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Benefits of inoculation, P fertilizer and manure on yields of common bean and soybean also increase yield of subsequent maize

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ABSTRACT

Common bean and soybean yield poorly on smallholder farms in Rwanda. We evaluated the benefits of inoculation combined with P fertilizer and manure on yields of common bean and soybean in three agro-ecological zones (AEZs), and their residual effects on a subsequent maize crop. In the first season, the treatments included inoculum, three rates of manure, and two rates of P fertilizer, with nine replications (three per AEZ). Both legumes responded well to inoculation if applied together with manure and P fertilizer. Grain yields varied from 1.0 t ha^{-1} to 1.7 t ha^{-1} in unamended control plots to 4.8 t ha^{-1} for common bean and 3.8 t ha^{-1} for soybean in inoculated plots with both P and manure addition. The response of common bean and soybean to inputs varied greatly between AEZs. In the AEZ with low and erratic rainfall (Bugesera), yields of both legumes and maize were low and maize after soybean failed to yield any grain due to drought. In this regard, early maturing legume varieties are advised in regions of low rainfall. Responses of maize to an input applied to the legumes strongly increased when other inputs were applied together to the legume. This allowed greater maize yields which ranged from 0.8 t ha^{-1} in control plots to 6.5 t ha^{-1} in treatments previously inoculated with P and manure added for maize grown after common bean and from 1.9 t ha^{-1} in control plots to 5.3 t ha^{-1} for maize grown after soybean. The amount of N_2-fixed measured using the ^{15}N-natural abundance method differed between the two legumes and varied between 15 and 198 kg N_2 ha^{-1} for common bean and between 15 and 186 kg N_2 ha^{-1} for soybean and differed enormously among treatments and AEZs. Application of inputs to the legumes also resulted in enhanced N and P uptake of the subsequent maize. The use of inoculum combined with manure and P fertilizer is a good option for smallholder farmers growing common bean and soybean in rotation with maize. We observed strong effects of environment and call for care when targeting crops and technologies for sustainable crop production.

1. Introduction

Legumes have an important role in improving soil health in sustainable agriculture (Vanlauwe et al., 2010). They have the ability, through symbiosis with rhizobia bacteria, to fix atmospheric nitrogen and yield well without mineral nitrogen fertilizer, improve soil fertility, and their rotation with cereals helps to control diseases and pests in cereals (Giller, 2001). However, the contribution of legumes to soil fertility is minimal if N_2-fixation by the legume is constrained by an adverse environment (Giller and Cadisch, 1995). Integrated soil fertility management (ISFM) has gained much attention as a key option for boosting crop productivity through combining fertilizer use with other approaches to soil fertility management, adapted to local conditions (Vanlauwe et al., 2010). Various studies have shown the benefits of integrating ISFM in existing cropping systems. For instance, application of P fertilizer to the legume in a legume-maize rotation cropping system yielded high grain and biomass of the legume, which in turn resulted in better performance of the subsequent maize crop, thus reducing the need for external N fertilizer (Kihara et al., 2010; Vandamme et al., 2014). Targeting biological nitrogen fixation (BNF) technologies to agro-ecological niches within farming systems is of importance since the fertilizer is an expensive input which is hard to access for many smallholder farmers (Giller et al., 2013). If legume stover is not retained in the field, residual N is largely contributed by root and nodule senescence and fallen leaves (Ledgard and Giller, 1995). The benefits of legumes to the subsequent crops result not only from enhanced N availability following the legume crop but also from other rotational, non-N effects (Sanginga et al., 1999; Franke et al., 2016). These

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rotational effects include a reduction of pests and diseases, mobilization of poorly soluble P and increased mycorrhizal colonization of a subsequent cereal crop leading to enhanced P uptake (Bagayoko et al., 2000; Franke et al., 2016).

Population increase in Rwanda has led to small farm sizes, land fragmentation and soil fertility decline mainly as a result of intensive cropping with little or no nutrient inputs. The use of fallows to restore soil fertility is no longer possible (Rutunga et al., 1998). Common bean and soybean are the most widely cultivated legumes and promoted in the Rwandan Government's Crop Intensification Programme (MINAGRI, 2009). The two legumes are grown for household consumption and for sale. Soybean cultivation is increasing due to its expanding market demand. Common bean is the main source of dietary protein: consumption was reported to be on average 38 kg of beans per person per year (CIAT, 2008). Yet, despite the high consumption of common bean and the expanding market demand of both beans and soybeans, yields achieved by smallholder farmers are poor: only 0.8–1.0 t bean ha^{-1} and 0.8–1.7 t soybean ha^{-1} (FAOSTAT, 2010).

Farmyard manure and mineral fertilizer are important options to increase crop productivity (Zingore et al., 2008a, 2008b). Manure contribute not only to the restoration of soil fertility in depleted fields, but also in improving the response of crops to other nutrients, and enhanced N and P uptake in the legume-cereal rotations. As manure supplies exchangeable bases and other micronutrients, this helps to alleviate deficiencies reducing legume nodulation and N_2-fixation. Despite the 'One cow per poor family' initiative which was introduced by the national government to boost agricultural productivity, the use of cattle manure in Rwanda is constrained by on-farm availability (MINAGRI, 2009). As elsewhere in Africa, the use of mineral fertilizers in Rwanda is limited by high costs (Kelly and Murekezi, 2000) and poor distribution systems (Vanlauwe and Giller, 2006).

Since indigenous rhizobia are not always in sufficient numbers, effective enough or compatible with the specific legume crop to stimulate BNF and increase yields, inoculation of legumes with rhizobia is an important option for enhancing BNF in crop production systems (Giller, 2001). The effectiveness of BNF is affected by agro-ecological factors. For instance poor nodulation and poor plant vigour in beans grown in soil with low extractable P led to a poor BNF (Amijee and Giller, 1998). However, if P fertilizer was added to beans, consistent responses to inoculation in BNF and grain yield were achieved. Other environmental stresses, such as high temperatures and dry soil can affect the symbiosis between common bean rhizobia, leading to a lack of responses to inoculation (Hungria et al., 2000).

Positive responses of cereal yields after the cultivation of legumes, relative to a cereal monoculture, have been reported frequently (Ojiem et al., 2014; Osunde et al., 2003; Franke et al., 2016). Yet we lack information on whether there are benefits of combined applications of inoculation with manure and/or P fertilizer application on the yields of grain legumes and whether these benefits are translated into increased yields of a subsequent cereal crop. We conducted a field study in three agroecological zones (AEZs) of Rwanda with the following objectives: (1) to assess the effect of inoculation, P fertilizer and manure addition on yield and yield components of common bean and soybean, (2) to evaluate the influence of environment on the response of the two legumes to inputs across the three AEZs, and (3) to evaluate how these treatments influence yield of a subsequent maize crop.

2. Materials and methods

2.1. Study sites

The study was carried out in farmers' fields in three contrasting AEZs of Rwanda. In each AEZ, one district was selected where trials were established. Bugesera district was selected from the Bugesera AEZ, located in the South-East of the country at 02°12′18″S and 30°08′42″E at an altitude of 1435 m above sea level (masl), with a mean annual rainfall of 800 mm. Kamonyi district from the Granitic ridge AEZ, in the central plateau of the country, at 2°00′25″S and 29°50′49″E, 1661 masl, 1200–1400 mm rain. Kayonza district from the Eastern plateau AEZ in the eastern part of the country, at 1°55′59″S and 30°31′13″E, 1601 masl, 1000–1200 mm rain.

2.2. Trial establishment

Three experimental fields per district were selected for each legume in the short rains (SR) 2014 and maize was planted in the same treatments after the two legumes in the long rains (LR) 2014. In Bugesera and Kayonza, each treatment block with common bean was next to the one with soybean and blocks were replicated on three different farms in the same village. In Kamonyi, all three common bean treatment blocks were placed next to each other on the same farm, and two soybean blocks were placed on one farm, and the third block on another farm.

Three treatment factors applied to the legumes were: 1) without or with inoculation with *Rhizobium tropici* CIAT 899 for common bean and *Bradyrhizobium japonicum* USDA 110 for soybean; 2) manure at three rates: 0, 5 and 10 t ha^{-1}; 3) P fertilizer at two rates: 0 and 30 kg P ha^{-1} added as triple super phosphate. The experiments were laid out in a split–split plot design with P fertilizer as the main plot, inoculum as sub-plot and manure as sub-sub-plot with a full set of treatments per block. Plot size was 5 m × 5 m. Next to each treatment block, a plot (5 m × 5 m) sown with maize served as a reference crop to assess BNF. The reference crop plots were fertilized with 5 t ha^{-1} of manure and weeds were controlled by hand. No P fertilizer was added to the reference crop.

The SR start in September and end in December, and the LR follow from March to June. Land was prepared with a hand hoe. Common bean variety RWR 2245 and soybean variety SB 24 were planted at a density of 50 cm × 10 cm for common bean and 40 cm × 10 cm for soybean with 1 m paths between main plots and sub plots to minimize cross-contamination. Manure applied to the experimental fields was provided by the participating farmers, and applied to her/his own field. In the LR 2014 season, maize variety ZM 607 was planted in all treatments at a density of 75 cm × 30 cm. No nutrients were added to the maize. No maize was planted at Kayonza as farmers mixed up the treatments during ploughing.

2.3. Measurements

2.3.1. Common bean and soybean

Prior to planting, soil and manure samples were collected from each experimental block for chemical analysis. Soil sampling (0–20 cm) at nine points in each field were done following a W shape. The nine samples were combined, air-dried and passed through a 2 mm sieve. Moreover, samples from the manure provided by the participating farmers were collected and chemically analysed. In the legumes, biomass and nodulation were assessed at mid-podding. A small sub-plot of 0.5 m^2 (leaving 0.5 m away from the plot border) was sampled. All plants were cut at ground level and fresh weight was determined. A sub sample was taken and weighed, sun dried, then oven dried at 65 °C to constant weight, and re-weighed for dry biomass yield determination. After cutting the biomass, the underground parts were gently uprooted, washed and nodule count was done by scoring 0–5 as follows: 0: No nodules; 1: < 5 nodules; 2: 5–10 nodules; 3: 11–20 nodules; 4: 21–50 nodules, and 5: > 50 nodules. Final grain and stover yields were determined at crop maturity by harvesting all pods from the net plots excluding the outer plant lines of both sides of the plot, and determining total fresh weight. A sub-sample was taken, weighed and sun-dried for several days and then threshed by hand. Grains were cleaned by winnowing and subsequently weighed and the moisture content was determined using an electronic moisture meter. The haulms were harvested by cutting them at ground level. Total fresh weight of the haulms was taken. Representative sub-samples of haulms from each plot were