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

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ABSTRACT

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.,

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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 M $NaHCO_3$ + 0.01 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	