Field Crops Research 212 (2017) 52–60

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Profitability of diammonium phosphate use in bush and climbing bean-maize rotations in smallholder farms of Central Burundi

Marie-Chantal Niyuhire[a,c,*], Pieter Pypers[b], Bernard Vanlauwe[b], Generose Nziguheba[b], Dries Roobroeck[b], Roel Merckx[c]

[a] Institut des Sciences Agronomiques du Burundi (ISABU), P.O. Box 795, Bujumbura, Burundi
[b] International Institute of Tropical Agriculture (IITA), c/o ICIPE, Kasarani, P.O. Box 30772-00100, Nairobi, Kenya
[c] Division of Soil and Water Management, Department of Earth and Environmental Sciences, K.U. Leuven, Kasteelpark Arenberg 20, P.O. Box 2459, 3001 Heverlee, Belgium

A R T I C L E I N F O

Keywords:
Bean-maize rotation systems
Bean varieties effect
Fertilizer
Net returns
Integrated soil fertility management

A B S T R A C T

Soil fertility decline is a major constraint to bean (*Phaseolus vulgaris* L.) and maize (*Zea mays*) production in the Central Highlands of Burundi. Nutrient sources, specifically fertilizers, are paramount to increasing the production in the regions. Hence, improving fertilizer use efficiency is considered as a key factor towards sustainable intensification. The use of grain legumes with low harvest indices, such as climbing beans, are assumed to improve soil fertility and fertilizer use efficiency. This study compares the rotational effects of bush and climbing bean varieties on maize and evaluates the profitability of diammonium phosphate (DAP, 18–46-0) fertilizer in the bean-maize rotations in 59 smallholder farms of Mutaho district, Gitega Province in Central Burundi. The application of DAP fertilizer significantly increased the grain yields by 14% and 21% for bush and climbing beans, respectively ($P < 0.001$). Positive effects of bean varieties were large for about 80% of the farmers. Climbing beans in general yielded more than bush beans for about two thirds of the farmers and fertilizer effects were positive. In the bean-maize rotations, the fertilizer induced on average a yield increase of 8% and 22% for maize following bush and climbing beans, respectively. Maize grain yields were significantly ($P < 0.001$) higher following climbing beans than following bush beans. The value cost ratio (VCR) more than doubled compared with the common practice (bush bean-maize rotation). Variation was substantial, and for approximately 67% of the farmers, DAP application was profitable (VCR > 2 \$ \$$^{-1}$) in a climbing bean-maize rotation while 45% of the farmers in a bush bean-maize rotation. Regression tree analysis showed that targeting fertilizer use to soils with higher C and clay content, and ensuring timely planting are the predominant factors to ensure fertilizer response and profitable returns. This study confirms the need for integrated soil fertility management (ISFM), and that a combination of judicious fertilizer use, an improved grain legume (climbing bean) and adjustment to local conditions (targeting to responsive soils) maximizes economic returns of legume-cereal rotation systems.

1. Introduction

Burundi is facing food insecurity due to a decrease in soil fertility and a high population density, with more than 90% of the population being traditional farmers. Burundi's population is currently growing at 3% per year, which is expected to continue (CIA, 2015). This leads to enormous land pressure resulting in continuous (intensive) cultivation and depletion of soil nutrients. In such conditions, soil fertility decline is a major factor limiting per capita crop production in the area. The smallholder farmers are not able to buy and apply adequate quantities of mineral fertilizers and/or organic sources of nutrients, precluding soil fertility replenishment.

Agriculture is considered as the backbone of Burundi's economy and is the second most important contributor to the gross domestic product (GDP) after the service industry. However, agricultural productivity is low and constrained by certain agro-ecological and socio-economic factors, like soil degradation and lack of market access (Worldbank, 2014). Especially the decline in soil fertility as a result of soil nutrient mining and erosion, is threatening a secure food supply.

Crop rotations with annual grain legumes have been reported to improve soil physical, chemical and biological conditions in the long run (Bagayoko et al., 1996; Chan and Heenan, 1996; Bagayoko et al.,

* Corresponding author at: Institut des Sciences Agronomiques du Burundi (ISABU), P.O. Box 795, Bujumbura, Burundi.
E-mail addresses: mariechantal.niyuhire@ees.kuleuven.be, maricha2014@gmail.com (M.-C. Niyuhire).

http://dx.doi.org/10.1016/j.fcr.2017.06.024
Received 8 April 2017; Received in revised form 21 June 2017; Accepted 21 June 2017
Available online 11 July 2017
0378-4290/

2000; Giller, 2001; Yusuf et al., 2009), thereby enhancing soil nutrient availability (Loewy, 1987). Not only the annual grain legumes are expected to increase soil N through the BNF, but they can also improve the N use efficiency and prompts changes in various N sources, affecting their availability to the plant (López-Bellido and López-Bellido, 2001). However, most annual grain legumes grown under smallholder farming conditions in sub-Saharan Africa (SSA), cannot supply alone all the N requirements by the non-legume component of the maize-based cropping system. The current practice of exporting all aboveground biomass of the legume at harvest often contributes to negative soil N balance (Sanginga et al., 2002). Supplementary N fertilizer would therefore be necessary to increase the yield of the subsequent maize crop.

Sustainable agricultural intensification is urgent and may be implemented through the integrated soil fertility management (ISFM) framework, recognized for boosting crop productivity (Vanlauwe et al., 2010). In this, improving fertilizer use efficiency is considered a key factor. One of the appropriate ways of addressing soil fertility depletion and increasing fertilizer use efficiency is the combined application of organic and mineral fertilizers. This has been shown to be especially relevant in low-external input systems, typical for SSA including Burundi and forms an integral part of ISFM (Vanlauwe et al., 2010).

Legume-cereal rotation is reported by Rayar (2000) cited by Ndayisaba (2013) as one of the well-established agronomic practices for successful ISFM. Its advantages are (i) addition of organic matter through incorporation of crop residues, (ii) improved soil moisture management, (iii) addition of Nitrogen (N) through the inclusion of legume in the rotation, (iv) effective control of insects and diseases, (v) effective weed control, (vi) assured income to the farmers, and (vii) an increased agronomic efficiency of mineral fertilizer. The sum of these effects explains why maize yields are consistently reported to be improved when grown following a legume in rotation. The size of the rotational yield effect varies with the legume varieties. From the literature, it was shown that climbing bean is of greater importance compared to bush bean for nitrogen fixation under different agronomic conditions (Graham and Rosas, 1977; Graham and Temple, 1984; Kipe-Nolt and Giller, 1993). Climbing bean is by far the bean type with high biomass production and probably high N fixation capacity; therefore, considerable rotational benefits are expected, and its integration in the production system can improve and sustain crop productivity (Lunze and Ngongo, 2011). The capacity to fix N can go up to 125 kg N ha^{-1} for climbing bean while 35 kg N ha^{-1} for bush bean (Guerena, 2016). However, a positive effect on soil-N depends on the harvest index of the beans, which may still imply a zero negative budget (Vanlauwe and Giller, 2006). In fact, van Schoonhoven and Pastor-Corrales (1992) reported by Lunze and Ngongo (2011) found that climbing bean develops extensive nodulation three times more than bush bean, which is an indication of higher capacity for N fixation. The evidence of benefit of climbing bean cultivation may exist, either as rotational effects or as improved nitrogen nutrition. There is necessity of rational use of this potential to develop farming practices that are economically viable. Although climbing bean is being extensively promoted in the potential regions to intensify productivity, the soil fertility benefits of climbing bean versus bush bean have been very little studied and exploited. It is, however, assumed that climbing bean promotion is the appropriate strategy for higher productivity and sustainability for smallholder farmers.

In the current study, the application of mineral fertilizers was tested with improved bean varieties, in rotation with a subsequent improved maize variety. Rotational effects of a bush and climbing bean variety were compared, and the profitability of diammonium phosphate (DAP, 18–46-0) fertilizer assessed in bean-maize rotations in smallholder farms of Mutaho district, Gitega Province in Central Burundi.

2. Material and methods

2.1. Study area

The study was conducted in Mutaho district, Gitega Province in Central Burundi. The climate is humid-tropical. The district is characterized by a bimodal rainfall pattern with long rains (LR) between February and June and short rains (SR) between October and January. The mean annual temperature varies between 15 and 20 °C (ISTEEBU, 2014). Rainfall during the first season (beans, LR 2012) was 569 mm, and during the subsequent season (maize, SR 2013) was 321 mm, while averages during the past 20 years were 520 mm and 369 mm for the LR and SR, respectively. The available rainfall data are estimates from the Tropical Rainfall Measuring Mission (TRMM) by National Aeronautics and Space Administration (NASA), with a resolution of 0.25 × 0.25°. The dominant soil types in the region are Ferralsols (WRB, 2015). Bean-maize rotation is one of the most important cropping systems, practiced by all rural households (CIALCA, 2015). We therefore implemented this type of rotation in a field experiment conducted over two seasons, comparing an improved bush and climbing bean variety planted in LR 2012 (February to June 2012), and a subsequent maize crop planted during SR 2013 (October 2012 to January 2013). Trials were set up in 59 farmer's fields in Mutaho district (29° 51′ E, 3° 09′ S), within a 5 km diameter area (average distance between fields of 1.8 km) to cover variation in local soil fertility while minimizing variation in rainfall conditions. Only fields with less than 10% of slope and having enough space for the experiment were selected. Fields next to the scrubland, recently cleared and/or isolated fields were avoided. Before trial establishment, the fertility status of the selected fields was characterized based on composite soil samples taken from the 0–20 cm layer in each farmer's field. Composite soil samples were taken at eight locations in each farmer's field, thoroughly mixed, then air-dried and sieved over a 2 mm screen before being shipped to the International Center for Tropical Agriculture (CIAT) in Nairobi for analysis. Soil pH was determined in a 1:2.5 w/w soil-water suspension (Metson, 1956). Olsen P was determined according to Olsen et al. (1954), using a buffered $NaHCO_3$ extraction (0.5 $\underline{M}$ $NaHCO_3$ + 0.01 $\underline{M}$ EDTA, pH 8.5) and measured colorimetrically (Riley, 1962). Soil texture was assessed using the hydrometer method (Bouyoucos, 1962). Total C and total N were analyzed by Gas Chromatography (GC), following oxidative digestion of samples under a controlled oxygen supply at high temperature (approx. 900 °C) in a C/N analyzer (Carlo Erba EA1110 elemental analyzer) (Dumas, 1826). Analysis results are presented in Table 1.

Table 1
Main characteristics of the study area (n = 59).
Source: Author, * Ouma et al. (2010) and ** ISTEEBU (2014).

Parameters measured	Unit	Mean	Range
Soil properties			
pH_{water}		5.8	4.9–8.5
Olsen P	mg kg^{-1}	8.2	2.7–27.1
TC	g kg^{-1}	23.7	11.3–34.5
TN	g kg^{-1}	1.8	1.0–2.8
Clay	%	36.9	32.4–45.3
Sand	%	41.0.	37.2–45.1
Silt	%	17.0	13.9–21.8
Biophysical characteristics			
Altitude (meters above sea level)	m	1559	1499–1618
Annual mean temperature**	°C		15–20
Topography			
Dominant soil type (WRB,2015)			Ferralsols
Slope	%	2.04	0.25–6.78
Socio-economic indicators			
Average farm size*	ha	0.5	0.4–0.8
Population density**	#km^{-2}	432	
Family size*	#	6	
Distance to main market**	km	42	

The trial establishment was performed at the onset of the season by the farmers and supervised by a team of an agronomist and technicians. All field operations during crop growth were performed by farmers, while observations during growth and at the harvest were taken by an agronomist and technicians. In each field, four plots were demarcated to accommodate two improved bean varieties each receiving two treatments, a control without fertilizer, and a treatment with DAP applied at one bag (50 kg) per hectare (9 kg N ha^{-1} and 10 kg P ha^{-1}). The experimental design was a latin-square (species randomized in the x-direction and fertilizer application in the y-direction).

All plots received a basal application of manure, applied along the planting rows as blanket treatment at a rate of 2500 kg ha^{-1} before planting. Manure was supplied by the Burundi Agricultural Research Center of Murongwe located in Mutaho district. The application of manure to crops is common in the area. The C/N ratio of the manure applied was 15.8, and nutrient contents were 20 g N kg^{-1}, 1.5 g P kg^{-1}, 21.6 g K kg^{-1}, 6.4 g Ca kg^{-1}, and 13.7 g Mg kg^{-1} on a dry matter basis.

The plot size was measuring 36 m^2 (6 m x 6 m). Improved varieties of bush bean and climbing bean, "MLB 122-94B" and "G13607", respectively, were planted at a spacing of 50 cm between planting lines and 40 cm between plants within lines, and two bean seeds planted per hill.

Maize *(Zea mays)* was planted in the SR season (SR2012) following the harvest of beans (*Phaseolus vulgaris* L.) on the same plots. An improved "ZM605-24C", an open pollinated maize variety from CIMMYT Zimbabwe, was planted at a spacing of 75 cm and 50 cm inter-and intra-row, respectively and two maize seeds were planted per hill. The control and fertilized treatments were laid out as for beans but with a different rate for DAP (two bags of 50 kg per hectare, or 18 kg N ha^{-1} and 20 kg P ha^{-1}). The DAP was applied as a single dose just before planting. In addition, 100 kg urea ha^{-1} (46 kg N ha^{-1}) was applied 45 days after planting as a blanket treatment to all plots of maize.

At maturity, bean and maize crops were harvested in a net plot (10 and 6 rows respectively for bean and maize crops in each plot) and the fresh weight of both grains was taken. The aboveground biomass was not measured and left to farmers. The bean and maize grains were then air-dried and the dry weight taken.

2.2. Statistical analyses

A Linear Mixed-Effect Model based approach was used to test the effects of fertilizer and bean variety yield, using the 'lmer' package (Bates et al., 2014) of the R statistical analysis software (Team, 2016). The model includes fixed effects for variety and fertilizer (and their interaction), and two random intercepts for farmer (or field), calculated separately for each level of variety and fertilizer, respectively. Maximum likelihood tests were carried out to ascertain contribution of the random effects to overall explained variance. The fixed effects assess whether there are differences between the means of the effects of the two bean varieties, fertilizer treatments and their interaction. Least square means with confidence intervals, and standard errors of difference (SED) were calculated to evaluate the significance of variety and fertilizer effects and their interaction at $P. \leq .0.1$, $P. \leq .0.05$ $P. \leq .0.01$ and $P. \leq .0.001$. The random part assesses whether there are differences in the distribution (variance) of yields in individual fields between bean varieties, or fertilizer treatments, and the variance associated with a change in bean variety or to fertilizer application were calculated based on the estimated variance and covariance components.

Thereafter, best linear unbiased prediction (BLUP) was used for the estimation of random effects of variety and fertilizer. By convention, BLUPs are referred to as predictions, calculated from the estimated mean and variance, and the data. Fertilizer and variety BLUPs were then tested for correlation with soil covariates (pH, Olsen P, total C, total N, Clay, Sand and Silt) and delay in planting. The delay in planting was defined as the number of days that passed since the first farmer planted. Rainfall was not included as a covariate, as trials were close to one another (within a 5 km diameter area) and therefore experienced little difference in rainfall.

Regression tree analysis was used as a way of making quantitative predictions (for soil covariates and delay in planting) and was fitted to each node to give the predicted values of the dependent variable (fertilizer/variety effects). The predictors were then plotted in regression trees using the "*rpart*" package (Therneau et al., 2015) and cross-validated for both variety and fertilizer effects. As the dataset is rather small (n = 59), only two levels were retained for each tree in order to maximize their probability.

2.3. Economic analysis

A simple financial analysis was performed to assess the profitability of the treatments. The total cost (TC) of the operations included the costs for land preparation, seeds, application of manure and/or DAP fertilizer inputs, staking for climbing bean, weeding, harvesting and post-harvest handling. Staking one hectare of climbing bean requires around 25,000 stakes, with a cost estimated at $ 350; corresponding to that used by Ruraduma et al. (2012). In this study, one stake was used for 4 plants (2 hills) and gave the highest yield (Ruraduma et al., 2012). Labor was valued at a wage of $ 0.17 per hour. One bag of 50 kg of fertilizer costed $ 40 and $ 26.67 for DAP and urea, respectively. Bean and maize grains were sold at 0.67 and 0.4 $ kg^{-1}, respectively. Opportunity cost for land were not included, as land was available in the area. This analysis was done for individual crops (bean and maize) and for the rotational cycle by using the farm gate prices of the inputs and outputs. Original prices were recorded in Burundi Francs (BIF) and converted to United States dollar ($). One $ was about 1500 BIF, February 2012.

Net benefits (NB), expressed in $ ha^{-1}, were calculated as the production value (PV) minus the total costs (TC). To assess profitability of fertilizer use, the value cost ratio (VCR, $ $^{-1}$) and marginal rate of return (MRR, $ $^{-1}$) were calculated as the ratio of the difference in PV between the treatment with fertilizer and the control, over the difference in TC, and the ratio of the difference in NB between the treatment with fertilizer and the control, over the difference in TC, respectively. To calculate the profitability for the rotational cycle, PV, TC and NB were summed for the bean and subsequent maize crop, and then the VCR and MRR were calculated. The VCR should have a minimum of 2 (CIMMYT, 1988) for alternative practices to be profitable to farmers.

Regression tree analysis was then performed to predict which covariates among the soil parameters (pH, Olsen P, total C, total N, clay, sand and silt) and delay in planting (renamed as delayPBeans and delayPMaize, as these are two different things when evaluating VCR of the system for beans and maize) that would explain the most profitable bean-maize rotation system.

3. Results

3.1. Productivity of bean-maize systems under different practices

3.1.1. Means and variation in distributions of varieties/systems and fertilizer effects

The productivity of different bean varieties and DAP fertilizer for the first season is summarized in Table 2. The average grain yield for bush beans is 1000 kg ha^{-1} in the control plots and 1138 kg ha^{-1} in the fertilized plots showing a fertilizer-induced yield increase of 14% (138 kg ha^{-1}). For the climbing beans, the grain yield is on average 1550 kg ha^{-1} in the control plots and 1871 kg ha^{-1} in the fertilized plots. The fertilizer-derived yield increase is 21% (321 kg ha^{-1}). The response to DAP fertilizer was significantly ($P < 0.001$) larger in climbing beans than in bush beans (Table. 2).

In the second season, the productivity of maize following the different bean varieties and as affected by DAP fertilizer is also

Table 2
Mean grain yields (kg ha^{-1}) of bush beans, climbing beans and maize (following bush beans/climbing beans) for both control and fertilized plots of the individual 59 fields in the study.

Treatment	First season		Second season	
	Bush beans	Climbing beans	BB-M	CB-M
	Overall mean grain yield (kg ha^{-1})			
Control	1000	1550	4008	4053
DAP	1138	1871	4342	4929
SED	95	128	370	400
SED fertilizer (F)	38***		200***	
SED bean species (S)	98***		253***	
SED F x S	144***		381***	

BB-M: Maize following bush beans; CB-M: Maize following climbing beans; SED: Standard error of difference (only presented when significant at $P \leq 0.05$); *** Significant at $P \leq 0.001$.

summarized in Table 2. For maize following bush beans (BB-M), the average grain yield was 4008 kg ha^{-1} in the control and 4342 kg ha^{-1} with fertilizer applied. The fertilizer-induced yield increase is on average 8% (334 kg ha^{-1}). For maize following climbing beans (CB-M), the grain yields were on average 4053 kg ha^{-1} in the control plots and 4929 kg ha^{-1} in the fertilized plots. The yield increase due to fertilizer application hence is on average 22% (876 kg ha^{-1}). Maize grain yields were not significantly ($P < 0.05$) different in the control treatments, but the response to fertilizer was significantly ($P < 0.001$) higher following climbing beans than following bush beans (Table 2).

Based on the variance and covariance components associated with farmer, the distribution of the effect of a change in bean variety (climbing beans instead of bush beans), and the effect of fertilizer application were calculated and plotted (Fig. 1). The effect of changing bush beans for climbing beans resulted in a yield increase for about 80% of the farmers. The effect of fertilizer application was positive for about two thirds of the farmers. Variance in the effect of a change in bean variety was larger than variance in fertilizer effect.

Similarly, in the subsequent season, the distribution in effects on maize yield of the preceding bean varieties, and the effect of fertilizer were calculated and plotted (Fig. 2). The variation between the different farmers was larger for fertilizer effects (yield in the treatment with DAP minus control yield), than for cropping system effects (yield of maize following climbing beans minus yield following bush beans). For about 60% of the farmers, fertilizer effects were positive. Maize grain yields of the CB-M system were larger than those for the BB-M system for about 48% of the farmers ($P < 0.05$).

3.1.2. Varieties/systems and fertilizer effects as affected by soil covariates and crop management

Regression tree analysis was performed to evaluate whether BLUPs for bean varieties effects or fertilizer effects can be related to soil parameters (pH, Olsen P, total C, total N, clay, sand and silt). We included as well “delay in planting” as a parameter, but no other parameters related to crop management (weeding, cropping cycle, etc.) because they were standardized and cannot explain variation, or rainfall data trials were near to one another (within 5 km diameter area) and did not experience much difference in rainfall.

In the first season, bean effects were larger in soils that have high total N (TN > 1.8 g kg^{-1}) and Olsen P (P > 4.9 mg kg^{-1}) contents. Fertilizer effects were larger when planted early (less than 3.5 days delay), and in soils with high total C content (TC > 25 g kg^{-1}) (Fig. 3). For the second season, effects of the preceding bean varieties were larger when planted early (less than 6.5 days delay) in soils with moderate pH (pH ≥ 5.8), or in soils with low clay content (less than 38% clay). Fertilizer effects on the subsequent maize were larger when planted early (less than 8.5 days delay) in soils with moderate clay (34–38%) content (Fig. 3).

3.2. Economic analysis

In the first season, farmers growing bush beans without fertilizer had on average higher net benefits (NB) than when growing climbing beans, as the benefits from the higher yield did not compensate for the

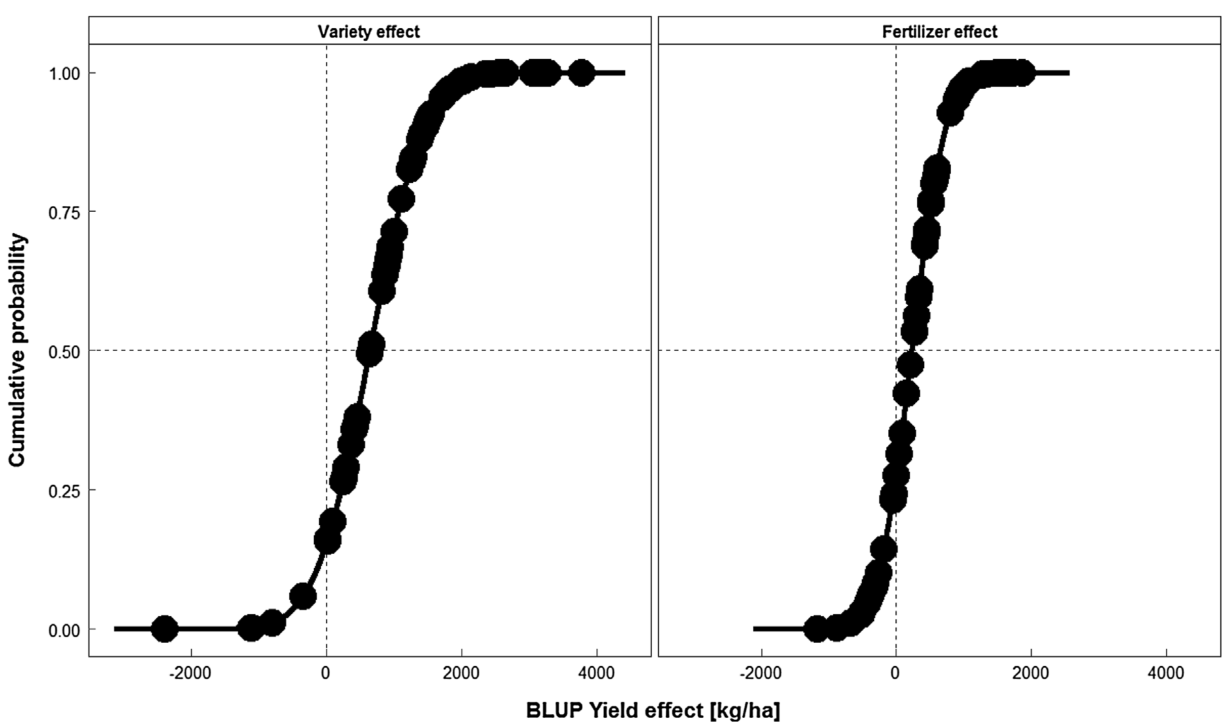

Fig. 1. Modeled variation in bean variety effect (climbing bean yield minus bush bean yield) (left) and the fertilizer effect (yield with fertilizer minus control yield) (right). ‘BLUPs (Best Linear Unbiased Prediction)’ are plotted for the individual 59 fields in the study. The cumulative probability (Y-axis) reflects the likelihood for obtaining an effect larger than a given yield effect (X-axis).

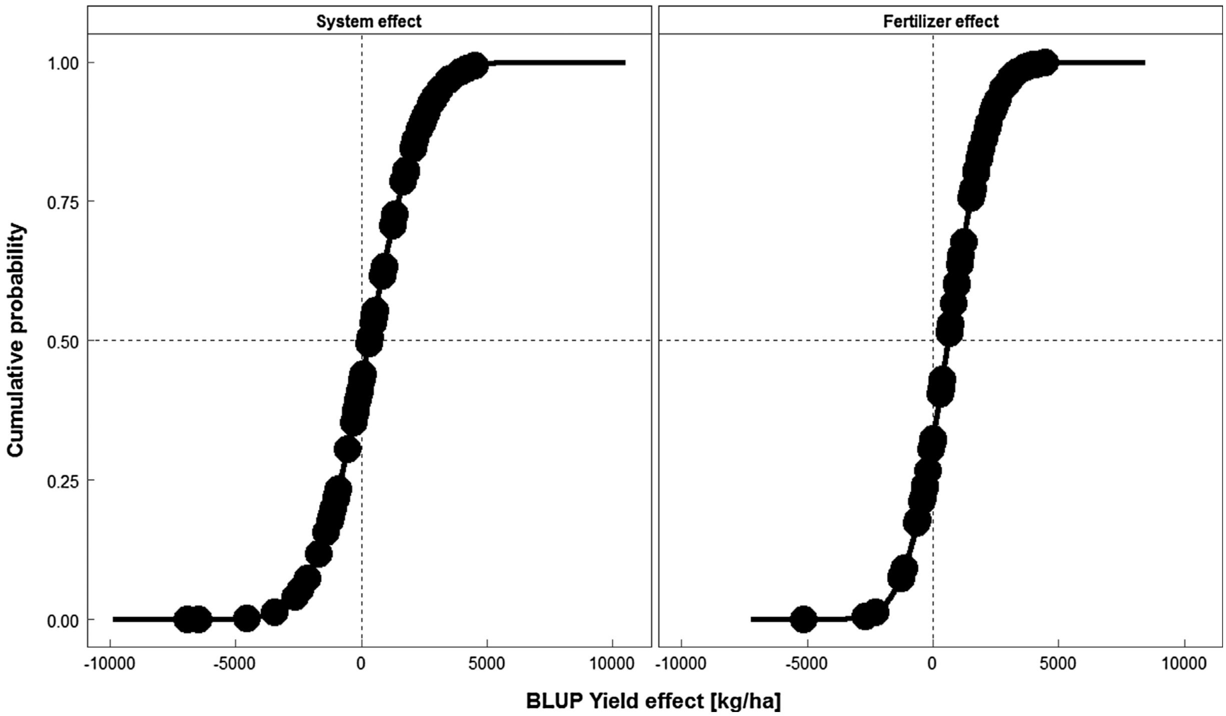

Fig. 2. Modeled variation in effect of preceding beans varieties (maize yield following climbing beans minus yield following bush beans) (left) and the fertilizer effect (yield with fertilizer minus control yield) (right). 'BLUPs (Best Linear Unbiased Prediction)' are plotted for the individual 59 fields in the study. The cumulative probability (Y-axis) reflects the likelihood for obtaining an effect larger than a given yield effect (X-axis).

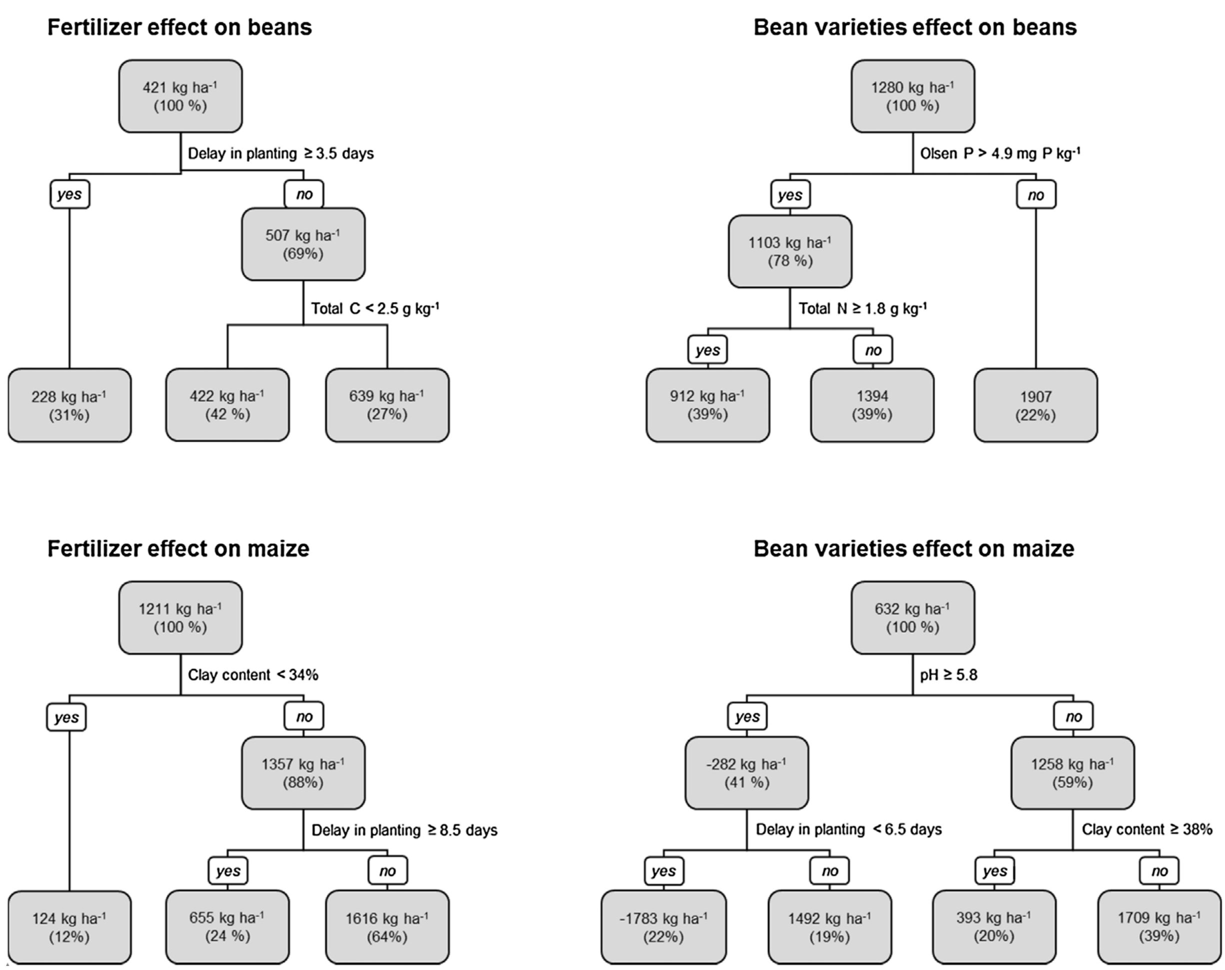

Fig. 3. Regression trees analysis results for the individual 59 fields in the study, restricted to two branching depths, for BLUPs for bean varieties or fertilizer effects as explained by soil parameters and delay in planting. The average grain yield effects and proportion of observations (%) are also shown at each node.

Table 3
Financial analysis, including total costs (TC), net benefits (NB), value cost ratio (VCR), and marginal rate of return (MRR) from the application of combined manure and DAP fertilizer to improved bush, climbing bean varieties cropped in rotation with maize crop at the end of their crop cycles for the individual 59 fields in the study.

System	TC		NB		VCR	MRR
	Control	DAP	Control	DAP		
	$ ha^{-1}				$ $$^{-1}$	
Bush bean-maize rotation						
BB	296.79	336.79	236.92	270.08	1.83	0.83
BBM	278.37	358.37	1057.95	1088.11	1.38	0.38
Total	575.16	695.16	1294.87	1358.19	1.53	0.53
Climbing bean-maize rotation						
CB	746.89	786.89	79.99	210.18	4.25	3.25
CB-M	278.37	358.37	1075.89	1284.89	3.61	2.61
Total	1025.26	1145.26	1155.88	1495.07	3.83	2.83
SED#	ns	ns	134.78	161.47	0.61	

BB-M: Maize following bush beans; CB-M: Maize rotated to climbing beans. SED: Standard error of difference. TC: Total cost ($ ha^{-1}); NB: Net benefit ($ ha^{-1}); VCR: Value cost ratio ($ $$^{-1}$); MRR: Marginal rate of return ($ $$^{-1}$); #SED: Standard error of difference (only presented when significant at $P < 0.05$); ns: not significant.

cost of staking (Table 3). Fertilizer use increased total costs (TC), slightly increased NB (on average) but significantly ($P < 0.05$) when applied to bush beans, and significantly large increased ($P < 0.001$) when applied to climbing beans. The value cost ratio (VCR) was more than doubled (4.25 $ $$^{-1}$) compared with the bush bean (1.83 $ $$^{-1}$). Generally, a value of 2 $ $$^{-1}$ is considered as cut-off point to consider an investment profitable (CIMMYT, 1988). For the subsequent maize crop, similarly, the application of DAP increased NB more following climbing beans than following bush beans, and the VCR values were profitable (on average, 3.61 $ $$^{-1}$). As yields of maize were higher following climbing beans, NB and profitability was also higher. Summed over both crops, net benefits were highest in the climbing bean-maize rotation with fertilizer applied with VCR values again profitable (on average, 3.83 $ $$^{-1}$).

Fig. 4 shows modeled variation in value cost ratio (VCR) for fertilizer cumulated over the first bean crop and subsequent maize crop. The VCR in climbing bean-maize rotation was profitable for 67% of the farmers, while only profitable for 45% of the farmers in the bush bean-maize rotation.

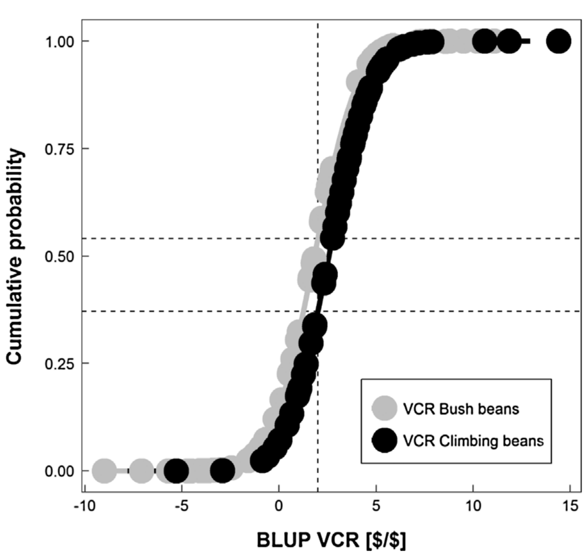

Fig. 4. Modeled variation in value cost ratio (VCR) for fertilizer cumulated over the first bean crop and subsequent maize crop, and 'BLUPs (Best Linear Unbiased Prediction)' plotted for the individual 59 fields in the study. The cumulative probability (Y-axis) reflects the likelihood for obtaining a value larger than a given VCR (X-axis). Vertical line denotes VCR = 2, and horizontal lines intersect with the cumulative distribution curves for bush beans and climbing beans as first crop.

The covariates that predict the high profitability in the climbing bean-maize rotation were soil total C larger than 23 g kg^{-1}, soil total N lesser than 2 g kg^{-1} and more than 37% of clay content (Fig. 5).

4. Discussion

4.1. The productivity of maize-based systems under different practices

The first cropping season was exclusively under bean production. Genetic characteristics of both climbing beans and bush beans could explain the yield differences observed between the two bean varieties (Marandu et al., 2013). The climbing beans are particularly more productive, efficient land users by producing two or three times more than bush bean types (Mazina et al., 2014). They were also more tolerant to environmental stresses including both abiotic (rainfall irregularity/drought, nitrogen and phosphorus deficiencies and acidic soils) and biotic (fungal, bacterial and viral diseases; insects pests) constraints (Beebe et al., 2012).

The high productivity of climbing beans is also due to their longer growth cycles and larger biomass accumulation (Blair et al., 2004). This biomass may provide ground cover, control weeds and contribute to soil organic matter when not all the leaves are harvested (Ramaekers et al., 2013). In our case study, the length of growing cycle ranged from 110 to 120 days for climbing beans ("G13607") and from 80 to 90 days for bush beans ("MLB 122-94B") varieties, respectively. MLB 122–94 B also called "MUSENGO" was selected for its high yield (600–800 kg ha^{-1}), size (medium) and color of the seeds (white streaked brown); and tolerance to pests and diseases (ISABU, 2012). G13607 locally called "TWUNGURUMURYANGO" was also selected for its high yield (750–1000 kg ha^{-1}) under farmer practices (Ntukamazina et al., 2009). The use of DAP fertilizer (50 kg ha^{-1}) increased on average grain yields up to 1000 kg ha^{-1} for bush beans and 1800 kg ha^{-1} for climbing beans, respectively.

With improved management practices, climbing beans can produce up to 4000 kg ha^{-1} while bush beans can produce between 1000 and 2000 kg ha^{-1}, as reported by CIAT (2005) cited by Mazina et al. (2014). The climbing beans are often preferred by smallholder farmers as a solution to decreasing land sizes as the same yield can be obtained on a smaller piece of land compared to bush beans (Ramaekers et al., 2013). However, farmers are constrained by the poor availability of improved seeds (Kalyebara and Buruchara, 2008; Ibrahim, 2013) at the local market. This may be explained by the poor adaptation of new varieties to most farmers' conditions; lack of incentives to motivate extension agents, extension services; poor farmers' ability to access improved seeds from the markets due to low incomes and lack of credit facilities, poor seed delivery system and inadequate seed security stocks and lack of a clear seed strategy (Ibrahim, 2013). Moreover, competition from farmer local seeds, strong regional preference specific varieties are some of the local market dynamics (Almekinders et al., 1994; David, 2004). At farm level, stresses biotic and abiotic stresses, poor availability and cost of stakes, and lack of knowledge on the best staking methods (Mazina et al., 2014).

Soil N and P were the most important soil characteristics determining the yield differences between the two bean varieties (Fig. 3). The higher the N and P the larger the bean yield differences. However, the effects of these two nutrients were more observed on climbing beans compared to the bush beans. In spite of these nutrients being relatively high, they were still below the critical values of fertilizer response. Especially for N, the value of 1.8 g kg^{-1} is below the critical value of 2.5 g N kg^{-1} presumed for N response as reported by Okalebo et al. (2002) cited by Koskey et al. (2017). Therefore, the climbing beans still fix N and this had contributed to high yields obtained from this legume (Beebe et al., 2012). In addition, the relatively high P may have enhanced more N fixation by the climbing beans compared to the bush beans (Beebe et al., 2012).

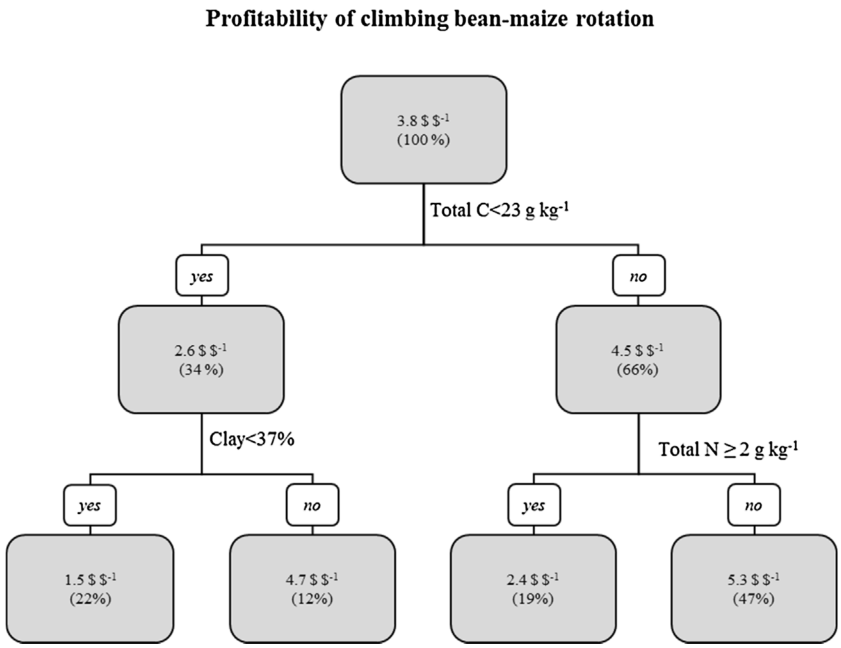

Fig. 5. Regression tree analysis results (n = 59), restricted to two branching depths, for profitability of climbing bean-maize rotation as explained by soil covariates and delay in planting (for beans and maize). The value cost ratio values and proportion of observations (%) are shown at each node.

Application of DAP fertilizer to the two bean varieties resulted in large yield differences when planted on time and on soils with a total C below 2.5%. Such response was expected since the initial soil analysis indicated that the soils in which beans were cropped, were of low fertility, acidic, with small amounts of total N, total C and Olsen P (Table 1). Acidic soils may render N and P unavailable, the latter through P adsorption and the former by slowing down nitrification (Stevenson and Cole, 1986). Micro-organisms that are important in mineralization of organic N and P compounds, are also inhibited in acidic soils (Stevenson and Cole, 1986).

In the second season, where maize was rotated with beans, the variety and fertilizer effects were large when maize was planted on time in soils with moderate clay (34–38%) content and a pH of about 5.8. These effects were mostly realized from the climbing bean-maize system compared to the bush bean-maize system. The effects may be attributed to a larger residual soil N from the former system compared to the latter (Bagayoko et al., 1996). These effects obviously derive from the larger amounts of above- and belowground biomass/residues returned to the plots after harvesting the beans and perhaps also because of changes in microbial activities after legumes (Shipton, 1977; Turco et al., 1990). The same effect is sometimes referred to as allowing subsequent crops to access more P (Johnson et al., 1992; Bainville et al., 2005). Combing manure with DAP gave larger grain yield compared to the application of manure alone. This underlines the importance combined use of inorganic and organic fertilizer resources for improved crop performance and the more so for these acidic soils (Vanlauwe et al., 2001).

Maize yields obtained from control plots were high due to the fact that those plots benefited from application of manure. Next to the application of manure to an improved maize variety, the good management practices provided by technicians of the research center of Murongwe also contributed to the high yields obtained in the control plots. All inputs were provided by the same research center and therefore of certified quality. In addition, the residual effect of bean biomass left to the fields may have also contributed to the high yields observed from the control plots, but its fate was not carefully monitored. The farmers may have used it for livestock, if any, or heaped it to compost.

Famers have variable access to sources of organic matter. They resort to leaving crop residues on the field, use compost and in rare cases green manures (Giller et al., 1997). In general, the amounts so recycled are small and of low quality. Sometimes when they have money they can buy livestock that will produce some manure, but often also of poor quality. Manure of good quality is mainly provided from farmers' organizations or cooperatives and agricultural research stations. Only few farmers are able to access such manure due to their general low income. The same applies for access to improved seeds. These can be available at the beginning of the season in agricultural research stations or farmers' cooperatives but at prices too high compared to the price of non-improved seeds which are always available at the local market. In general, Burundi is still facing inadequate seed security stocks and lacks a clear seed strategy (Ibrahim, 2013).

Manure can influence nutrient availability through (i) the total nutrients added, (ii) the control of net mineralization-immobilization patterns, (iii) serving as a source of C and energy to soil microbes, (iv) serving as precursors of soil organic matter resulting in more favorable soil physical and chemical properties (De Ridder and Van Keulen, 1990), and (v) through interactions with the mineral soil in complexing toxic cations and reducing the P sorption capacity of the soil (Palm et al., 1997). An application of 2500 kg ha^{-1} of manure supplied the following amounts of nutrients per hectare: 50 kg N, 37.5 kg P, 54 kg K, 16 kg Ca and 34 kg Mg respectively for both bean and maize crops. These values are close to those reported by Lupwayi et al. (2000) while evaluating plant nutrient contents of cattle manure from small-scale farms and experimental stations in the Ethiopian highlands. They applied 3000 kg ha^{-1} of manure from which supplied nutrients were on average per hectare: 35 − 82 kg N, 7 − 21 kg P, 32 − 163 kg K, 30 − 74 kg Ca, 10 − 37 kg Mg, 11 − 67 kg Fe, 0.8 − 5.7 kg Mn, 0.02 − 0.26 kg Cu and 0.15 − 0.65 kg Zn. The differences in nutrient contents are due to the animal type and diet and the way manure was stored. Under African conditions, however, where animal diets are often very poor, the composition of macronutrients may be lower than the values indicated above that are derived from a research station (Bayu et al., 2005). The positive effect of these nutrients on maize yields was realized for about 60% of the farmers. With the use of the same nutrients, maize following climbing beans out yielded maize following bush beans for about 48% of the farmers (Fig. 2).

4.2. Economic analysis

Low grain yields obtained from the control under bush beans resulted in small net benefits. This was not the case for its corresponding fertilized treatment where yields and net benefits were increased by 14% respectively. On the other side, climbing beans had high yields and large net benefits although the staking was quite expensive (Table 3).

Large fertilizer and bean variety effects consequently resulted in large value cost ratio. For climbing beans, VCR values on average, 4.25 $ $^{-1}$ more than doubled the average of 1.83 $ $^{-1}$ obtained from bush beans. The same trend was also observed for maize planted after beans, where the control maize plots on average yielded 4000 kg ha^{-1}. The value cost ratio was on average two times larger when maize followed climbing beans than when it followed the bush beans (Table 3).

The application of DAP was highly profitable (VCR ≥ 2) for the climbing bean-maize rotation (Fig. 4). Such profitability was realized when maize yields had ranges between 1067 and 4622 kg ha^{-1}. This yields were obtained from fields with high total C (TC > 23 g kg^{-1}), low total N (TN < 2 g kg^{-1}) and high clay content (more than 37% clay) (Fig. 5). However, the delay in planting failed to predict the profitability for the climbing bean-maize rotation since high delays in beans did not coincide with high delays in maize. In fact, all farmers who planted their beans late planted their maize on time, and vice versa. This explains why there is only a negligible predictive value in the delay parameters.

The total costs and the net benefits were significant and largely different between the control and DAP fertilizer treatments ($P < 0.001$) across all cropped fields (n = 59) and for both bean-maize systems (Table 3). The use of manure in combination with DAP fertilizer for the climbing bean-maize system resulted in larger grain yields, larger net benefits, larger value cost ratio and marginal rate of return than in the bush bean-maize system. It is essential to achieve durable yield improvements, but intensification can only proceed if farmers have access to markets to buy seeds, commercialize their produce at a reasonable price and purchase inputs at a subsidized price. Farmers are encouraged to adopt this practice to improve soil fertility and be assured of net returns to investments (Kimani et al., 2004). Therefore, it is paramount to account for economic net return of introduced practices. Profitability is the main driver for adoption by farmers, but risk and uncertainty also influence farmers 'decision-making (Chianu et al., 2002 cited by Pypers et al. (2012)).

5. Conclusion

Results from this study revealed that an improved climbing bean preceding an improved maize on soils enriched with manure in combination with DAP fertilizer is a promising alternative to the local smallholder farmers' practices. This may lead to a more sustainable maize production in Mutaho District of Central Burundi. The climbing bean-maize rotation was more profitable compared to the bush bean-maize rotation.

For the system to be profitable, there is a need for integrated soil fertility management, and that a combination of judicious fertilizer use, an improved grain legume (climbing bean) and adjustment to local conditions (targeting to responsive soils) maximizes economic returns of legume-cereal rotation systems.

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