.27**	1.69**
Ln(Distance from home to parcel)	1.48	0.42**	-0.02	-0.36*	1.04***
Agricultural potential (Low=1, high=0)	74.60***	3.86***	-0.11	-18.29***	15.05***
Tropical livestock unit (TLU)[1]	-6.92***	-0.27***	0.07*	-1.39***	-1.19***
Had extension contact? (yes=1, no=0)	-5.18	-1.19*	0.21	12.65***	2.80***
Education (secondary or higher education=1, otherwise=0)	-20.31**	-0.11	-0.03	-11.89***	-0.32
Market access (high=1, otherwise=0)	131.32***	3.76***	0.09	-20.88***	28.97***
Crop diversity (# of crops grown)	1.59	-0.71***	0.01	-0.79*	-1.19***
Ln(farm size)	25.20***	1.77***	0.19	-0.77	0.81
Non-farm as primary activity of household head? Yes=1, no=0	49.77***	0.42	0.64	-1.17	-8.11**
Constant	-41.41***	-1.77**	-0.37	31.57***	1.59
# of observations (households)	54	54	54	54	54
Prob > χ^2	0.000	0.000	0.023	0.000	0.000

Notes: Asterisks denote associated coefficient is significant at: P<0.05 (*); P<0.01 (**) and P<0.001 (***)

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)	11.45***	-1.28	-13.46**	-22.84***
Ln(distance from home to parcel)	3.98***	0.37	-2.77**	-0.32
Agricultural potential (Low=1, High=0)	21.65***	-15.81***	-101.89***	-50.36***
Tropical livestock unit (TLU)	4.41***	0.84***	3.80***	16.18***
Had extension contact? (yes=1, no=0)	-17.95***	-1.08	23.73***	-25.23*
Education (secondary or higher education=1, otherwise=0)	13.01	4.99	-13.34	37.11*
Market access (high=1, otherwise=0)	-22.53***	-22.19***	-107.99***	-125.40***
Crop diversity (# of crops grown)	-0.16	1.57***	-5.56**	8.83**
Ln(farm size)	6.18*	-2.84***	-9.38*	-28.82**
Primary activity (non-farm=1, otherwise=0)	50.44***	12.10***	-8.55	28.72**
Constant	-74.95***	7.18	139.85***	-31.84*
# of observations (households)	53	39	40	54
Prob > χ^2	0.000	0.000	0.000	0.000

Notes: Asterisks denote associated coefficient is significant at: P<0.05 (*); P<0.01 (**) and P<0.001 (***)

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