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Effects of mineral and organic fertilizers on crop productivity and nutrient use efficiency in smallholder farms of Southern Rwanda

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Abstract

Smallholder farms in southern Rwanda are characterized by soil fertility depletion due to continuous cultivation without nutrient replacement, leading to poor crop productivity and threatening food security. Fertilizer application is therefore a pre-requisite to improve productivity in these soils. A study was conducted to determine the effects of combined mineral and organic fertilizers on maize (Zea mays L.) and beans (Phaseolus vulgaris L.) and nutrient use efficiency in farms selected from southern part of Rwanda. Simbi and Maraba were selected as representative sectors, and Umurera and Gasharu as representative villages in the two sectors, respectively. Farms were selected based on key socio-economic status (land size, livestock ownership, type of house, and labour availability). Two fields under either maize or bean crop were demarcated on each farm and one of them received fertilizer application comprising manure (1600 kg/ha) and mineral fertilizer (NPK 17-17-17) at a rate of 200 kg/ha. Maize plots were top-dressed with additional urea fertilizer at a rate of 50 kg/ha at flowering. Other two fields grown with the same crops without fertilizer application served as control treatment. In addition, a greenhouse experiment was run to assess crop response in semi-controlled environment. Soils were the most fertile in Simbi and in wealthier farms. Maize plants were significantly (P = 0.03) shorter in Simbi (1.7 m) than in Maraba (1.8 m). Grain yield was higher in Simbi (3.2 t ha^{-1}) than in Maraba (1.9 t ha^{-1}) and increased up to 3.4 t ha^{-1} in fields with fertilizer application. Similar trend was observed in the greenhouse. In beans, fertilizer application significantly (P<0.001) increased the number of pods per plant, the number of grains per pod and bean yield of 1.4 t ha^{-1}. Agronomic efficiency (AE) was higher in Simbi than in Maraba and was the highest in wealthier farms. It was concluded that biophysical factors (field location and initial soil fertility status) greatly influenced crop yield and fertilizer.

Keywords: *Bean, maize, fertilizer response, farm type, Rwanda*

1. Introduction

Smallholder farming systems of sub-Saharan Africa (SSA) are generally characterized by poor productivity. In tropical areas, high population densities lead to high pressure on land, resulting in poor and declining soil fertility because the majority of smallholders remove nutrients from the soils without applying sufficient quantities of manure or other fertilizers to replenish the soil (Stoorvogel and Smaling, 1990). Low agricultural productivity in smallholder farms is the direct cause of food insecurity in sub-Saharan Africa (Sanchez, 2002). These problems are likely to increase, as the human population is growing faster in Africa than in other parts of the world (Sanchez et al., 1997). An assessment of productivity of farming systems and soil fertility status in Maraba and Simbi sectors in southwestern Rwanda showed food security concerns due to low crop productivity (Bucagu et al., 2011). The major reason for this was widespread poor soils with acute N and P deficiencies.

There is a strong relationship between soil fertility and food production in tropical areas (Sanchez, 2002). However, only 15% of farmers in SSA use mineral fertilizers, 55% use organic fertilisers made of farmyard manure and crop residues, while only 30% use farmyard manure mainly on food crops such as maize, beans and sweet potato (Bucagu et al., 2011). Mineral fertilizers are sparsely used by smallholder farmers due to limited purchasing power and the unfavourable macroeconomic environment (Wopereis et al., 2006; Heisey and Mwangi, 1996). In many cases, small amounts of mineral fertilizers are combined with organic fertilizers (manure, compost, etc..) and this has shown to be a promising option to reverse the cycle of perpetual depletion of nutrients and improve soil fertility (Vanlauwe et al., 2010).

Smallholder farms in Africa operate under diverse biophysical conditions (Tittonell et al., 2005a) and have marked spatial heterogeneity in soil fertility (Scoones and Toulmin 1999; Prudencio, 1983). Different zones receive varying amount of rainfall and disparities in rainfall distribution are even recorded between zones within the same agro-ecological zone (Tittonell et al., 2005). Soil fertility management is rarely homogenous in the region and factors underlying this heterogeneity may be related to natural processes (e.g.

parental material and topography) or to differential farm resource management through concentrating resources around specific fields (mostly infields) at the expense of fields further away from home (Tittonell et al. 2007a).

Numerous studies conducted in SSA have produced evidence of differential crop response to fertilizer application in soils. These studies have demonstrated that fields close to homestead are often rich in organic matter and respond positively to application of mineral fertilizer more than poor soils located further away and this is a direct consequence of differential management on different fields (Vanlauwe et al 2007). Strong response to fertilizers is directly linked to the ability of crops to utilize nutrients applied by producing larger biomass or consumable products. The large amount of harvestable products is the consequence of accumulation of large quantities of nutrients into plant organs. Therefore, the amount of nutrients taken up by plants is an important indicator of whether nutrients are efficiently used or not (Gardner et al. 1985).

This study aimed at assessing the effects of organic and mineral fertilizers on two important crops, bean and maize by evaluating the crop growth, amount of nutrient uptake and use efficiencies in targeted crops in selected farms.

2. Materials and Methods

Sites characteristics

The study was conducted in Central Plateau agro-ecological zone. Two sectors (Simbi and Maraba) were selected due to their contrasting aspects in terms of land use systems. Bananas (*Musa* spp.), beans (*Phaseolus vulgaris* L.), maize (*Zea mays* L.), sweet potatoes (*Ipomoea batatas* L.) and cassava (*Manihot esculenta* L.) are the predomiant food crop species in the area. Coffee is the main cash crop and the predominant animals are cattle, goats, pigs and chicken. Those animals are sources of manure and income for smallholder farmers. Tree species are diversified and comprise timber species with *Eucalyptus spp.* being the most dominant, forage species (*Calliandra calothyrsus*, *Leucaena leucocephala*) and other indigenous species mostly planted next to home compounds (Djimde, 1988; Niang &

Styger, 1990). Simbi is located at 1634 m a.s.l with an average temperature of 20^{o}C and Murera village was selected to represent Simbi sector. The Farming systems are predominantly characterised by a mix of cereals, root and tubers in the upland and a rotation of cereals and Irish potato in wetlands. In home garden fields, banana (*Musa* spp.) is intercropped with beans and indigenous vegetables (e.g. *Colocasia esculenta* L. (Schott), *Amaranthus* spp.). In fields further away from home, beans or maize are commonly mixed with sweet potatoes or cassava that constitute the basic diet for most rural household communities. Coffee is grown as a monocrop in most cases. In Maraba, Gasharu village was selected as the study site. Beans and cassava are major food crops and coffee is the main cash crop. In both locations, livestock comprises cattle but also small ruminants (goats, pigs and sheep); poultry is less developed due to disease outbreaks. Cattle are largely local bred cows (Ankole) but there is a shift to cross-bred cattle due to the ongoing 'one cow for one poor family' policy that aimed at enabling vulnerable households to own an improved dairy cow.

Farm selection

Farmers were classified based on wealth status and soil types. Wealth categorization was based on land size, livestock ownership, type of house, and labour availability. Farmers were classified into three socio-economic categories namely poor, moderately wealthy and wealthy. Poor farmers were characterized as having limited land (mostly < 0.5 ha), rearing small ruminants and relying on off job to put food on the table. Moderately wealthy farmers own more land (0.7 ha) than poor farmers, own a cow and may apply modest amounts of manure and produce sufficient food for family consumption and, sometimes, a little surplus for the market. A wealthy farmer may own one or two cattle (one of them being a cross bred) and a number of small ruminants or pigs, own large land (> 1.0 ha) and may hire labour for some agricultural practices. Wealthy farmers often hold leadership positions or working for paid jobs. Nine farmers belonging to each of the three farm types were selected from each village (poor, moderate and wealthy) making a total of 54 farms selected in both Simbi and Maraba sectors.

Field experiment

Experiments were conducted in 54 farms during 2011 season A (Sept 2010 to February 2011). Four fields each of 10 x 10 m were demarcated in each farm and grown to maize and bean. Fields were ploughed manually by farmers using the hoe. All residues of previous crops and weeds were removed as necessary to avoid residual effects of nutrients from previous crops. This was followed by harrowing and leveling the soil to provide a good seedbed before planting. Two fields were grown to maize (Variety KATUMANI) and beans (Variety Rwandarushya) crops and fertilizers comprising manure at a rate of 1600 kg/ha and mineral fertilizer (NPK 17-17-17) at a rate of 200 kg/ha were applied. On maize plots with fertilizers, additional urea fertilizer was added at a rate of 50 kg/ha as top dressing at flowering. Two other unfertilized plots per farm grown to similar crops and managed similarly served as control plots. Maize was sown at 25 x 50 cm spacing, resulting in a density of 80,000 plants/ha. Beans were sown at 20 x 50 cm spacing, resulting in 100,000 plants/ha. Weeding occurred two weeks after planting to reduce competition for water and nutrients with the crop. Pesticide (Sumithion) was applied to combat maize stem borer. Various disease symptoms (*Pithium*) were observed on bean plants but were not controlled as they had no major impact on crop growth and productivity. Also, pesticide application is not a common farmer practice in bean cropping in Rwanda. The experiment was set-up as a 2x3x2 factorial with sector, farm group and fertilizer as factors in 9 replicates per trial. Both experiments were run on a total of 216 plots demarcated in 54 different farms.

Greenhouse experiment

A parallel trial was conducted in a greenhouse to investigate the potential of both crops to respond to fertilizer application in a controlled environment where factors such as moisture, diseases and pests were controlled. Soils from the 54 farms were collected in bags and brought to the Faculty of Agriculture. Pots of 15 cm height and 22.5 cm diameter were filled with 3 kg of soil from the different farms and half (27) of pots were applied with manure and mineral fertilizers (NPK 17-17-17). Organic (manure) and mineral fertilizer (NPK) were applied as in the farmer field experiment. Manure was applied at rate of 160 to 200 g of manure (DM basis) per pot. Compound fertilizer was applied at a rate of 2.5 g per pot in maize pot and 2 g per pot in bean pot. No urea was applied for top dressing in maize since plants were harvested before reaching the flowering stage. Three seeds were sown per pot at the depth of 2 cm and thinned to one plant. The sowing was done on 17th March 2011 and harvested after 4 months. Watering was done twice a day, before sun rise and at sun set. As in the field study, the greenhouse experiment was set-up as factorial experiment with sectors (Maraba and Simbi), farmer groups (poor, moderate and wealthier) and fertilizer treatments (with or without NPK) as factors and replicated three times.

Data collection

Field trials: Plant height and stem diameter were measured as averages of 20 plants selected at random in each field when at least 50% of maize plants were at flowering stage. Maize was harvested at about 20 weeks after planting from an area of 10 m by 10 m, excluding one border row on each side of the harvested area. To determine the dry weight of the grain and stover yield, 250g of maize grains and stover were dried in the oven for 48 hours at 70^{o}C and the results allows to derive the total dry weight of the maize yield in the tons per hectare (t/ha). For beans, data were collected on the total number of pods per plant, the number of grains per pod and the total bean yield at harvesting time (3 months after planting).

Greenhouse trial: In maize, plant height was measured in each pot 8 weeks after planting. The total fresh biomass for two plants was collected per plot to determine the total dry biomass following the procedure described above. In beans, number of pods/plant and number of grains per pod were recorded in each pot.

Soil nutrient analysis: Soils were sampled before the start of the experiments to characterise different fields in each of the two farms in Simbi and Maraba. Topsoil (0-20 cm) samples were taken with an auger at the four corners per field from the two fields chosen within each farm. Samples were mixed and a composite sample of approximately 0.5 kg taken for laboratory analysis. The soil samples were air-dried in the laboratory, crushed and ground, sieved using a 2 mm sieve and analysed for pH, N, P, K, organic carbon and cation exchange capacity (CEC). Soil pH was determined on a 1:2.5 soil: H_2O suspension with a glass electrode pH meter. Organic carbon was determined calorimetrically by measuring chromic ions after oxidation with sulphuric acid and potassium dichromate mixture. Total nitrogen was determined using Kjeldahl digestion method. Available phosphorus was determined using Bray^{-1} method. K was analysed using humid digestion method and measured with Atomic Absorption Spectrophotometer (AAS) (Anderson and Ingram, 1993). To assess N uptake by maize crop, maize stover and grain samples were dried ground to less than 0.5 mm for N concentration and measured using the Kjeldahl digestion method (Anderson and Ingram 1993).

Data analysis

Data on crop growth and yield were analysed by computing analysis of variance using linear mixed Model (RML) procedures of GENSTAT (Genstat® Discovery Edition 3, 2009) assuming Sector, Farmer group, 'fertiliser treatment and their interactions as fixed and farm (replicate) as a random factor. Only standard error of the differences (SEDs) for main effects of sector, farmer group and fertiliser treatment are shown because interactions were not significant. Simple linear regressions were used to relate yield parameters to the bean yield to better undersand the extent to which these paremeters influence the total bean yield.

Nutrient use efficiency was estimated using the concept of 'Crop Nutrient Equivalent'. Since the maize yield was due to the combined effects of N, P and K applied as a fertiliser compound, we could not attribute yield increment to individual elements. We, therefore, expressed the effect of N, P and K in kilogram of crop equivalent nutrient (kCNE) (Janssen, 1998, 2011) where for maize; 1kCNE equals 1 kg N, 0.145 kg P and 0.8 kg K. A kCNE represents the quantity of the nutrient that would result in the same yield increase as 1 kg of nitrogen under conditions of balanced nutrition.

Total nutrients applied in the field were calculated by summing up nutrients from 200 kg/ha of NPK (17-17-17), 50 kg/ha of urea (N) and 1600 kg/ha of manure. Nitrogen, P and K levels were assumed to be 1.45 % N, 0.24 % P and 1.06 % K (Palm et al., 1995). Nutrient use efficiency was estimated using agronomic use efficiency (*A*E) expressed in kg grain produced per kg nutrient applied using the following formula:

Where Y_F and Y_0 refer to maize yield in the treatment where nutrients were applied and in the control plots respectively and F_{app} is the amount of fertilizers and/or organic nutrients applied.

$$AE_N = \frac{Y_F - Y_0}{F_{app}}$$

3. Results

Soil physical and chemical properties on selected study sites

Soil data are reported in Table 1. pH was statistically similar across study locations but differed significantly ($P < 0.001$) among farm types. pH was significantly lower in the fields of poor farmers than those of moderately wealthy and wealthy farmers, and in moderately wealthy than wealthy farms. Soil organic C was significantly ($P < 0.001$) greater in Simbi than in Maraba, on wealthier than moderate farms and was lowest on poor farms (Table 1). Total N content was the highest in wealthier than in moderate and poor farms but remained very low based on standards of Mutwewingabo and Rutunga (1987). Extractable P concentration was generally very low, but significantly higher in Simbi than in Maraba. In all locations, K levels ranged from moderate to high. Wealthier farms had higher values compared to moderate and poor farms. The cation exchange capacity (CEC) value was also higher in Simbi than in Maraba sector and was highest in wealthier farms.

Table 1: Soil pH, organic carbon, total N, available P in 54 farms in Simbi and Maraba sectors of Rwanda

	pH (H_20)	Soil organic C (%)	Total soil N (%)	Extractable P (ppm)	K^+ (cmol (+) kg^{-1})	Exchangeable cation capacity (cmol (+) kg^{-1})
Sectors						
Maraba	5.00	2.5	0.08	22.1	0.9	8.8
Simbi	5.02	2.6	0.09	30.7	0.3	11.9
Farm type						
Poor	4.4	1.6	0.08	22.7	0.5	5.3
Moderate	5.0	2.6	0.09	26.4	0.6	7.1
Wealthier	5.6	3.5	0.11	30.1	0.7	10.0
P sector	*ns*	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
P farm type	< .001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
SED sector	0.08	0.035	0.002	0.81	0.025	0.87
SED farm type	0.10	0.040	0.003	0.99	0.035	0.65

Maize growth and yield as influenced by location, farm type and fertiliser treatment

Growth and productivity of maize as influenced by the treatments in the field experiment are presented in Table 2. Plants were significantly (P=0.03) taller in Simbi than in Maraba, averaging 1.85 m over the two sectors. Plants grew similarly on all farms and ranged from 1.82 to 1.90 cm on average four months after planting. Fertilizer application significantly increased plant height by 18 % compared to the unfertilized treatment (control). Similarly, stem diameter was significantly (P < 0.001) greater with fertilizer application compared to the control treatment. Maize stover dry matter and grain yield significantly (P = 0.01) increased by 38% and doubled, respectively, when fertilizer was applied. Grain yield was 68 % higher in Simbi than in Maraba (1.9 t ha^{-1}).

Table 2: Plant height and diameter, dry matter and maize grain yield as a function of location (sector), farm types and fertilizer regime in Maraba and Simbi sectors of Rwanda

	Plant height (m)	Diameter (mm)	Dry matter (t ha^{-1})	
			Stover yield	Grain yield
Sector				
Maraba	1.8	18.5	3.6	1.9
Simbi	1.9	19.6	3.8	3.2
Farm type				
Poor	1.8	18.2	3.4	1.9
Moderate	1.9	19.6	3.3	2.5
Wealthier	1.8	19.3	4.4	3.2
Fertilizer status				
With Fertil.	2.0	20.4	4.3	3.4
Without Fertil.	1.7	17.6	3.1	1.7
P sector	0.03	0.19	0.56	0.01
P farm type	0.71	0.46	0.08	0.10
P fertilizer status	<0.001	<0.001	<0.001	<0.001
SED sector	0.06	0.8	0.40	0.49
SED farm type	0.03	1.00	0.49	0.60
SED fertilizer status	0.14	0.37	0.28	0.39

*Interactions between farm type and fertilizer were not significant at P = 0.05

Similar trends were observed in the greenhouse as in the field experiment (Table 3). Plant height and grain yield were significantly (P = 0.025) influenced by location (Table 3). The effect of farm type was not significant for any of these parameters. Fertilizer application significantly (P < 0.001) influenced plant height and total dry matter (Table 3).

Table 3: Maize plant height (m) and dry matter productivity (g pot^{-1}) as a function of Location (sector), farm types and fertiliser treatment in a 8 weeks greenhouse trial in the Maraba and Simbi sectors of Rwanda.

	Plant height (m)	Dry matter (g pot^{-1})
Sector		
Maraba	0.57	25.71
Simbi	0.63	29.75
Farm type		
Poor	0.59	17.02
Moderate	0.64	18.28
Wealthier	0.57	17.89
Fertiliser status		
With Fertilizer	0.66	18.76
Without Fertilizer	0.54	16.20
P sector	0.025	< 0.001
P farm type	0.060	0.25
P fertilizer status	< 0.001	< 0.001
SED sector	0.002	0.62
SED farm type	0.02	0.76
SED fertilizer status	0.02	0.39

*Interactions between factor, farm, fertiliser were not significant at P < 0.05

Maize nutrient uptake and use efficiency indices

Table 4 shows N, P and K uptake by the maize crop in the field experiment. Nitrogen levels were significantly higher in stover (P = 0.003) and grain (P = 0.008) with fertilizer application than in the control treatment. No significant location and farm type effects were observed for nutrient uptake. Phosphorus levels of maize stover and grain were higher in plots with fertilizer application than in unfertilized plots. Phosphorus level was larger in maize grain at Simbi compared than in Maraba.

Table 4: Maize N, P and K uptake (kg ha^{-1}) by maize crop in the field experiment in the Maraba and Simbi sectors of Rwanda

	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	Stover	Grains	Stover	Grains	Stover	Grains
Sector						
Maraba	24.7	17.3	3.9	1.1	15.8	10.5
Simbi	16.7	32.4	3.6	3.0	16.7	13.6
Farm type						
Poor	15.6	14.5	2.6	1.2	11.4	8.01
Moderate	21.8	23.0	4.0	2.4	18.8	13.0
Wealthier	24.8	36.9	4.6	2.5	18.6	15.1
Fertilizer status						
With Fertilizer	24.6	31.1	4.4	2.4	17.6	14.4
Without Fertilizer	16.8	18.5	3.1	1.6	14.9	9.71
P sector	0.077	0.126	0.48	0.025	0.98	0.58
P farm type	0.238	0.070	0.15	0.159	0.34	0.19
P fertilizer	0.003	0.008	0.002	0.010	0.53	0.05
SED sector	4.76	7.95	0.84	0.64	5.17	3.46
SED farm type	5.82	9.73	1.01	0.79	6.33	4.23
SED fertilizer	2.09	3.64	0.28	0.23	3.76	2.00

*Interactions between factor, farm, fertiliser were not significant at $P < 0.05$

Maize nutrient uptake and use efficiency indices

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Table 4: Maize N, P and K uptake (kg ha^{-1}) by maize crop in the field experiment in the Maraba and Simbi sectors of Rwanda

	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	Stover	Grains	Stover	Grains	Stover	Grains
Sector						
Maraba	24.7	17.3	3.9	1.1	15.8	10.5
Simbi	16.7	32.4	3.6	3.0	16.7	13.6
Farm type						
Poor	15.6	14.5	2.6	1.2	11.4	8.01
Moderate	21.8	23.0	4.0	2.4	18.8	13.0
Wealthier	24.8	36.9	4.6	2.5	18.6	15.1
Fertilizer status						
With Fertilizer	24.6	31.1	4.4	2.4	17.6	14.4
Without Fertilizer	16.8	18.5	3.1	1.6	14.9	9.71
P sector	0.077	0.126	0.48	0.025	0.98	0.58
P farm type	0.238	0.070	0.15	0.159	0.34	0.19
P fertilizer	0.003	0.008	0.002	0.010	0.53	0.05
SED sector	4.76	7.95	0.84	0.64	5.17	3.46
SED farm type	5.82	9.73	1.01	0.79	6.33	4.23
SED fertilizer	2.09	3.64	0.28	0.23	3.76	2.00

*Interactions between factor, farm, fertiliser were not significant at P < 0.05

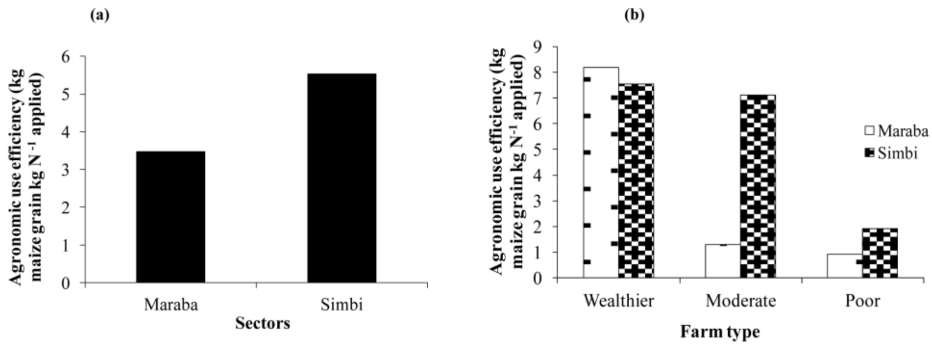

Figure 1. Agronomic N use efficiency in Maraba and Simbi (a) and in wealthier, moderate and poor farms of Maraba and Simbi sector (b).

Beans yield as influenced by location, farm category and fertiliser treatment

The results on bean productivity are reported in Table 5. The average number of pods per plant was significantly ($P<0.001$) influenced by fertilizer application. On average, plants had 5 pods in fertilized fields against 3 in unfertilized fields. The number of grains per pod was similar in both locations but was significantly ($P<0.03$) larger in fertilized fields (average 5 grains pod^{-1}) compared to 4 grains per pod in unfertilized fields. Bean yield was similar across locations and across farms. Fertilizer application significantly ($P<0.001$) increased bean yield by 61% relative to the yield in unfertilized field. Number of pods per plant and number of grains per pod were closely related to the total beans yield by a linear relationship with R^2 greater than 50% (Figure 3).

Table 5: Number of pods plant^{-1}, grains pod^{-1} and bean yield (kg ha^{-1}) in the field experiment in the Maraba and Simbi sectors of Rwanda

	Number of pods plant^{-1}	Number of grains pod^{-1}	Bean yield (kg.ha^{-1})
Sector			
Maraba	5	4	1064
Simbi	5	4	1277
Farm type			
Poor	4	4	891
Moderate	5	4	1272
Wealthier	5	4	1030
Fertiliser status			
With Fertil.	5	5	1446
Without Fertil.	3	4	895
P sector	0.063	0.573	0.087
P farm type	0.005	0.855	0.105
P fertiliser status	<0.001	0.03	<0.001
SED sector	0.86	0.9	142.6
SED farm type	0.24	1.82	149
SED fertiliser status	0.04	0.2	215.6

*Interactions between factor, farm, fertiliser were not significant at $P < 0.005$

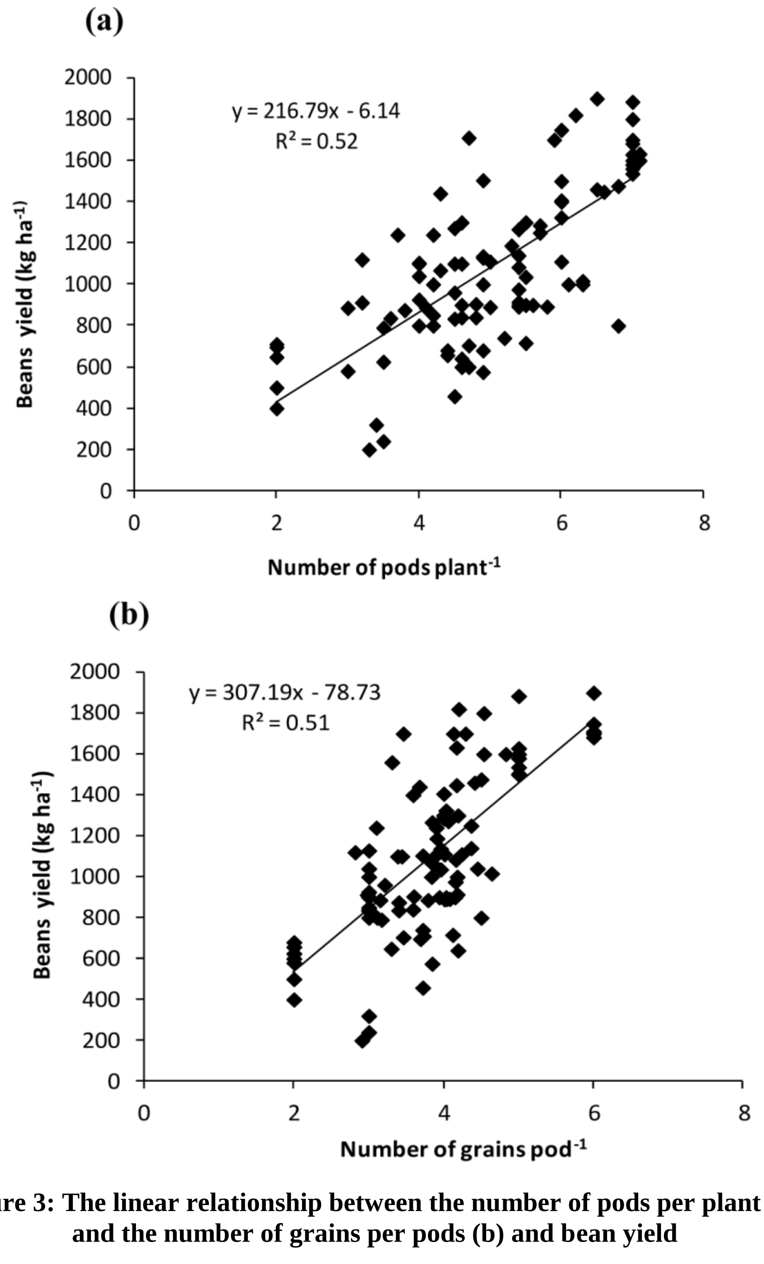

Figure 3: The linear relationship between the number of pods per plant (a) and the number of grains per pods (b) and bean yield

4. Discussion

The two study locations were selected from the same agro-ecological zone and therefore biophysical conditions were broadly expected to be similar. However, differences at local level (farm level) are reflected in cropping systems and soil fertility status of both locations. Soils in Maraba are relatively poor, as revealed by most of soil fertility indicators (Table 1). Tuber and root crops such as sweet potatoes and cassava adapt well to these soils. In Simbi, loamy soils dominate on uphill and clay soils in wetland, resulting in relatively higher water retention, allowing cultivation of a mix of cereals and legumes, root and tubers in the area. Due to differences in farmer management practices, local conditions (farm or field level) largely differ from one farmer or group of farmers to another and such variability greatly influences soil fertility status and subsequent crop productivity. Diversity in farming systems appears to be a general feature in sub-Saharan Africa and it has been largely reviewed by a number of authors (Tittonell et al., 2005a, 2005b; Zingore et al., 2007). In smallholder farms in East Africa, large differences in soil fertility status were noticed among fields even within farms as small as 1.5 ha (Tittonell et al., 2005a), suggesting that the magnitude of differences between smaller farms may be significant at farm and village level and may substantially impact on crop production. Therefore, biophysical and socio-economic conditions are important when conducting research at farm level.

Maize and bean showed better crop response in Simbi than in Maraba due to more fertile soils in the former site (Table 1). Maize grain yield was the highest in Simbi with fertilizer application (Table 2). Similar effects were confirmed by greenhouse experiment (Table 3). Higher maize yield in Simbi is a result of more nutrients taken up by maize crops (Table 4) but also better use of these nutrients as indicated by better nutrient use efficiency (Figure 1). Though maize crop yield differed between locations, bean yield was similar in Maraba and Simbi despite differences in soil fertility status. This could partly be to the fact that bean is a N fixing species and used N fixed from the atmosphere in addition to N from the soil. In this study, we could not differentiate the individual effect of N from the fertilizers applied from the effect of N from the biological nitrogen fixation (BNF) process. Quantifying N fixed through BNF requires complex methods that are outside the scope of this study.

Farm type had no effect on maize yield, despite clear differences in soil fertility between farm types (Table 1). However the trend indicated higher maize and beans yield on farms from the moderate and wealthier categories compared to the poor farmer category (Tables 2 & 3). Also levels of nutrient uptake were comparatively larger in plants harvested from moderate or wealthier farms than in plants from poor farms (Table 4). In beans, the number of pods per plant was significantly influenced by the farm type where the highest number of pods per plant was recorded on the moderate and wealthier farms (5 pods per plant) and the smallest recorded on the poor farms (Table 5). The number of pods per plant is a determinant of bean yield as evidenced by a linear relationship between this parameter and beans yield (Figure 3), implying that the number of pods can potentially be used as a proxy of beans yield.

Agronomic use efficiency by maize crop was much better in Simbi than in Maraba. The results indicated that nutrients were used in a more efficient way in fertile soils. The same trend was noticed in earlier studies across SSA (e.g. Zingore et al., 2007). However, soil fertility may not be the only factor explaining greater response on fertile soils compared to degraded soils; other factors may greatly influence the agronomic use efficiency, including soil texture and crop variety (Tittonell et al., 2007; Zingore et al., 2007).

Unlike previous works done in several sites of Rwanda, the current study attempts to assess the level of nutrients uptake and the amount that accumulate in harvestable crop parts on a basis of fertilizers applied. The calculation of nutrient use indices is of importance since fertilizer applications are often based on blanket recommendations in most African countries (Vanlauwe and Giller, 2006). In Rwanda, recommendations mineral fertilizers are still subjective and not based on variable soil fertility context within different farms. Yet a number of priority crops maize and rice grown on large areas are receiving huge amount of subsidized mineral fertilizer from the Government. Determining site-specific recommendation rates for expensive fertilizers at several locations in Rwanda may be beneficial. Knowledge about the amount of nutrients that are effectively utilized by crops can potentially help in adjusting the amount of fertilizers needed on a given soil type and for different crop species and possibly realize savings on fertilizer use.

5. Conclusion

Soil fertility management had a significant influence on the productivity of maize and bean crops. Maize yield was greater in Simbi than in Maraba, demonstrating that biophysical factors such as location (sector) and the initial soil fertility in the field greatly influence the crop yield. Nutrient use efficiency was highest at Simbi with 5.54 kg maize grain kg^{-1} fertilizers applied and in wealthier farms, indicating that both biophysical and farmer management practices may influence crop resource use on-farm. The approach using the resource use indices may be useful in terms of adjusting the fertilizer rate recommendation for different farms and crops and, possibly avoiding application of surplus fertilizers and realizing economic savings.

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