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On farm testing of integrated nutrient management strategies in eastern Uganda

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Abstract

This paper reports on a Participatory Learning and Action Research (PLAR) process that was initiated in three villages in Eastern Uganda in September 1999 to enable small-scale farmers to reverse nutrient depletion of their soils profitably by increasing their capacity to develop, adapt and use integrated natural resource management strategies. The PLAR process was also used to improve the participatory skills and tools of research and extension personnel to support this process. The farming systems of the area were characterised for socio-economic and biophysical conditions that included social organisations, wealth categories, gender, crop, soil, agro forestry and livestock production. Farmers identified soil fertility constraints, their indicators, and causes of soil fertility decline, and suggested strategies to address the problem of soil fertility decline. Soil fertility management diversity among households indicated that most farmers were not carrying out any improved soil fertility management practices, despite previous research and dissemination in the area. Following the diagnosis stage and exposure visits

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to other farmer groups working on integrated soil fertility projects, the farmers designed 11 experiments for on-farm testing. One hundred and twenty farmers then chose, for participatory technology development, sub-sets of these 11 experiments, based on the major agricultural constraints and the potential solutions identified and prioritised by the farmers. Quantitative and qualitative results from the testing, farmer evaluation and adaptation, training, dissemination strategies and socio-economic implications of these technologies are discussed.

Keywords: Soil fertility management; Integrated nutrient management; Participatory methods; Uganda

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1. Introduction

Intensification of agriculture in the high-density sub-humid areas of Africa, generally without addition of plant nutrients, has resulted in 'nutrient mining' and subsequent land degradation (Stoorvogel and Smaling, 1990). Nutrient depletion is most intense in East Africa because of high outputs of nutrients in harvested products, erosion and the relatively high inherent fertility of the soils. 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) found that estimated nutrient balances for small-scale farming systems in eastern and central Uganda were negative for all crops except for nitrogen (N) and phosphorus (P) in the banana-based land use type (LUT). Inorganic fertilisers are not used but organic manures from homesteads are applied on bananas. The annual crops LUT occupied more land than other LUTs in eastern Uganda and accounted for more nutrient loss than all other LUTs combined. Crop harvests and soil erosion were the major causes of nutrient losses at the crop and LUT levels. The cumulative effect of several low-input management practices was estimated to give nutrient balances of near zero for N and P, but potassium (K) losses at the field-level were particularly high (Wortmann and Kaizzi, 1998). Therefore, despite low productivity, the current farming systems in eastern Uganda are not sustainable. However, recent studies in eastern and southern Africa indicate that nutrient depletion is a reversible constraint and increased agricultural production can be realised with appropriate soil nutrient management including integrated use of organic and inorganic sources (Palm et al., 1997; Sanchez et al., 1997; Bekunda et al., 1997; Budelman and Defoer, 2000).

Several low-input practices offer potential for improving soil fertility management in eastern Uganda. 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, and use of low levels of N and P fertilisers on maize and beans (Wortmann et al., 1998; Wortmann and Kaizzi, 1998). However, adoption of "improved" integrated nutrient management (INM) practices generally has been poor. For example, the use of mineral fertilisers by smallholder farmers in Africa remains low because of socio-economic constraints and is estimated to be currently less than

10 $kg ha^{-1} year^{-1}$ (Heisey and Mwangi, 1996; Mwangi, 1997) and even less in Uganda.

Improved soil nutrient management is crucial for maintaining and improving soil productivity in Africa, and strategies are required that address farmer requirements and priorities. The hypothesis tested in this study is that systematic learning with stakeholders, and farmers perceiving economic incentives, are necessary for changing farming practices (Deugd et al., 1998; Defoer and Budelman, 2000). This paper presents the quantitative and qualitative results of participatory on-farm testing of farmer-designed INM strategies in eastern Uganda during a two-year Participatory Learning and Action Research (PLAR) process.

2. Materials and methods

2.1. Study area and characteristics of the farming system

The study was carried out in three villages in Imanyiro sub-county of Mayuge District in eastern Uganda. Imanyiro sub-county of Bunya County is located at 0° 35′ N, 32° 29′ in eastern Uganda. The district lies at an altitude of 1070–1161 meters above sea level (m.a.s.l.) and covers an area of about 11,113 km^2. The district has a bimodal rainfall pattern varying from 1250 to 2200 mm (average 1345 mm for 22 years) per annum. The first rains (season A) occur between March and June and the second rains (season B) between August and December. The soils at Ikulwe District Farm Institute (DFI) in Imanyiro sub county are reddish brown sandy loams and sandy clay loams (Harrop, 1970). According to the FAO soil map of Africa, orthic Ferralsols are predominant in Iganga District (FAO, 1977). Most soils have a low organic matter (OM) content (range 1.1–3.1 OM) and are deficient in N and P (Fischler, 1997; Wortmann and Kaizzi, 1998).

The farming systems are biologically and agronomically diverse with small but numerous parcels of land having varying cropping associations, planting dates etc. The average farm size in the area varies between 1.8 and 2.0 ha and 90% of the farmers are the sole owners of the land. About 36% of farmers own other pieces of land far from the main homestead (Wortmann et al., 1998; Esilaba et al., unpublished data). The main crops grown in the area are bananas, maize, cassava, beans, coffee, fruits, vegetables and sweet potato (Esilaba et al., 2001b; Woelcke, 2002; Woelcke and Berger, 2002). Most farms have a few 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).

2.2. Methodology

A Participatory Learning and Action Research (PLAR) process (Defoer et al., 2000) was initiated in September 1999 in Imanyiro sub-county of Mayuge District. This site was selected because it is one of the few areas of Uganda where farmers have had exposure to soil productivity innovations during an earlier CIAT and National Agricultural Research Organization (NARO) participatory research project in the area. During the diagnostic phase of the PLAR process farmers analysed soil fertility management diversity and resource endowment among farms in the three villages of Buyemba, Mayuge and Magada (Esilaba et al., 2001b). Wealth ranking (Grandin, 1988) by farmers generated a list of attributes that included land size, number of cattle, capital, labour, types of crops, type of house, level of education and sources of income, which distinguished between resource endowments and categorised households into groups (Esilaba et al., 2001b).

Household characteristics in Imanyiro were determined by a diagnostic survey of 140 randomly selected farmers from the three participating villages in October–November 1999. The survey included some characteristics that farmers themselves had identified as criteria for farm classification, and the data were used to verify the farm classification made by key informants (Esilaba et al., 2001b).

2.3. Farmer experimentation

Twenty farmers representing three soil fertility management classes in the three villages were chosen by the farmer groups as test farmers for intensive monitoring of the on-farm experimentation. In addition, 100 other farmers asked to be involved in the trials but researchers did not closely monitor these non-test farmers. The test farmers who tried out the new options for improved soil fertility management were the PLAR group representatives of the farmers in the area. The selected farmers drew resource flow maps (RFMs) for analysis of their current soil fertility management practices and to identify possible improvements. During the planning phase, farmers were taken on a farmer exchange visit to meet other farmer innovators who practise some of the proposed technologies. At a planning workshop, farmers and the PLAR team of researchers and extension agents identified and discussed appropriate options for improved soil fertility management in their villages. The farmers were encouraged to try to integrate various options according to their resources and particular needs. Test farmers made a planning map (Budelman and Defoer, 2000) indicating the crops they intended to grow and the activities they planned to undertake the following season. Farmers designed 11 experiments and they proposed data collection procedures for monitoring and evaluation. The experimental design of the 11 trials established in the February–July 2000 season (season 2000A) until August–December 2001 (season 2001B) varied from a minimum of two treatments to a maximum of five treatments in a randomised complete block design (RCBD) with one replicate per farm. Evaluation of the resource flows was conducted at the end of every season. The information gathered during the PLAR process was recorded and analysed using the Resource KIT software (Defoer et al., 2000).

Soil samples (topsoil at 0–20 cm depth) were collected from 28 test-farmers' plots for laboratory analysis according to methods by Foster (1971) and Okalebo et al. (1993) for available Bray-P. Organic matter was determined using an oxidation procedure derived from the Walkley and Black method as described by Jackson (1958). Total nitrogen (N) was determined by the standard Kjeldahl procedure. The extracting solution used for calcium (Ca), Magnesium (Mg), sodium (Na) and potassium (K) was hydrolyzed lactic acid in ammonia solution based on Egner's extracting solution (Foster, 1971). Plant growth was monitored for germination percentage, crop performance, weed management, pests and disease incidence, time of harvesting, and crop yield. Data analysis was conducted using SAS (1990).

3. Results and discussion

3.1. Farm characteristics and soil fertility management

Soil diversity analysis and problem diagnosis led farmers to identify and prioritise 12 soil fertility and management constraints. Drought was the main constraint, followed by lack of knowledge and skills on soil fertility management, low inherent soil fertility, and soil-borne diseases and pests. The high cost of inorganic fertilisers was ranked number sixth, while soil erosion and poor tillage methods were ranked seventh. Farmers identified and ranked indicators/causes of soil fertility decline (Esilaba et al., 2001b). The indicators of soil fertility decline were reduced plant growth, yellowing of crops, stunted crop growth, low soil moisture retention, increased pest incidence, wilting of plants, weeds as indicators and increased weed growth. The causes of soil fertility decline were ranked as continuous cropping, poor soil management, soil erosion, unplanned intercropping practices, poor management of available organic materials, poor tillage methods, reduced fallows, nutrient removal through crop harvests, burning of bushes, and lack of soil erosion materials, respectively (Esilaba et al., 2001b). Soil fertility management diversity among households was attributed to use of fertilisers (both organic and inorganic), soil erosion control measures, green manure, fallow, and agro forestry. Farms/households using four or more of these measures were considered "good" soil fertility managers (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" soil fertility managers (Class III). Out 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 previous research and dissemination in the area.

Most farmers in Class I own land, use hired labour, and are members of farmer groups. More farmers in Class I practise improved soil fertility management that includes use of fertilisers, manure, compost, fallows, intercropping and crop rotations, compared with Classes II and III (Esilaba et al., 2001b). The results show that soil fertility management is related to resource endowment as determined by the farmers' ranking criteria (Esilaba et al., 2001b).

3.2. Farmer experimentation

Class I farmers implemented more experiments than Classes II and III farmers (Esilaba et al., 2001a). The main reasons for Class III farmers not implementing

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experiments were lack of land, limited household labour, and lack of inputs (manure, mulching, composting materials, seeds and planting materials).

3.2.1. Soil fertility

The major physical and chemical characteristics of the soils from the 20 test farmers in the three villages are presented in Table 1. The results for soil analysis on test farms indicate that the soils were sandy clay loams, sandy loam and loamy sand, and that some of the farms are deficient in N and P (Table 1). Soil pH varied from 4.0–5.9 with a median pH of 5.2, which is below the range (pH 5.5–7.0) for good nutrient availability without toxicity problems (Landon, 1984). The organic matter content varied from low to medium (1.3–3.6%) with a median of 2.5%. The nitrogen content varied from very low to low (0.04–0.13) with a median of 0.10% and the mean available Bray P-2 was 3.0 $mg\,kg^{-1}$. According to Foster (1971), critical values for soil pH, organic matter, total N, P and K are 5.2, 3.0% 0.18% 5 mg kg and 13.3 $cmol\,kg^{-1}$ respectively. Foster (1973) reported that crops are unlikely to respond to N and P fertilisers in Uganda at soil nutrient levels of 6% organic matter and 20 ppm extractable P. The soil analysis results also indicate that most soils in the area should respond to nitrogen and phosphorus fertilisers. However, the pH of the soils in the study area is generally quite low and therefore the potential for aluminium toxicity is high and this would probably reduce potential responses to the various fertilisers and amendments.

Soil fertility test strips (SFTS) were established on test farms to determine whether N, P and K are limiting crop growth. The SFTS consisted of one replicate per farm of five treatments, a control with no fertiliser application and different combinations of N, P and K at 100 $kg\,ha^{-1}$ (Table 2). The results during the first season (2000A) showed a significant response to N and P and the N, P and K treatments in Mayuge. However, there were no significant residual responses to these nutrients in the second season except the N, P, and K treatment in Mayuge. Application of 30 $kg\,N\,ha^{-1}$ and 10 $kg\,P\,ha^{-1}$ per season was estimated to give an increase in maize yield of 1000 $kg\,ha^{-1}$ in Iganga District (Wortmann and Kaizzi, 1998).

Table 1
Soil chemical and physical properties (0–20cm) of test farms

Site:	Mayuge	Buyemba	Magada
Parameter			
pH (water)	5.2 ± 0.24	5.0 ± 0.20	5.5 ± 0.11
Organic matter (%)	2.9 ± 0.19	2.3 ± 0.26	2.6 ± 0.12
N (%)	0.11 ± 0.01	0.08 ± 0.01	0.09 ± 0.01
P (Bray P-2, $mg\,kg^{-1}$)	0.91 ± 0.28	3.66 ± 1.73	3.54 ± 1.46
K ($cmol\,kg^{-1}$)	20.8 ± 1.53	15.0 ± 3.70	24.1 ± 2.22
Na ($cmol\,kg^{-1}$)	5.3 ± 0.31	3.8 ± 0.88	6.1 ± 0.55
Ca ($cmol\,kg^{-1}$)	48.6 ± 3.22	34.5 ± 7.06	52.6 ± 4.69
Mg ($cmol\,kg^{-1}$)	27.6 ± 3.72	18.6 ± 3.29	28.5 ± 2.10
Sand (%)	62 ± 3.80	70 ± 3.55	67 ± 2.09
Clay (%)	29 ± 4.00	21 ± 3.13	24 ± 2.05
Silt (%)	9 ± 0.66	9 ± 0.63	9 ± 1.12

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Table 2
Maize grain yield (kg ha^{-1}) in soil fertility test strips[a]

Site:	Mayuge		Buyemba		Magada	
Season:	2000 Feb–Jul	2000 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec
Treatment						
Control	3546a	5658a	3169a	3994a	3514a	3380a
Nitrogen (N)	2668a	4575a	2794a	4398a	3755a	2723a
Phosphorus (P)	2854a	5250a	3526a	4732a	2724a	2732a
N and P	4101ab	5660a	3868a	5203a	3663a	3398a
N, P and Potassium (K)	3675ab	6074ab	3748a	5929a	3764a	3566a

Means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($p < 0.05$).

[a] The treatments were: control (no fertiliser), N at 100 kg N ha^{-1}, P at 100 kg P ha^{-1} and K at 100 kg K ha^{-1}. Data was collected from eight farms.

3.2.2. Tillage

Deep tillage (20 cm) and herbicide (Roundup at 3 l ha^{-1}) application did not affect maize biomass yield when compared with the control (farmers' practice of surface scraping at 1–4 cm) as combined analysis of the maize grain, stover and total biomass yield data identified no significant differences between site (parish), year, season and treatments. However, the two methods generally increased grain yield compared with the control in all the sites (Table 3). The best grain and stover yields were from deep tillage but the farmers preferred the use of herbicides once socio-economic considerations had been discussed during the evaluation meetings. The total cost of using Roundup was estimated to be 40 compared with $109 per hectare for manual cultivation and weeding twice in a season.

3.2.3. Farmyard manure

Application of farmyard manure at 10 t ha^{-1} fresh weight tended to improve maize grain yield in the two years in all villages in Mayuge District (Table 4). Although the grain yield increases were not significant, farmers had observed treatment differences earlier on in the season and they were ready to adopt the technology on a large scale. Previous studies indicate that an increase in maize yield of 700 kg ha^{-1} per season is expected with application of manure containing 22.6, 9. 3 and 33.7 kg ha^{-1} year^{-1} of N, P and K, respectively (Wortmann and Kaizzi, 1998). Long-term studies on manure use are required to determine the impact of this technology on crop yields. However, the availability, quantity and quality of the manure in the area is a major constraint to wide-scale adoption of this technology. Wortmann and Kaizzi (1998) found that manure accounts for a relatively small proportion of nutrient transfers in Uganda. Manure was generally applied to banana and amounted to a significant transfer of nutrients from grazing areas to banana. The amount of manure produced by an average of 1.7 cows and sheep/goats, 0.9 pigs and 12 chickens per farm is relatively small, and manure management was generally poor with infrequent removal from livestock holding pens (Wortmann and Kaizzi, 1998). It is estimated that one livestock unit (1 LU = 500 kg live mass) produces

Table 3
Effect of tillage on maize grain yield (kg ha^{-1})[a]

Site:	Mayuge				Buyemba				Magada			
Season:	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec
Treatment												
Control	2987a	5111a	5696a	2595a	–	4687a	2402a	1482a	1969a	–	2247a	2607a
Deep tillage	3862a	6751a	6634a	3384a	–	4327a	2898a	2775a	2279a	–	2622a	4384a
Herbicide	–	5522a	5503a	3699a	–	3699a	–	1932a	–	–	2654a	1747a

Means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($p < 0.05$).
[a] The treatments were: control (4 cm depth), deep tillage (20 cm depth) and herbicide (Roundup at 3 l ha^{-1}).

Table 4
Effect of farmyard manure on maize grain yield (kg ha^{-1})

Site:	Mayuge				Buyemba				Magada			
Season:	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec
Treatment												
Control (0 t ha^{-1})	3620a	5556a	5216a	3103a	2616a	3809a	2235a	2054a	1683a	3356a	–	1537a
Manure (10 t ha^{-1})	4204a	6013a	6198a	3860a	2468a	3980a	2954a	3146a	1785a	3736a	–	2542a

Means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($p < 0.05$).

about 7 t of recoverable manure per year when stabled all day. This declines to 2–3 t per year of usable manure (i.e. 30–40% recovery) if the animals are stabled only overnight (Murwira et al., 1995; Schleich, 1986). Therefore, livestock contributed little to the flow of nutrients to and from farms in Uganda (Wortmann and Kaizzi, 1998). Improved crop and livestock integration in farming systems would overcome some of the constraints to adoption of manure technology.

3.2.4. Comparison of phosphorus sources

The farmers designed an experiment to evaluate various sources of P fertilizers. There were five treatments, a control with no fertilisers, Busumbu Blend (90% Busumbu rock phosphate with 10% TripleSuperphosphate (TSP)), Busumbu rock phosphate (BRP), Minjingu rock phosphate (MRP) and TSP all at 80 $kg\,P\,ha^{-1}$. Nitrogen at 100 $kg\,N\,ha^{-1}$ as Urea and 60 $kg\,K\,ha^{-1}$ as KCl were applied to fertilised plots once per year (Table 5). There was significant response to the various sources of phosphate fertilisers on maize grain yield during 2000 and 2001 (Table 5). Minjingu rock phosphate and TSP significantly improved maize grain yields in Mayuge and Buyemba compared with BRP, Busumbu Blend (BB) and the control. The TSP and MRP treatments gave the highest yields followed by BB, BRP and the control, respectively. The response to P in the second season followed a similar trend in the two villages (Table 5). Wortmann and Kaizzi (1998) reported high P-use efficiency and crops continued to respond for three seasons after application of 100 $kg\,ha^{-1}$ of TSP in Mayuge District. The results in Magada indicate that there was no significant response to P fertilisers in the first season (2000A). However, there were significant responses to P in the second season (2000B) and in the two seasons in 2001. The response in Magada in 2000 was highest for BRP followed by BB, MRP, TSP and the control respectively. The TSP treatment was not significantly different from the control in 2000 but it was significantly higher in 2001B (Table 5). The soils in Magada have a higher mean pH of 5.5 and are generally sandier. A combined analysis of variance across sites (parish), years, seasons and treatments indicated significant site, year, treatment and year × season interactions for maize grain yield. However, there were no significant season × treatment interactions. The phosphate fertiliser trial results suggest that MRP is a better source of available P than BRP in two locations whereas in one location BRP has a better residual value. Studies conducted on an acid soil (pH 4.8) in Rwanda showed that P recovery from BRP was similar to that from TSP and that composting improved BRP handling and application properties. Bean yields were increased most by application of BRP in combination with compost and manure while yield increase with BRP was similar to TSP and BRP with compost (Wortmann, 1999). Bio-economic modelling using the 2000 and 2001 maize grain yield data in two villages (Buyemba and Magada) showed a comparatively high yield response to BRP (Woelcke and Berger, 2002). The positive yield responses to BRP, BB, NP and NPK (SFTS trials) treatments had an average yield increase of 40% compared with 26% for TSP and 16% for MRP. The conclusion was that the positive yield response, in combination with low input costs, would make adoption of BRP profitable leading to positive impacts of P nutrient balances in the soil. However, capital constraints were identified as fac-

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Table 5
Effect of various sources of phosphorus fertiliser on maize grain yield (kg ha^{-1})[a]

Site:	Mayuge				Buyemba				Magada			
Season:	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec
Treatment												
Control	3026b	4436b	5187b	3065b	2083b	2420b	2405b	1677abc	2222a	2596b	2141b	2355b
Busumbu Blend (BB)	3309b	5291abc	5736b	3726ab	2428abc	3001ab	2655b	1582bc	2097a	3924a	3404b	3211a
Busumbu (BRP)	3365b	4591bc	5899b	3528b	2389bc	2882ab	3064ab	1495c	2363a	4148a	3604a	2884ab
Minjingu (MRP)	3745ab	5567abc	7271a	4598a	2820abc	3888a	3441a	2727ab	2563a	3743a	2525b	3261a
TSP	4173a	6078a	7502a	4541a	2982a	3779ac	3403a	2775a	2214a	3057ab	3037b	3462a

Means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($p < 0.05$).

[a] The treatments were: control (no fertiliser), BB (Busumbu RP (90%) with TSP (10%) at 80 kg P ha^{-1}), BRP (Busumbu RP at 80 kg P ha$^{-1)}$, MRP (Minjingu RP at 80 kg P ha$^{-1)}$, TSP at 80 kg P ha^{-1}. N as Urea was applied at 100 ha^{-1} and potassium as KCl at 60 kg K ha^{-1}were applied in all the fertiliser treatments once in a year.

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tors affecting further adoption of new technologies (Woelcke and Berger, 2002). Long-term P fertiliser studies need to be conducted at these locations in Iganga District to determine the optimum rates, timing, method of application, combinations of rock P with manure and compost and residual value of the various sources of phosphorus fertiliser.

The results of another experiment with Minjingu rock phosphate (MRP) Prep-pacs, which consist of N (urea at 40 $\mathrm{kg\,N\,ha^{-1}}$) and P fertilisers (MRP at 100 $\mathrm{kg\,P\,ha^{-1}}$), rhizobium inoculant, legume seed and adhesives and lime pellets (Okalebo, 1999; Nekesa et al., 1999), were not significant (Table 6). Maize grain yields in 2000 on test farms increased by 475 and 591 $\mathrm{kg\,ha^{-1}}$ in the first season in Buyemba and Magada, respectively. Residual effects of Prep-pacs indicate that grain yields decreased by 279 $\mathrm{kg\,ha^{-1}}$ (Mayuge) and increased by 157 $\mathrm{kg\,ha^{-1}}$ and 259 $\mathrm{kg\,ha^{-1}}$ in Buyemba and Magada, respectively (Table 6). Combined analysis of the data for the two years for maize grain and total biomass yields were only significant for the site (parish) but not significant for the treatment effects and the various interactions. However, analysis of results for the two seasons in 2000 on 41 non-test farms in seven districts in eastern Uganda show significant increases of 1244 $\mathrm{kg\,ha^{-1}}$ in maize grain yield from 3085 to 4329 $\mathrm{kg\,ha^{-1}}$. There was no significant response to P and N on test farms in Mayuge District during the two years. The soils in Mayuge District vary from pH 4.0 to 5.9 (Table 1). Minjingu rock P requires acidic conditions (pH <5.5) to dissolve and soils below pH <5.2 are associated with toxic Al^{3+} and Mn^{2+} cations that greatly reduce crop performance (Okalebo, 1999). However, both aluminium and manganese toxicity do not usually occur in the same soil. Reports from western Kenya show that Prep-pacs increased maize yields from an average of 800 kg to almost 2000 $\mathrm{kg\,ha^{-1}}$ (Okalebo, 1999) and from 640 to 1360 $\mathrm{kg\,ha^{-1}}$ (Nekesa et al., 1999). Prep-pacs did not significantly increase bean yields on the test farms but grain yields improved by 14–157 $\mathrm{kg\,ha^{-1}}$ in the two seasons in 2000 (Table 7). However, there was no significant response in 2001B. Bean yields improved in 2001A and 2001B when the control was compared with MRP and Prep-pacs, respectively (Table 7). Combined analysis for the two years of bean yield data indicated significant site (parish), season, treatment and year × site × season interaction. However, the bean total biomass data showed significant year, site, season, treatment, year × season and year × site × season interactions.

Bio-economic modelling studies in Mayuge District showed no impact of Prep-pacs on yield when compared with the control (Woelcke, 2002; Woelcke and Berger, 2002). However, analysis of results for the two seasons in 2000 on 41 non-test farms in seven districts in eastern Uganda show significant increases of 881 $\mathrm{kg\,ha^{-1}}$ in bean yield from 1316 to 2197 $\mathrm{kg\,ha^{-1}}$. Bean yields in western Kenya were increased by Prep-pacs from less than 200–500 $\mathrm{kg\,ha^{-1}}$ (Okalebo, 1999) and yields for bush and climbing beans increased from 25 to 125 kg and from 200 to 450 $\mathrm{kg\,ha,^{-1}}$ respectively (Nekesa et al., 1999). Use of a combined Prep-pac and climbing bean package increased maize and bean yields by 720 and 250 $\mathrm{kg\,ha^{-1}}$, resulting in a 161% return on investment. The profitability of Prep-pacs is dependent upon soil conditions and the accompanying legume intercrops and their economic values (Nekesa et al., 1999).

Table 6
Effect of Minjingu rock phosphate (Prep-pacs) on maize grain yield ($kg\,ha^{-1}$)[a]

Site:	Mayuge				Buyemba				Magada			
Season:	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec
Treatment												
Control	2680a	4122a	3735a	1945a	1601a	2436a	2075a	1109a	1350a	1980a	2545a	1833a
Pure Minjingu RP	2090a	3805a	4396a	1682a	1576a	2250a	1648a	1049a	1429a	2215a	3122a	1659a
MRP Prep-pacs	2679a	3843a	4426a	1809a	2076a	2593a	1889a	1432a	1941a	2239a	1495a	1921a

Means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($p < 0.05$).

[a] The treatments were: control (no fertiliser), Pure Minjingu RP (MRP at 100 $kg\,P\,ha^{-1}$),and MRP Prep-pacs (Urea at 40 $kg\,N\,ha^{-1}$, MRP at 100 $kg\,P\,ha^{-1}$ and rhizobium inoculant, adhesives and lime pellets).

Table 7
Effect of Minjingu rock phosphate (Prep-pacs) on bean yield (kg ha^{-1})[a]

Site:	Mayuge				Buyemba				Magada			
Season:	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec
Treatment												
Control	517a	452a	530a	181a	337a	74a	417a	431a	308a	342a	225a	106a
Pure Minjingu RP	567a	564a	839a	415a	440a	165a	498a	773a	382a	269a	442a	273a
MRP Prep-pacs	531a	540a	498a	466a	494a	190a	530a	759a	396a	360a	431a	127a

Means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($p < 0.05$).
[a] Same treatments as in Table 6.

3.2.5. Green manure

Canavalia ensiformis, *Mucuna pruriens*, *Crotalaria ochroleuca* and *Lablab purpureus* green manures were relay cropped in a 2–3 weeks maize crop. Green manure dry matter biomass yields in the relay cropped trials indicated that during the first season (2000A) the yield varied from 200 to 3505 kg ha^{-1} which was low for all the tested green manure. Higher biomass yields were obtained during the second season except in Buyemba and varied from 116 to 6029 kg ha^{-1}. The mean annual dry matter (DM) yields were significantly different and canavalia and mucuna had the highest yield followed by crotalaria and lablab (Table 8). However, the DM yields were lower (4125–4867 kg ha^{-1} for *Canavalia ensiformis*, 1852–2271 kg ha^{-1} for *Mucuna pruriens*, 1960–2524 kg ha^{-1} for *Crotalaria ochroleuca* and 2500–3186 kg ha^{-1} for *Lablab purpureus*) than results reported in intercropping studies in the area (Fischler, 1997).

Maize grain yield was not significantly improved by the green manure on 6 test farms in the two seasons in 2000 (Table 9). Analysis showed that maize grain yields for the two seasons were not significantly different. Maize grain yield on 39 other non-test farms was also not significantly different except in the second season in Magada. The highest yield in Magada was obtained under Lablab and then Canavalia, Crotalaria, Mucuna and the control (Table 9). Maize grain yields for the two seasons on the non-test farms were not significantly different. Significantly increased maize grain yields were obtained under Mucuna and Canavalia in Buyemba and Magada in 2001A. Combined analysis of the maize grain yield data for the two years, three sites and four seasons showed significant year, year × site and year × season interactions but no significant treatment differences. However, the total biomass yields were significant for the site, season, year × season, year × site, season × site and year × season × site interactions. Farmers in Mayuge District have been using green manure for more than five years (Wortmann et al., 1998) and therefore they proposed that this technology should be disseminated without any further on-farm testing.

3.2.6. Improved fallows

The mean dry matter yields of *Calliandra* were significantly different from *Sesbania* and *Tephrosia* after one year as improved fallows planted without crops. The total biomass yields were highest for *Calliandra* (9853 kg ha^{-1}) followed by *Sesbania* (6053 kg ha^{-1}) and *Tephrosia* (3700 kg ha^{-1}). Maize planted a year after the fallow period and after incorporation of the legumes did not yield significantly more in 2001A. The highest yield was in the control plots (3907 kg ha^{-1}), followed by *Tephrosia* (3271 kg ha^{-1}), *Calliandra* (3181 kg ha^{-1}) and *Sesbania* (2982 kg ha^{-1}), in the first season of 2001 (2001A).

3.3. Farmer evaluation of INM technologies

Farmers assessed the technologies using innovation assessment priority matrices and pairwise ranking, and reviewed project activities using a sustainability analysis matrix (Table 10). The data were also analysed for the acceptance of ten technologies (except SFTS) using the logistic preference ranking analysis for evaluating

Table 8
Green manure biomass dry matter yield (kg ha^{-1})

Site:	Mayuge				Buyemba				Magada			
Season:	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec
Treatment												
Control	–	–	–	–	–	–	–	–	–	–	–	–
Mucuna	898a	4274a	1852a	–	368b	302ab	1198a	–	2183a	6029a	1288a	–
Crotalaria	383a	1373a	1115b	–	400ab	116b	590b	–	1202a	3027ab	1423a	–
Canavalia	1031a	4858a	1376ab	–	653a	494a	254b	–	3505b	4306ab	751a	–
Lablab	1092a	464a	141c	–	206b	259a	416b	–	2169a	1205b	216a	–

Means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($p < 0.05$).

Table 9
Effect of green manure on maize grain yield (kg ha^{-1})

Site:	Mayuge				Buyemba				Magada			
Season:	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec	2000 Feb–Jul	2000 Aug–Dec	2001 Feb–Jul	2001 Aug–Dec
Treatment												
Control	3325a	5023a	4017a	2838a	2141a	2585a	1719b	1469a	1996a	2201a	2050b	2257a
Mucuna	3217a	5730a	3589a	3022a	1922a	1863a	2249ab	1805a	1542a	2498a	2216b	2549a
Crotalaria	3326a	5036a	3920a	2228a	1631a	2884a	1755b	1881a	1806a	2531a	2145b	2338a
Canavalia	3342a	5233a	4244a	2905a	2241a	3324a	2316ab	2285a	1735a	2411a	2814a	2265a
Lablab	3755a	5465a	4007a	2956a	1937a	2473a	1601b	1259a	1075a	2357a	2358b	1778a

Means followed by the same letter are not significantly different by Duncan's Multiple Range Test ($p < 0.05$).

Table 10
Technology assessment priority matrix and pairwise ranking by farmers in Imanyiro

Class:	Class I				Class II				Class III				
Rank:	R+	R++	R+++	R*	R+	R++	R+++	R*	R+	R++	R+++	R*	R**
Technology													
Farmyard manure	4	3	2	1	2	4	–	1	–	4	1	2	1
Tillage	1	8	9	7	1	6	9	7	–	–	–	–	7
Minjingu RP	8	7	5	8	6	2	6	7	3	–	6	6	7
Green manure	5	6	3	5	4	4	4	4	1	5	4	2	4
Mulching	3	2	–	1	4	–	2	1	3	3	3	2	1
Trenches	6	9	–	9	6	–	1	4	6	1	–	5	6
Improved fallow	10	–	6	9	11	–	7	10	8	–	–	9	10
Compost	2	3	–	1	8	1	3	4	2	2	2	1	3
Agro forestry	11	–	8	11	9	–	7	9	9	–	–	10	11
Busumbu RP	8	1	7	5	2	2	5	1	5	–	5	6	4
Soil fertility test strips (SFTS)	6	3	4	4	10	–	–	11	7	–	–	8	9

Key: 1 = best: 11 = worst.
R+ = Ranking from technology assessment priority matrix in August 2000; R++ = Pairwise ranking in February 2001; R+++ = Pairwise ranking in August 2001; R* = Average ranking; R** = Overall mean ranking.

technology options (Hernandez-Romero, 2000). Significant ($p < 0.15$) positive intercepts of acceptance of technologies were obtained with farmyard manure (0.87), mulching banana in plantations (0.87) and compost (0.67). Positive but not significant intercepts were obtained with BRP (0.16) and green manure (0.13). Minjingu rock P (MRP) had a significant but negative intercept (−0.38) whereas soil conservation trenches (−0.18), agro forestry (−0.27), improved fallows (−0.29) and tillage (−0.40) had negative but non-significant intercepts. Using pairwise ranking of the different treatments in the trials, farmers ranked the various treatments as better than farmers' practice or the control (Esilaba et al., 2001a). Most farmers identified positive benefits of the limited areas on which they had been able to implement the different soil fertility improvement technologies. Farmer evaluation of the soil fertility management technologies shows that the simple technologies that require little labour and are inexpensive, or that use locally available resources such as farmyard manure, compost, green manure, and mulches, were ranked as the best options (Table 10). Technologies that required purchase of inputs (Busumbu and Minjingu rock phosphates) or were labour intensive (soil conservation trenches) were rated as average. Long-term technologies with no immediate benefits, such as improved fallow and agro forestry, were ranked low.

4. Conclusions

Farmers in the study area are aware of the declining soil fertility problem and the resulting declines in agricultural production. Soil analysis and soil fertility test strip (SFTS) results indicate that most soils in the study area should respond to N and P fertilizers. Resource flow analysis results show that the annual partial balances for N, P and K are negative at the field level, leading to a depletion of soil nutrient reserves

(Esilaba et al., 2002; Woelcke, 2002; Woelcke and Berger, 2002). Farmers suggested various soil fertility management strategies to address the problem of soil fertility depletion in the area. Among the tested technologies, deep tillage, farmyard manure, green manure, Prep-pacs and improved fallows did not significantly improve maize grain yields. This was due to the nature of the farmer experimentation that involved different environments and variable management practices among the test-farmers (Steiner, 1987). The trials did not have within farm replications as each farmer conducted the trials using one replicate per farm due to the small size of the farms. Bio-economic modelling of the impact of different technology options showed no impact of farmyard manure, Prep-pacs, and green manure but positive yield responses for Busumbu rock phosphate, Busumbu Blend, NP, NPK, TSP and Minjingu rock phosphate (Woelcke, 2002; Woelcke and Berger, 2002). Long-term P fertiliser studies need to be conducted in Iganga District to determine the optimum rates, timing, method of application, combinations of rock P with manure and compost, and residual values of the various sources of phosphorus fertiliser.

Farmer evaluation of on-farm experiments shows that simple, inexpensive technologies requiring little labour and locally available resources have a high potential for adoption. However, bio-economic modelling studies showed that a substantial improvement in the socio-economic environment is needed to give farmers sufficient incentives to adopt more sustainable land management practices (Woelcke, 2002; Woelcke and Berger, 2002). The results supports the hypothesis that systematic learning with stakeholders, and farmers perceiving economic incentives, are necessary for changing farming practices. However, the capacity of different farmers to invest in improving soil fertility management depends on access to labour, livestock, land, capital and cash at the household level. The options available to poor farmers are much more constrained than those available to the well endowed farmers who are able to invest in large-scale use of organic and inorganic sources of nutrients. Further studies are required to determine diffusion, adoption and potential of up-scaling of integrated soil fertility management technologies in the area.

5. Uncited references

FAO (1989), Smaling and Braun (1996) and Theis and Grady (1991).

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