Resource flows and nutrient balances in smallholder farming systems in Mayuge District, Eastern Uganda

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Abstract

Resource flows and farm nutrient balance studies were carried out in eastern Uganda to ascertain the movement of organic resources and nutrients in and out of the farm system. Resource flow mapping was conducted during a participatory learning and action research (PLAR) process. The resource flows were transformed into nutrient flows and partial nutrient balances were calculated for the crop production, animal production, household and out of farm systems using the Resource Kit computer package. Results of a farmers' soil fertility management classification at the start of the PLAR intervention in 1999 revealed that 3% of the farmers were good soil fertility managers, 10 % were average soil fertility managers (class II) and 87% were poor soil fertility managers (class III). There was a strong relationship between wealth ranking according to the farmers' own criteria and soil fertility management classification. Soil chemical and physical properties of the soils in the three soil fertility management classes did not differ significantly despite the differences perceived by the farmers. The study revealed that very low quantities of resources and nutrients enter the farm system, but substantial amounts leave the farm in crop harvests. The main source of nutrients on the farm is the crop production system and the major destination is the household system. The livestock component contributed little to the flow of nutrients in the farm system due to the low levels of livestock ownership. The results indicate that the net farm nutrient balances kg ha^{-1} per season for all the nutrients (N, P, and K) were negative for both the good and the poor soil fertility managers. Class 1 farm balances irrespective of the season, were however more negative than those of class 3 farms. For the long rains seasons (LR 2000,2001 and 2002), the average net farm nutrient balances for N, P, and K for class I farms were -5.0, -0.6 and – 8.0 kg ha^{-1} year^{-1}, while for the short rains seasons (SR 2000 and 2001), the nutrient balances were –3.5, - 0.5 and -6.0 kg ha^{-1} year^{-1} respectively. For the class III farms, the average net farm nutrient balances for N, P, and K in the long rain seasons (LR 2000,2001 and 2002) were –3.3, -0.3 and –4.0 kg ha^{-1} year^{-1} while for the short rains seasons (SR 2000 and 2001), the nutrient balances were –3.5, 0.5 and –5.0 kg ha^{-1} year^{-1} respectively. The partial nutrient balances for the various subsystems in the short rains for class 1 farmers were lower than those of the long rains season. Significant nutrient loss occurred in the crop production system as almost no nutrients return to the system. Potassium export from the farm was severe especially for farmers who sell a lot of banana. Soil management interventions for these small-scale farmers should aim at reversing nutrient depletion with a focus on profitable management of the crop production system, which is the major cause of nutrient depletion. Strategic management of nutrients that enter the household system such as through home gardening and composting near the household would greatly increase the return of nutrients to the crop production system.

Keywords:

Farm classification, farming systems, nutrient balances, resource flows, soil fertility, eastern Uganda.

Introduction

Soil nutrient balance studies in Africa show evidence of widespread nutrient mining leading to severe nutrient deficiencies across ecological zones. Soil nutrient stocks are not static entities and studies in different parts of Africa at different spatial scales show that nutrients are being depleted at alarming rates (Stoovogel and Smaling, 1990; Van der Pol, 1992; Smaling *et al*., 1993; Smaling and Braun, 1996; Smaling *et al*., 1997; Scoones, 2001). Nutrients are annually taken away in crops or lost in processes such as leaching and erosion which far exceed the nutrient inputs through fertilisers, deposition and biological fixation (Smaling and Braun, 1996). Nutrient mining has been estimated to average 660 kg of nitrogen (N), 75 kg of phosphorus (P) and 450 kg of potassium (K) per hectare per year during the last 30 years from about 200 million hectares of cultivated land in 37 countries in Africa (Stoorvogel and Smaling, 1990; Sanchez *et al*., 1997; Smaling *et al*., 1997). Losses of 130 kg N, 5 kg P and 25 kg K ha^{-1} per year have been reported in the East African highlands (Smaling *et al*., 1997). Wortmann and Kaizzi (1998) estimated nutrient balances for small-scale farming systems in eastern and central Uganda to be negative for all crops except for nitrogen (N) and phosphorus (P) in the banana-based land use type (LUT).

The concern for soil nutrient depletion and low soil fertility has led to the development of several integrated soil fertility management technologies that offer potential for improving soil fertility management in Africa (Scoones and Toulmin, 1999). These include improved soil erosion control using living barriers or micro-catchments, inoculation of grain legumes for improved N-fixation, efficient use of manure and other locally available organic materials, use of green manure and cover crops (Delve and Jama, 2002) and use of low levels of N and P fertilisers on maize and beans (Wortmann *et al*., 1998; Wortmann and Kaizzi, 1998) in eastern Uganda. There are a limited number of long-term studies monitoring the nutrient status of soils, nutrient balances, and crop productivity in Uganda (Bekunda *et al*., 1997; Swift *et al*., 1994). It is important to calculate and monitor nutrient flows to quantify the impact of INM systems on soil fertility and sustainable agricultural productivity (Smaling and Braun, 1996; Defoer *et al*., 2000). Monitoring of nutrient stocks and flows is a tool for assessing the degree of nutrient mining in an agro-ecosystem. When applied to systems where INM practices are being introduced, nutrient monitoring can be used to assess the effects of INM strategies on soil nutrient stocks and flows (Van den Bosch *et al*., 1998). However, there has been limited uptake of these "improved" INM practices. Improved soil nutrient management is important for maintaining and improving soil productivity in Uganda and strategies are required that more closely address farmer requirements and priorities (Deugd *et al*., 1998). This study used resource/nutrient flows to work with farmers to better understand their current practice, their constraints and their opportunities for reversing nutrient depletion. Therefore, the objectives of this study was to determine resource flows and estimate nutrient balances in three different farm typologies and to investigate if improved soil fertility management impact on sustaining agricultural productivity on the smallholder farms in Eastern Uganda

Materials and Methods

Characteristics of the farming system

A study was carried out in three villages of Magada, Kavule and Buyemba in Imanyiro sub-county of Mayuge District in Eastern Uganda. This area is located at 0^0 35^1N, $32^0 29^1$ E and lies at an altitude of 1070-1161 m.a.s.l (meters above sea level) covering an area of about 11,113 km ^{2}. The area has a bimodal rainfall pattern varying from 1250 to 2200 mm (average

1345 mm for 22 years) per annum. The first rains (long rain (LR) season) occur between March and June and the second rains (short rain (SR) season) between August and December. The soils are reddish brown sandy loams and sandy clay loams on red (gritty) clay loam and laterite (Harrop, 1970) and classified as Orthic Ferralsols (FAO, 1977). Most soils in the area have an average organic matter content of 1.1 - 3.1 % but are deficient in N and P (Fischler, 1997; Wortmann and Kaizzi, 1998). The farming systems show a high degree of biological and agronomic diversity and complexity. Average farm size is 1.8-2.0 ha and 90 % of the farmers are the sole owners of the land. The main crops grown in the area are bananas, maize, cassava, beans, coffee, fruits, vegetables and sweet potato (Esilaba *et al*., 2001b; Woelcke and Berger, 2002). The majority of the farms have few or no livestock and the mean numbers are 1.5 local cows, 0.2 improved cows, 1.7 goats or sheep, 0.9 pigs and 12.0 chickens per farm (Wortmann *et al*., 1998; Wortmann and Kaizzi, 1998).

The PLAR process

A Participatory Learning and Action Research (PLAR) process (Defoer *et al*., 2000) was initiated in September 1999 in Imanyiro sub-county, Mayuge District. The PLAR process comprises four phases: diagnosis and analysis, planning, implementation and evaluation. During the diagnostic phase of the PLAR process, farmers analysed soil fertility management diversity and resource endowment of farms in Buyemba, Kavule and Magada villages (Esilaba *et al*., 2001b). The soil fertility management diversity classification were standardised into three categories (good, average, and poor managers) and were attributed to: 1) use of fertilisers (both organic and inorganic), 2) use of soil erosion control measures, such as vetiver grass strips, terracing and mulching, 3) use of green manure, such as mucuna, canavalia, crotalaria and lablab, 4) leaving land to fallow and 5) use of agroforestry technologies. Farms/households using four or more of these measures were considered “good” (class I). Farms using one to three measures were considered “average” (class II), while those farms not using any of these measures were considered “poor” (class III).

Twenty farmers representing the three soil fertility management classes in the three villages were selected as test farmers for intensive monitoring, on-farm experimentation and resource flow mapping. Soil samples were collected from the test farms for laboratory analysis according to Foster (1971) and Okalebo *et al*., (1993).

Resource flow- mapping

Resource flow maps were used to visualise the farmers’ soil fertility management situation of the farm during of the PLAR process. The selected farmers drew resource flow maps (RFMs) to visualise, plan and analyse their current, planned and implemented soil fertility management practices and to identify possible improvements at the beginning and end of each season. Test farmers from the three soil fertility management diversity classes drew resource maps indicating the different elements of their farms, including fields, food stores, livestock shelters, compost pits, etc (Budelman and Defoer, 2000a). The current and preceding crops were noted for each field and farmers drew arrows to show the flows of resources entering and leaving the farm as well as flows between fields and other farm components (Figure 1). Farmers estimated the quantity of resources using simple local units of measurement (such as tins, debes, piece meals etc.) and labelled the direction of flow of the resources accordingly using appropriate arrows and symbols. Similar information was recorded on several recording forms relating to 1) farm level data, 2) field level data and to various flows, 3) resources leaving the fields: produce and crop residues; 4) resources entering the fields (fertilisers); 5) resources leaving the household and animal production system; 6) resources entering the household and animal production system and fed into a computer using the Resource Kit software for analysis (Defer *et al*., 2000). Nutrient flow analysis was used in evaluating land use, the relative intensity of cropping, the ratios between inputs and outputs and comparing systems along these lines (Budelman and Defoer, 2000a). The unit of analysis was the farm system, which is part of the village land use system (consisting of several farms and communally used resources). There are three sub-systems within the farm: the crop production system (CPS), the animal production system (APS), and the household system (HHS). For each of the sub-systems, links with the elements outside the farm system are presented as IN for flows entering the farm from outside, and OUT for flows leaving the farm. Links between the sub-systems of the farm are presented as (INT); referring to internal flows (Defoer *et al*., 1998). The resource flows are presented in Table 1. After five seasons of experimentation and resource flow mapping, farmers evaluated themselves to establish a continuum as to whether they had moved from one soil fertility management class to another or remained in the same class and establish factors that led to these scenarios (Table 2).

Results

Soil fertility management diversity classification

Farmers together with a multidisciplinary team consisting of researchers, extension agents and NGOs established and monitored soil fertility management diversity among farmers from November 1999 to November 2002 in three villages of Buyemba, Kavule and Magada. Soil fertility management diversity among households was identified by farmers and attributed to: use of fertilisers (both organic and inorganic), use of soil erosion control measures, such as vetiver grass strips, terracing and mulching, use of green manure, such as mucuna, canavalia, crotalaria and lablab, leaving land to fallow, agroforestry (Esilaba *et al*., 2000). Farms/households using four or more of these measures were considered “good” (class I). Farms using one to three measures were considered “average” (class II), while those farms not using any of these measures were considered “poor” (class III). Out of a total of 569 households only 20 (3.5%) were in class I, 55 (10%) in class II and the majority (494 or 87%) were in class III. Most farmers were not carrying out any improved soil fertility management practices, despite the previous NARO and CIAT work in this area (Table 2).

When key informants were asked to reclassify the farmers after two years they indicated that 10 % of the farmers from the 1999 class III classification had moved to class I and II. Some farmers in class I had to be relegated to class II and III (Table 2). The PLAR process had more impact on farmers in the newest research village (Magada).

Farmer soil fertility management diversity classification and wealth ranking

Wealth rankings (Grandin, 1988) obtained during the diagnostic phase of the PLAR process (Esilaba *et al*., 2001b) were compared with data from the soil fertility management diversity classification for the same households in the three villages. The wealth ranks were standardised into four categories (wealthy, average, poor and very poor) for correlation with soil fertility management classes (Table 3). The majority of the respondents (74%) were in soil fertility class III while class II and I each had 13%, respectively. There were trends indicating a relationship between wealth ranks and soil fertility management classes. Seventy five percent (75%) of the farmers in soil fertility management class 1 were wealthy, another 25% average, and none were poor or very poor. For class 2 farms, 67% of the farmers were average, 33% were very poor and none was wealthy or poor. In class 3, 7% of the farm households were wealthy, 23% average, 31% were poor and 39% were very poor.

Data on soil properties for farms in the 3 soil management classes are presented in Table 4. No significant differences were observed in the soil chemical and physical properties among the 3 soil fertility management classes despite farmers' assessment. The soil pH was generally favourable except on one (Balabyeki's) farm, which has a low pH. Total (Kjeldahl) N, soil organic matter (SOM), available P are inadequate while exchangeable K is relatively adequate (Foster, 1971 and 1973; Landon, 1984). Critical values for soil pH, organic matter, total N and K in Uganda are 5.2, 3.0 %, 0.18 %, 5 mg kg^{-1} and 13.3 cmol kg^{-1} respectively (Foster, 1971). The soil textural class at all sites was dominantly loam.

Farm characteristics and resource endowment

The results show that farmers using different soil fertility management measures varied also in terms of resource endowment, for example, size and activeness of household members, labour availability, farm size, land tenure, livestock ownership, off-farm employment and farm structures (Table 5). This further supports the farmers' perceptions of wealth being correlated with soil fertility management. However, farmers in class II and III did not differ in most of the aspects above and therefore only the extreme cases of class I and III are reported in this paper. Results of analysis of test farmers who tried out new options for improved soil fertility show that farm classes differed in terms of resource endowments and the way in which the resources were managed. Class I farmers on average had relatively smaller families (8 people) compared to class III (9 people). Women and children contributed more to the agricultural activities compared to men. The number of active members as far as agricultural productivity is concerned did not change over the seasons. The average class I total farm size was considerably larger (3.3 ha) than class III (1.4 ha) with the implication that class I farmers can threrefore leave more land under fallow (0.7 ha) than class 3 farmers (0.2ha) to restore soil fertility. In fact, class 1 farmers do no rent in land. Class I farm households sometimes hire labour to work on their farms (3-4 hhs per season) and perform more work on other off-farm enterprises than their colleagues in class III. Class III farmers hardly hire labour for agricultural activities and the family is the sole source of labour. The livestock component plays a small role on the farm. Farmers in class I owned a few cattle while small livestock like goat/sheep and chicken were common among class III farmers. Class III farmers owned more chicken than class I because poultry are easier to manage and do not require big pieces of land for management. It is also known to be a major source of income for the poorest of the poor farmers. For all the classes, any surplus food is stored in the main houses or kitchens and not in graneries or food stores. The custom of storing food in graneries was abondoned due to escalating theft cases. Garbage/compost pits were also observed more in class I than in class III farms. Other studies also revealed that poor farmers are poor soil fertility managers, have little contact with extension agents, few are members of farmer groups and hence they have insufficient information on improved agricultural technologies while wealthy and average farmers are good soil fertility managers as they have the resources, are members of farmer groups and they are in contact with extension agents (Esilaba *et al*., 2001a).

Resource flow mapping

The resource flow mapping exercise was used as a learning tool for the researchers, extension staff and farmers to visualise the farm system and its subsystems, the flow of resources within the farm systems and outside the farm system. The complexity of the flows within and outside the farm system was evident from the exercise. The farmers together with the extension staff were able to examine the quantities and direction of the flows of the main agricultural resources and possible options to minimise losses and concentrate resources in key areas. Most of the maps were characterised by one field but with many plots (1 – 20) and of different sizes (Figure 1). The plot sizes ranged from 0.125 to 2 hectares. Farmers in this area divide their land into many plots because of the need to distribute the risk of crop failure by growing a variety of crops. The fields/plots were divided according to the crop growing or intended to be grown for that particular season.

Resource flows

The farm sub-systems, types of flow, resources are shown in Table 6 and average quantities of resources that were displaced in the LR and SR for classes I and III are presented in Table 7. For all the farm classes, most of the resources within the farm system came from crop fields (crop production system) into the household system (CPS-HHS) as food, and out of the farm system (OUTcps) as sale of surplus food (Table 7 and Figures 1and 2). On the other hand, very limited resources were returned to the farm and to the crop production system (INcps). There were no seasonal differences in the direction of flow of the resources but there was for the quantities of resource flows.

Farmers in this region grow a wide range of crops, which are often intercropped. Common intercrop combinations include maize/beans, maize/groundnuts, banana/coffee, maize/bean/cassava and banana/beans. The main annual crops grown were maize, beans, sweet potato and vegetables and the main perennial crops were bananas, coffee and cassava. The main cash crop is coffee but surplus food crops are also sold (Esilaba *et al*., 2001b; Woelcke and Berger, 2002). Food crops are either consumed immediately when they come from the field or are temporarily stored for food or sale to the market. However, these are subsistence farmers and therefore most of the produce (80%) is consumed on the farm, with the exception of coffee. Intercropping is practised to reduce on labour demands, maximise land use and reduce risk due to drought. Apart from land allocation for crops, there is no significant difference in the crops cultivated, crop pattern (sole vs intercropping), yields, crop residue management and general crop husbandry between the two farm classes, despite farmers in class I being known to be ‘good’ soil managers. There are also no major differences in yield, crop types and size of land allocation between the long rains and short rain seasons. Nutrients are exported from the farms mainly through coffee, food crops and crop residues (banana) fed to livestock and also used as compost. There was very little evidence of fertilizer use on the farms apart from previous on-farm testing by research and development organisations. Soil fertility is maintained mainly through natural fallows, improved fallows and leguminous cover crops such as *Mucuna*, *Canavalia* and *Tephrosia.*

Nutrient flows and balances

Nutrient flow analysis (NFA) was used to compare situations and outcomes in relative terms (Budelman and Defoer, 2000a). Nutrient balances of the three production subsystems (crop, animal, and household production systems) and out of the farm system for N, P and K are presented in figures 1 and 2. For the crop production system, N, P and K balances were negative in all the five seasons for both class I and III. The nutrient balances for the LR seasons are about twice as much as for the SR seasons. In the LR more crops are cultivated and therefore there are more harvests. Thus, in the LR season, farmers have more surplus of produce for sale and therefore export more nutrients out of the farm. The animal production system had zero or positive nutrient balance in both LR and SR seasons for both farm classes. The household system had positive N balance but with either zero or negative P and K balances for both classes in all the five seasons. This further emphasises the point that nutrient stocks of individual plots within farms and village territories can differ considerably due to management. Thus plots around the homestead, which receive substantial amounts of nutrients from animal manure and household waste, maintain a relatively high level of productivity (Smaling and Braun, 1996; Hilhorst *et al*., 2000). However, the farm system had net negative balance for all nutrients in all the seasons and for all the farm classes. The average N, P and K balances due to crop removal from the partial crop production system for class I and III farmers in the LR and SR seasons were –7.3 kg N ha^{-1}, -1.3 kg P ha^{-1}, -10.0 kg K ha^{-1} and –4.0 kg N ha^{-1}, -1.5 kg P ha^{-1}, -8.5 kg K ha^{-1} and -0.6 kg N ha^{-1}, -0.6 kg P ha^{-1}, -4.3 kg K ha^{-1} and -3.0 kg N ha^{-1}, -0.5 kg P ha^{-1}, -6.0 kg K ha^{-1} respectively (Table 7). The balance was negative due to crop removal of maize, beans sweet potatoes, cassava, and bananas. Nitrogen, P and K balances for the animal production system were marginal or zero as no nutrient entered or left the system. The household system had positive N, P and K balance because of the food crops that entered the system from the crop production system.

Looking at the whole farm system, the export of nutrients from the farm as sales was greater than the imports. The average farm-level nutrient exports for class I and III farmers were more in the LR season than in the SR season (Table 7). Of all the nutrients, substantial amounts of K were exported through banana fruit and residues, thus making the K balances more negative. Potassium export through banana either consumed or sold also poses a problem as much of it remains in the bodies of the farm inhabitants, while the rest is excreted but not returned to the fields.

The limited nutrients that enter the farm system are mainly added to the crop production system, with lower amounts entering into the household system as food or animal feed. Despite these additions, significant losses occur from the CPS. The crop production system, which is the major source of the nutrients leaving the farm, has the highest risk for soil nutrient depletion. Woelcke and Berger (2002) in bio-economic modeling studies in the study area using the nutrient balance calculation methods used by Wortmann and Kaizzi (1998) and different scenarios found similar nutrient balances. For example, the N balances varied from –28 kg N ha^{-1} (subsistence farm households) to –77 kg N ha^{-1} (commercial farm households) in the case of the baseline scenario under current land management and socio-economic conditions (Woelcke and Berger, 2002). The commercial households had higher yields and therefore higher amounts of nutrients were exported in the harvested produce. The results of the NFA suggest that there is need for a more targeted approach to soil fertility interventions that differentiate between farm components and socio-economic conditions (Elias *et al*., 1998).

Discussion

Farmer soil fertility management diversity classification and wealth ranking

This study shows that farmers classified themselves into three soil fertility management classes of good, average and poor soil fertility managers. However, soil chemical and physical properties revealed no significant fertility differences. Furthermore, the nutrient flows and balances also revealed that there is no significant difference in nutrient management for the three soil fertility classifications. It is instead observed that class 1 farmers', despite being good managers, lose/export more nutrients from the farm than class 3 farmers. The soil chemical analysis and the nutrient balance studies results do not reflect the farmers' soil fertility assessment and therefore require further analysis. However, De Jager *et al*. (1998) followed a budget approach in linking household objectives and wealth to nutrient management and mining and found a strong correlation between market orientation of farm households and the nutrient balance. Thus inspite of higher input use in market oriented farms, outputs were so high that the balance was more negative than in subsistence farming.

Conclusions

Resource flows and nutrient balances from this study show that soil nutrient depletion is a major problem in the study area. Nutrient mining is more intense in the crop production system of the smallholder farmers in eastern Uganda. Harvesting of crops for food and the surplus for sale are the most important sources of nutrient mining in the crop production system. Therefore attempts to correct the imbalance need to address these and other socio-economic factors. Given the high costs of fertilisers, intensifying use of legume cover crops as intercrops or improved fallows and strategic management of crop residues such as through home gardens are some of the options for minimising nutrient depletion.

The PLAR process enabled farmers to diagnose, plan, implement and evaluate their own activities for soil fertility improvement on their farms. The resource flow mapping exercise was an important tool in guiding farmers in selecting technologies and solutions according to the available farm resources as well as stimulating them to take action. This study also demonstrated that the maps drawn by the farmers were a source of information in determining resource flows and calculating nutrient balances that were used as indicators for improvements in soil fertility management.

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References

Bekunda, M. A., Bationo, A., Ssali, H. 1997. Soil fertility management in Africa: A review of selected research trials. In: Buresh, R. J., Sanchez, P. A., Calhoun, F. (Eds.), Replenishing Soil Fertility in Africa. Soil Science Society of America Special Publication No. 51. Soil Science Society of America, American Society of Agronomy, Madison, Wisconsin, USA, pp.63-79.

Budelman, A., Defoer, T. 2000a. Not by nutrient alone: a call to broaden the soil fertility initiative. Natural Resource Forum 24, 173-184.

Budelman, A., Defoer, T. 2000b. PLAR and resource flow analysis in practice. Case studies from Benin, Ethiopia, Kenya, Mali and Tanzania (Part 2). In: Defoer, T., Budelman, A. (Eds.), Managing Soil Fertility in the Tropics: A resource guide for participatory learning and action research. Royal Tropical Institute, Amsterdam, The Netherlands / International Institute for Environment and Development, London, U.K, 192 pp.

Defoer, T., Budelman, A. 2000. Managing soil fertility in the tropics. A resource guide for participatory learning and action research. Defoer, T and Budelman, A. (Eds.). Royal Tropical Institute, Amsterdam, The Netherlands / International Institute for Environment and Development, London, U.K.

Defoer, T., Budelman, A., Toulmin, C., Carter, S.E. 2000. Building common knowledge. Participatory learning and action research Part 1). In: Defoer, T., Budelman, A. (Eds.). Managing Soil Fertility in the Tropics: A resource guide for participatory learning and action research. Royal Tropical Institute, Amsterdam, The Netherlands / International Institute for Environment and Development, London, U.K, 208 pp.

Defoer, T., De Groote, H., Hilhorst, T., Kante, S., Budelman, A. 1998. Participatory action research and quantitative analysis for nutrient management in southern Mali: a fruitful marriage? Agriculture, Ecosystems and Environment 71, 215-228.

De Jager, A., Kariuki, I., Matiri, F.M., Odendo, M. and Wanyama, J.M. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV. Linking farm economic performance and nutrient balances in three districts in Kenya. Agriculture, Ecosystems and Environment 71, 81-92.

Delve, R. J., Jama, B. 2002. Developing organic resource management options with farmers in eastern Uganda. (In press).

Deugd, M., Rolling, N., Smaling, E.M.A. 1998. A praxeology for integrated nutrient management, facilitating innovation with and by farmers. Agriculture, Ecosystems and Environment 71, 269-283.

Elias, E., Morse, S., Belshaw, D. G. R. 1998. Nitrogen and phosphorus balances of Kindo Koisha farms in southern Ethiopia. Agriculture, Ecosystems and Environment 71, 93-113.

Esilaba, A. O., Byalebeka, J.B., Nakiganda, A., Mubiru, S., Ssenyange, D., Delve, R., Mbalule, M., Nalukenge, G. 2001a. Farmer evaluation of integrated nutrient management strategies in Eastern Uganda. A paper presented at The Southern and Eastern Africa Association of Farming Systems Research and Extension (SEAAFSRE-E) 8Th Conference held in Nairobi, Kenya 20-24 August, 2001. SEAAFSRE-E, Egerton University and Kenya Agricultural Research Institute, Nairobi, Kenya.

Esilaba, A. O., Byalebeka, J.B., Nakiganda a, A., Mubiru, S, Ssenyange, D., Delve, R., Mbalule, M., Nalukenge, G. 2001b. Integrated nutrient management in Iganga District, Uganda: Diagnosis by participatory learning and action research. Network on Bean Research in Africa, Occasional Publications Series, No. 35, CIAT, Kampala, Uganda.

FAO. 1977. Soil Map of the World, 1:5,000,000. Food and Agriculture Organization of the United Nations and the United Nations Educational, Scientific and Cultural Organization. Vol. VI.

Fischler, M. 1997. Legume green manures in the management of maize-bean cropping systems in eastern Africa with special reference to crotalaria (*C. Ochroleuca* G. Don.) PhD. Thesis, Swiss Federal Institute of Technology, Zurich, Switzerland.

Foster, H. L. 1971. Rapid soil and plant analysis without automatic equipment. I. Routine soil analysis. East African Agricultural and Forestry Journal 37, 160-171.

Foster, H. L. 1973. Fertilizer recommendations for cereals grown on soils derived from volcanic rocks in Uganda. East African Agricultural and Forestry Journal 38, 303-313.

Grandin, B. 1988. Wealth ranking in smallholder communities: A field manual. Publications Intermediate Technology Publications, Nottingham, England.

Harrop, J.F. 1970. Soils. In: Jameson, J.D. (Ed.), Agriculture in Uganda. Oxford University Press, U.K, pp. 43-71.

Hilhorst, T., Muchena, F., Defoer, T., Hassink, J., De Jager, A., Smaling, E., Toulmin, C. 2000. Managing soil fertility in Africa: diverse settings and changing practice. In: Hilhorst, T., Muchena, F. (Eds.), Nutrients on the move- soil fertility dynamics in African farming systems. International Institute for Environment and Development, London, pp. 1-25.

Landon, J. R. 1984. Booker tropical soil manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Booker Agricultural International Limited.

Okalebo, J.R., Gathua, K.W., Woomer, P.L.1993. Laboratory methods of soil and plant analysis. A working manual, Soil Science Society of East Africa, UNESCO/ROSTA, Nairobi, Kenya.

Sanchez, P. A., Shepperd, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Izac, Anne-Marie, N., Mokwunye, A. U., Kwesiga, F. R., Ndiritu, C. G., Woomer, P.L. 1997. Soil fertility replenishment in Africa: An investment in natural resource capital. In: Buresh, R. J., Sanchez, P. A., Calhoun, F. (Eds.). Replenishing Soil Fertility in Africa. Soil Science Society of America Special Publication No. 51. Soil Science Society of America, American Society of Agronomy, Madison, Wisconsin, USA, pp. 1-46.

Scoones, I. 2001. Dynamics and diversity: soil fertility and farming livelihoods in Africa: case studies from Ethiopia, Mali, and Zimbambwe. Earthscan Publications Ltd., London, 244 pp.

Scoones, I., Toulmin, C. 1999. Policies for soil fertility management in Africa. Department of International Development (DFID), London, 128 pp.

Smaling, E. M. A., Braun, A. R. 1996. Soil fertility research in sub-Saharan Africa: New dimensions, new challenges. Commun. Soil Sci. Plant Anal. 27, 365-386.

Smaling, E. M. A., Nandwa, S. M., Janssen, B. H. 1997. Soil fertility in Africa is at stake. In: Buresh, R. J., Sanchez, P. A. and Calhoun, F. (eds.). Replenishing Soil Fertility in Africa. Soil Science Society of America Special Publication No. 51. Soil Science Society of America, American Society of Agronomy, Madison, Wisconsin, USA, pp. 47-61.

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

Stoorvogel, J.J., Smaling, E.M.A. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Report 28. The Winand Staring Centre, Wageningen, The Netherlands.

Swift, M. J., Seward, P.D., Frost, P., Qureshi, J., Muchena, F. 1994. Long-term experiments in Africa: Developing a database for sustainable land use under global change. In: Leigh, R. A., Johnston, A. E. (Eds.), Long-term experiments in agricultural and ecological sciences. CAB International, Wallingford, England, pp. 229-251.

Van den Bosch, H., De Jager, A., Vlaming, J. 1998. Monitoring nutrient flows and economic performance in African farming systems (NUTMON) II. Tool development. Agriculture, Ecosystems and Environment 71, 54-64.

Van der Pol, F. 1992. Soil mining: an unseen contributor to farm income in southern Mali. Bulletin 325. Royal Tropical Institute, Amsterdam, 47 pp.

Woelcke, J., Berger, T. 2002. Land management and technology adoption in Eastern Uganda: An integrated bio-economic modeling approach. A paper presented at The Final Workshop on Policies for Improved Land Management in Uganda, April 17-19, 2002. International Food Policy Research Institute (IFPRI), Washington, D.C. U.S.A.

Wortmann, C. S., Fischler, M., Alifugani, F. and Kaizzi, C. K. 1998. Accomplishments of participatory research for systems improvement in Iganga District, Uganda 1993 to 1997. Occasional Publication Series, No. 27. CIAT, Kampala, Uganda, 40 pp.

Wortmann, C. S. and Kaizzi, C. K. 1998. Nutrient balances and expected effects of alternative practices in the farming systems of Uganda. Agriculture, Ecosystems and Environment 71, 117-131.

Table 1. Resource flows within the various sub systems.

Link within and/or between the farm and farm sub-systems	Description
Incps	Flows entering the CPS from outside the farm system
OUTcps	Flows leaving the CPS to out of the farm system
INaps	Flows entering the APS from outside the farm system
OUTaps	Flows leaving the APS to out of the farm system
Inhhs	Flows entering the HHS from outside the farm system
OUThhs	Flows leaving the HHS to out of the farm system
INTcps-aps	Flows from the CPS to the APS
INTaps-cps	Flows from APS the to the CPS
INTcps-hhs	Flows from the CPS to the HHS
INThhs-cps	Flows from the HHS to the CPS
INTaps-hhs	Flows from the APS to the HHS
INThhs-aps	Flows from the HHS to the APS

Table 2. Soil fertility management diversity continuum over three years

Village	Number of farmers							
	Using 4 or more practices (Class 1)		Using 1-3 practices (Class 2)		Using 0 practices (Class 3)		Total	
	1999	2002	1999	2002	1999	2002	1999	2002
Buyemba	7	10	19	35	165	153	191	198*
Kavule	8	10	28	18	94	104	131	132
Magada	4	4	8	51	235	192	247	247
Total	20	24	55	104	494	449	569	577

* Other new farmers had joined the village hence the increase in the number

Table 3. Relationship between soil fertility management classification and wealth ranking

Soil fertility management			Wealth rank			
Class	Farmers No./(%)		Farmers (%)			
	1999	2002	Wealthy	Average	Poor	Very poor
Class I	20 (3)	24 (4)	75	25	0	0
Class II	55 (10)	104 (18)	0	67	0	33
Class III	494 (87)	449 (78)	7	23	31	39

Table 4. Soil chemical and physical properties (0-20 cm) of typical farms in the 3 soil fertility classes

Parameter	Class I (Boobo)	Class II (Waiswa)	Class III (Balabyeki)
PH (water)	5.1	5.4	4.0
Organic matter (%)	3.2	3.4	2.9
N (%)	0.13	0.13	0.13
P (Bray P-2, mg kg^{-1})	0.82	0.45	0.97
K (cmol kg^{-1})	19.3	24.1	18.9
Na (cmol kg^{-1})	4.98	6.04	4.74
Ca (cmol kg^{-1})	42.8	55.2	46.2
Mg (cmol kg^{-1})	33.1	39.2	20.2
Sand (%)	59	59	55
Clay (%)	33	31	35
Silt (%)	8	10	10

Table 5. Socio-economic characteristics of typical class I (n=9) and III farms (n=9).

Farm characteristic	**Class I**							**Class III**						
	2000		2001		2002	Average		2000		2001		2002	Average	
	LR	SR	LR	SR	LR	LR	SR	LR	SR	LR	SR	LR	LR	SR
Average family size	8	8	8	8	8	8	8	9	10	9	9	8	8	9
Active members														
• Men	1	1	1	1	1	1	1	1	1	1	1	1	1	1
• Women	1	1	1	1	1	1	1	1	1	1	1	1	1	1
• Children	2	2	2	1	1	1	1	1	1	1	2	1	1	1
Households that hired labor	3	4	6	3	4	4	3	1	0	1	0	1	1	0
Average farm size (ha)	3.3	3.3	3.4	3.4	3.4	3.3	3.3	1.4	1.2	1.6	1.6	1.4	1.5	1.4
Land tenure: (rent out) ha	2	2	2	3	2	2	2	0	0	2	0	0	0	0
(rent in) ha	0	0	0	0	0	0	0	1	1	1	2	2	1	1
Land under fallow (ha)	0.7	0.8	0.9	0.6	0.5	0.7	0.7	0.1	0.2	0.1	0.2	0.2	0.2	0.2
Livestock														
• Number of cattle	1	2	1	1	1	1	1	0	0	0	0	0	0	0
• Number of pigs/goats/rabbits	3	3	3	3	3	3	3	2	2	1	1	1	1	1
• Number of chicken	9	7	8	8	12	9	7	7	10	22	10	10	13	10
Off farm employment	4	4	5	4	6	5	4	3	4	4	4	3	3	4
Farm structures														
• Main house														
Permanent:	5	5	6	7	7	6	6	4	4	4	4	4	4	4
Semi –permanent:	3	3	3	2	2	2	2	4	4	4	4	4	4	4
Temporary:	1	1	0	0	0	0	0	1	1	1	1	1	1	1
• Foodstore	0	0	0	0	0	0	0	2	2	2	2	2	2	2
• Compost/garbage	1	3	4	6	6	3	4	0	2	3	3	4	2	2

Table 6. Resource flows for typical class I and III farms

System	Type of flow	Type of resource
Crop production system (CPS)		
	INcps	Minjingu rock phosphate (MRP), Busumbu rock phosphate (BRP), Urea, Di-ammonium phosphate (DAP), Triple supper phosphate (TSP), Potassium chloride (KCL), Animal manure, Banana residues
	OUTcps	Banana, Coffee, Maize, Groundnuts, Cocoa, Fruits, Sweet potatoes and legume cover seed sold, Sweet potato, Banana residues burnt, Napier grass given to neighbour
Animal production system (APS)		
	INaps	Maize bran, rabbit pellets and mineral leak bought for livestock
	OUTaps	Chicken, eggs, rabbit sold
Household production system (HHS)		
	INhhs	Maize seed bought for planting
	OUThhs	Stored produce that was sold: Maize, Coffee, Rice, mucuna seed, Tephrosia seed, Groundnuts, Beans,
CPS-HHS		
	INTcps-hhs	Produce consumed: Banana, Maize, Beans, Cassava, Groundnut, Sweet potato, Soyabean, Millet, Mucuna seed (temporarily stored), Vegetables/fruits
	INThhs-cps	Compost/garbage to fields, Mucuna seed planted in field
CPS-APS		
	INTcps-aps	Napier grass fed to livestock, Crop residues fed to livestock
	INTaps-cps	Animal manure taken to crop fields
APS-HHS		
	INTaps-hhs	Nil
	INThhs-aps	Nil

Table 7. Net partial farm balances and partial CPS balances for class I and III farms

Season	**Partial farm balance** = INcps + INaps + INhhs – OUTcps –OUTaps -OUThhs						**Partial CPS balance** = INcps + INTaps – cps + INThhs – cps – OUTcps – INTcps – aps – INTcps –hhs					
	Class I			Class III			Class I			Class III		
	N kg/ha	P kg/ha	K kg/ha	N kg/ha	P kg/ha	K kg/ha	N kg/ha	P kg/ha	K kg/ha	N kg/ha	P kg/ha	K kg/ha
LR 2000	-9	0	-12	-4	0	-6	-8	0	-11	-12	-1	-12
LR 2001	-5	-1	-10	-2	-1	-2	-7	-2	-10	0	0	-2
LR 2002	-1	-1	-2	-4	0	-4	-7	-2	-9	10	-1	1
Average	**-5**	**-0.6**	**-8**	**-3.3**	**-0. 3**	**-4.0**	**-7. 3**	**-1. 3**	**-10**	**-0.6**	**-0.6**	**-4. 3**
SR 2000	-6	0	-8	-5	0	-7	-5	0	-10	-9	-1	-7
SR 2001	-1	-1	-4	-2	1	-3	-3	-3	-7	3	0	-5
Average	**-3. 5**	**-0. 5**	**-6**	**-3. 5**	**0. 5**	**-5**	**-4**	**-1. 5**	**-8. 5**	**-3**	**-0. 5**	**-6**

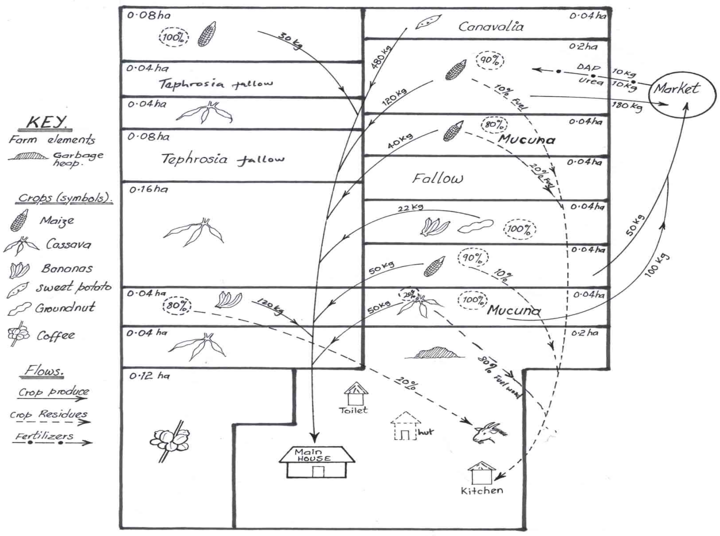

Figure 1. Typical resource flow map

Figure 2. Average N, P and K balances per hectare per season for all locations of typical class I farms for the CPS, APS, HHS and OFS over five seasons

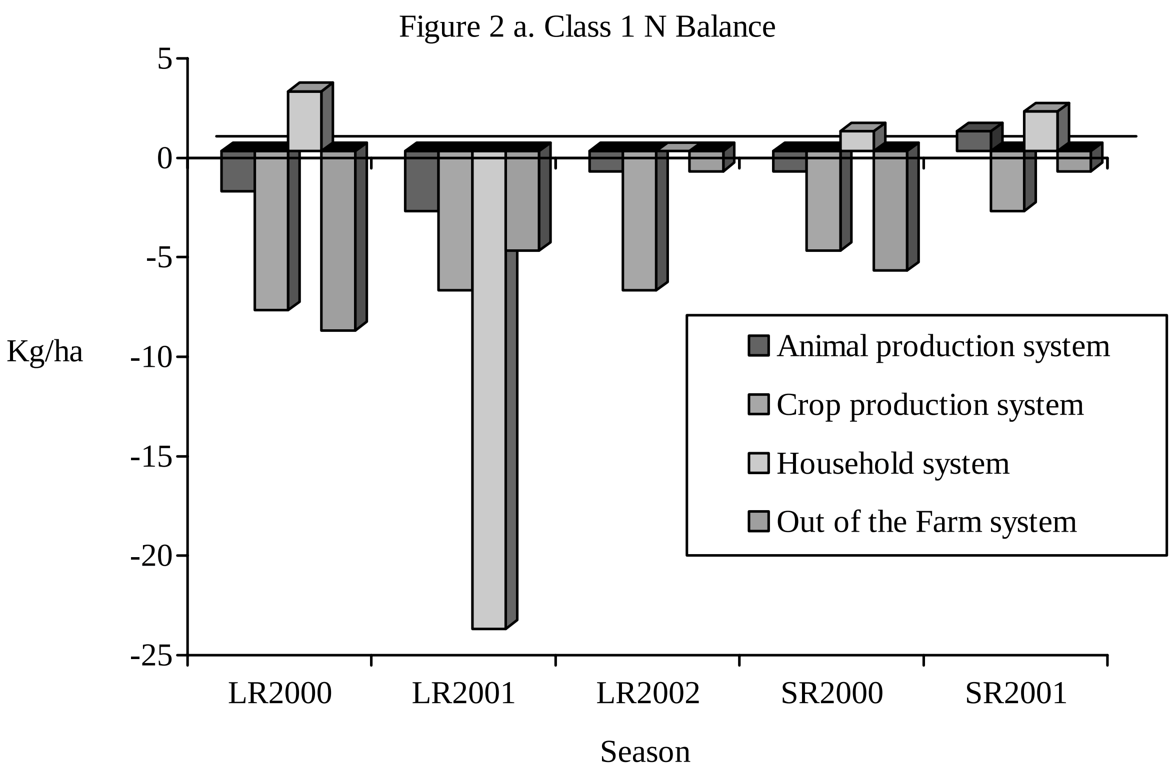

Figure 2 b. Class 1 P Balance

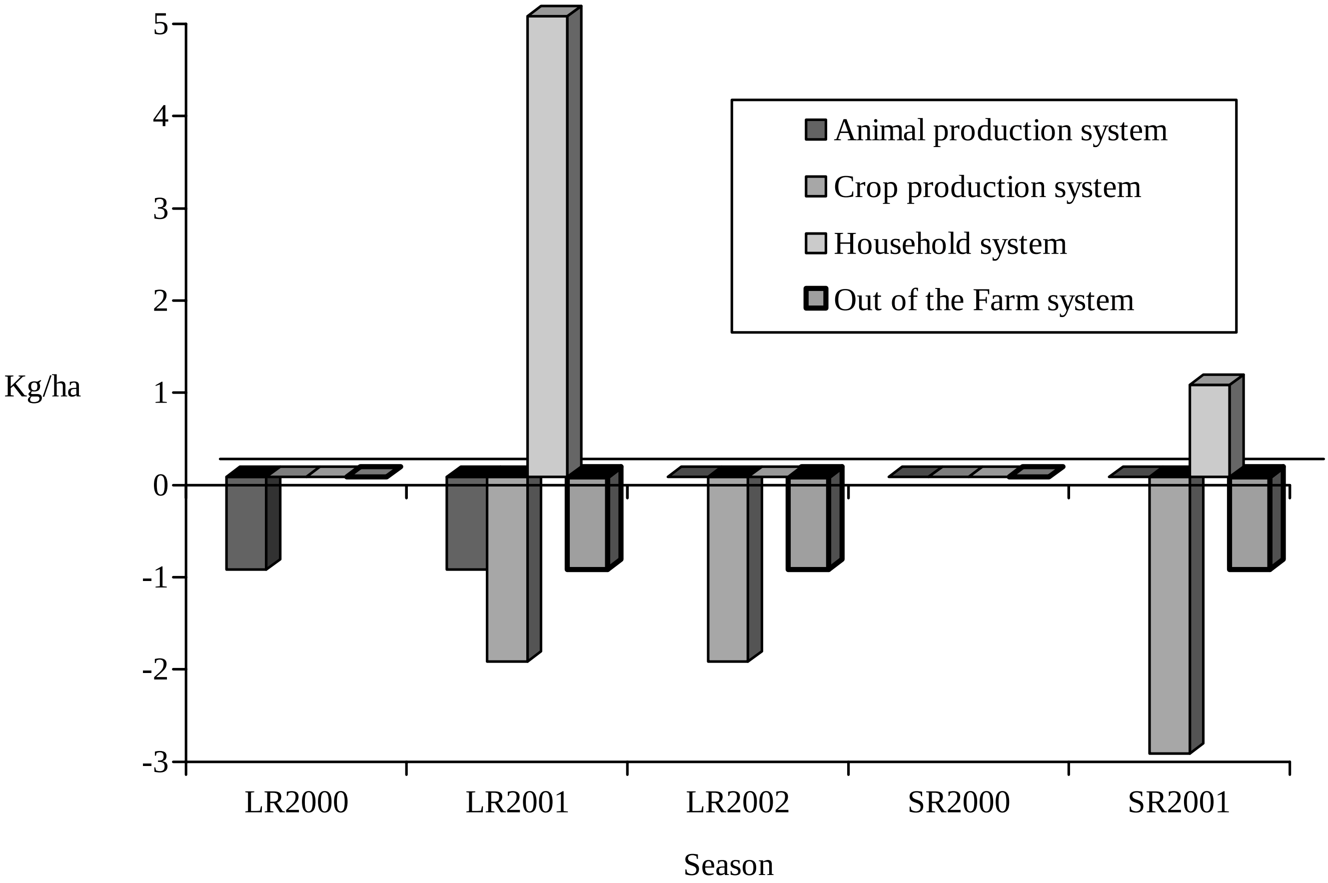

Figure 2 c. Class 1 K Balance

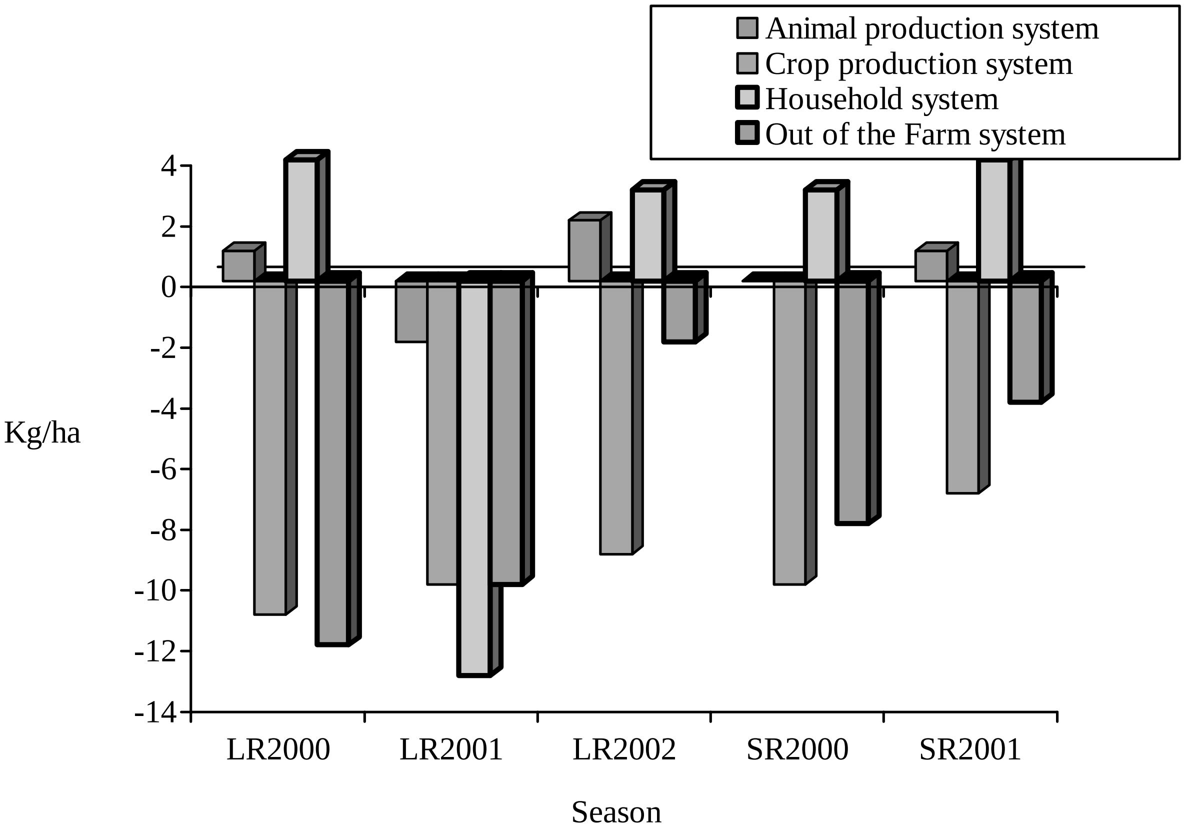

Figure 3. Average N, P and K balances per hectare per season for all locations of typical class III farms for the CPS, APS, HHS and OFS over five seasons

Figure 3a Class 3 N Balance

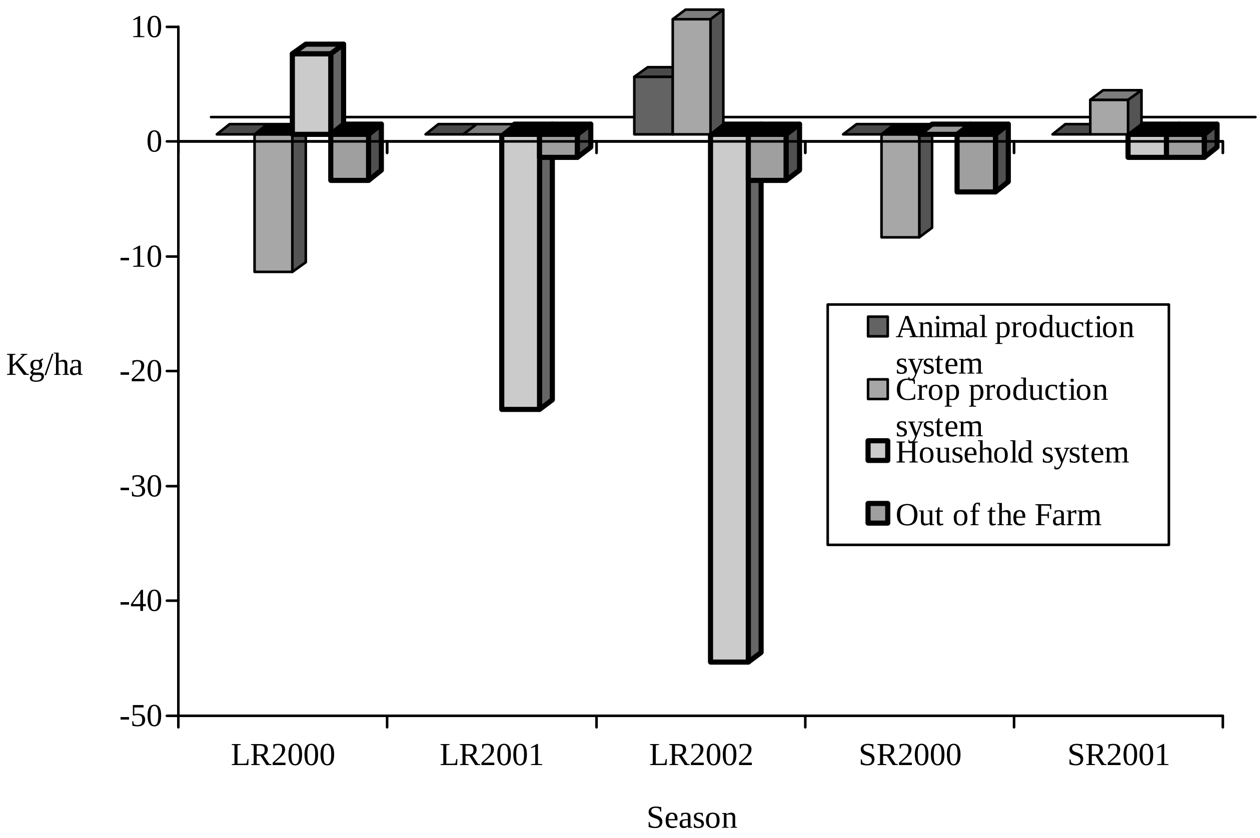

Figure3 b. Class 3 P Balance

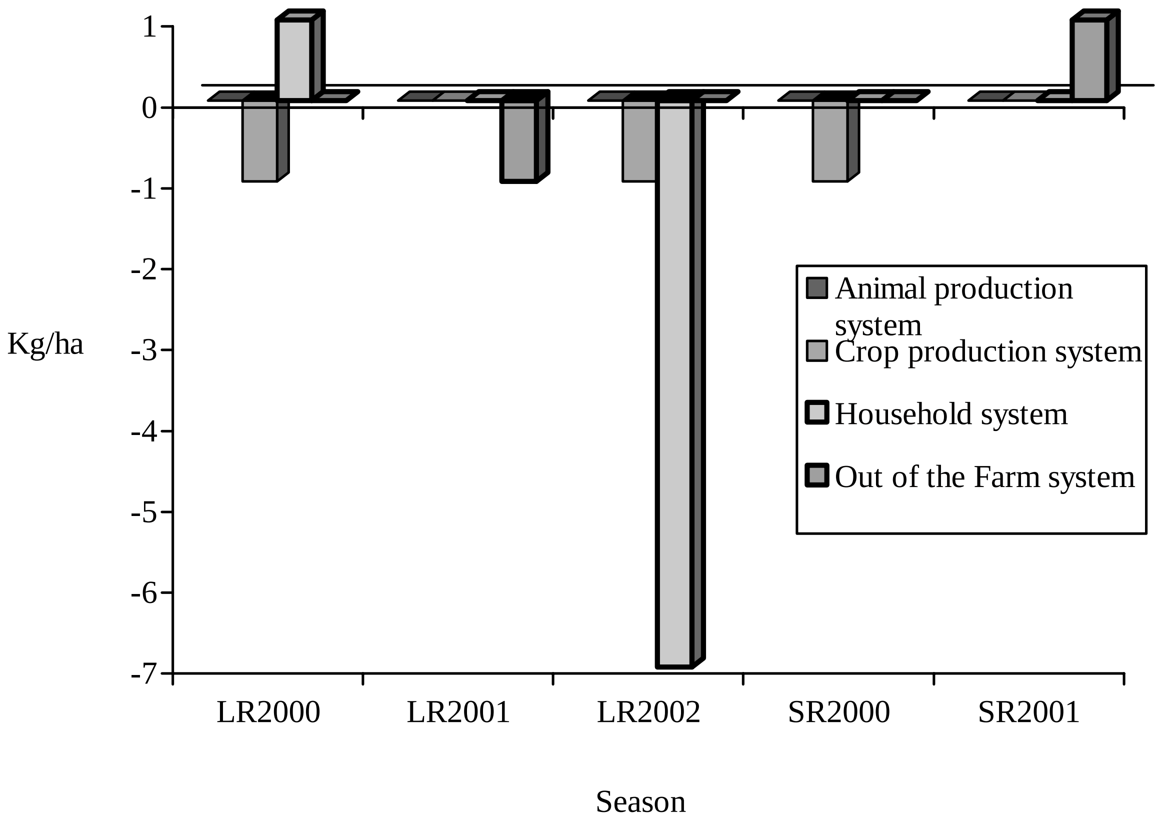

Figure 3c Class 3 K balance