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On-farm evaluation and determination of sources of variability of soybean response to *Bradyrhizobium* inoculation and phosphorus fertilizer in northern Ghana

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ABSTRACT

Soybean yields on smallholder farms in sub-Sahara Africa (SSA) are far below the potential yield thus creating a huge yield gap. Interventions are thus needed to bridge this yield gap and ascertain the factors influencing the yield variation. This study evaluated the on farm response of soybean to rhizobia inoculation and or mineral P fertilizer in Northern and Upper West regions of Ghana in a single non-replicate trial using four treatments: no input (control), TSP fertilizer (P), rhizobia inoculant (I) and TSP plus inoculant (P + I). In addition, the study sought to develop a robust approach for determining responsiveness and non-responsiveness using agronomic and economic indices. The results showed that the average grain yield of plots that received P or I were higher than control plots. Higher grain yield responses were however, obtained by the plots that received combined application of P and *Bradyrhizobium* inoculant. Grain yield response in the Northern region was higher than in the Upper West region. Response to P and or I were highly variable within and between locations. The cumulative rainfall and some soil factors including soil nitrogen, phosphorus, soil type, organic carbon, pH and texture explained about 42–79% of these variations in soybean grain yield. The agronomic approach for determining responsive and non-responsiveness revealed that 17–40 % and 6–17% of the locations within the Northern and Upper West regions, respectively were responsive to P fertilization and/ or *Bradyrhizobium* inoculation. However, the economic approach indicated that 64–75% and 14–24% of the locations within the Northern and Upper West regions, respectively were responsive to P fertilization and *Bradyrhizobium* inoculation. The results imply that rhizobia inoculation is an effective strategy for increasing soybean yield and improving livelihood of smallholder farmers.

1. Introduction

Soybean plays an important role in the diets of many due to its protein content. In addition, production of soybean generates income for smallholder farmers and improve their livelihood. However, its production is largely limited by the inherent low fertility nature of smallholder farms in SSA. Soybean like any other legume requires high amount of N to attain optimum growth (Hungria and Kaschuk, 2014). The low amount of soil N and P in smallholder farms, coupled with minimal or no external inputs to boost production have resulted in low grain yields. The current grain yields recorded by farmers are less than 1 t ha^{-1} and that far below the potential yield of 2.5 t ha^{-1} (Mensah, 2014; Dugje et al., 2009)

Various interventions have been proposed to address this issue but the most significant and affordable one is the provision of N and P through rhizobia inoculation and mineral P fertilization, respectively. Combined application of rhizobia inoculant and mineral P fertilizer is known to mostly increase grain yield of legumes such as soybean and cowpea. Ronner et al. (2016) reported a significant increase in grain yield of 452 kg ha^{-1} and 447 kg ha^{-1} due to rhizobia inoculation and single superphosphate application in Nigeria. Masso et al. (2016) reported a significant increase in grain yield of 426 kg ha^{-1} and 482 kg ha^{-1} due to the application of rhizobia inoculant and triple superphosphate in Ghana. Greater yield response are obtained when rhizobia

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inoculant and phosphorus fertilizer are combined. For instance, Ronner et al. (2016) and Masso et al. (2016) reported grain yield increases of 777 kg ha^{-1} and 631 kg ha^{-1}, respectively in soybean when inoculant application was combined with phosphorus fertilizer. Kyei-Boahen et al. (2017) also reported 56% yield increase in cowpea when inoculant was applied together with P in Mozambique.

Nonetheless, soybean – rhizobia symbiosis is affected by the environment, management, rhizobia strain and legume genotype (Woomer et al., 2014). These factors determine the success or otherwise of the symbiosis in increasing yield. In situations, where only one strain of rhizobia is involved and the legume genotype is promiscuous, the environmental factors and management practices will be the major contributing factors, controlling yield. For example, Ronner et al. (2016) reported that 16–60% of the variations were explained by the environmental factors. Fermont et al. (2009); Bielders and Gerard (2015) and Falconnier et al. (2016) also reported that the environmental, management and soil factors explained 20% 58% and 49% of the variability in cassava, millet and sorghum-cowpea-soybean yields, respectively under smallholder farmer conditions. Soils in sub-Sahara Africa exhibit a wide variability in soil fertility (Giller et al., 2011) and this contributes to the limitation of the treatment potential in increasing yield and the spatial response to the treatments on smallholder farmers.

The spatial variability in soil fertility on smallholder farms in SSA has also led to the classification of soils as responsive and non-responsive (Vanlauwe et al., 2010; Kihara et al., 2016). This is of major interest and the discussion about finding appropriate method for classification is still an on going research. The current method involve setting of yield ceilings and percentages; however, this method is very subjective. Kihara et al. (2016) used K-means clustering to determine maize response to fertilizer in their nutrient omission trial setting a yield threshold of 3 t ha^{-1}.

The N2Africa and COMPRO II Projects have disseminated legume rhizobia technology to smallholder farmers in the northern Ghana aiming at high adoption rates by the farmers. Given that adoption of such technologies represent risk of forgoing their current practices, it is imperative to establish which locations within the region will demonstrate effective and stable crop responses. Although, it is true that the spatial variation in nutrients on smallholder farms causes yield variation, little is known of the magnitude and direction (positive or negative) of such effects. This study therefore sought to (i) evaluate the on-farm response of rhizobia inoculant and or mineral P fertilizer; (ii) develop a robust approach for determining responsive and non-responsiveness using agronomic and economic indices; and (iii) identify the major factors limiting soybean response on smallholder farms in northern Ghana. This work will allow for better targeting of future dissemination technologies to areas where the potential of the treatments could be maximized. In addition, having knowledge of the factors limiting soybean response to inoculation and phosphorus application will lead to initiation of measures to address these challenges.

2. Materials and methods

2.1. Study area

Agronomic trials for testing the response of soybean to rhizobium inoculant and phosphorus fertilizer were set up in Northern region (Savelugu – Nanton and Gushiegu - Karaga districts) and Upper West region (Sissala West, Sissala East and Wa municipal) during the 2015 cropping season as illustrated in Figs. S1 and S2. The rainfall pattern in the study locations is unimodal with an average annual rainfall of 1000–1200 mm and mean temperature between 26 and 30 °C with little variation throughout the year. The rainfall data were downloaded from www.awhere.com

2.2. Soil sampling and analyses

Seven soil core samples were taken from each plot, thoroughly mixed and composite samples taken into transparent polythene bags and kept in a refrigerator at 4 °C prior to laboratory analysis. The soil parameters analysed were particle size (hydrometer method), soil pH (1:2.5) (H_2O), organic carbon (modified Walkley and Black procedure as described by Nelson and Somers (1996), total nitrogen (Kjeldahl method as described by Bremner and Mulvancy (1982), available soil phosphorus (Bray No. 1 solution as outlined by Olsen and Sommers (1982) and exchangeable potassium (ammonium acetate (NH4OAc) extract. Calcium and magnesium were determined in 1.0 *M* ammonium acetate (NH4OAc) extract (Black, 1965). Active carbon was determined following the procedure of Culman et al. (2012).

2.3. Training of agricultural extension agents (AEAs) on protocol (treatments)

Due to the large number of demonstration sites, the experiment was conducted in partnership with AEAs and farmers. It was imperative to equip the AEAs with technical knowledge for successful implementation of the trials. The training focused on the handling, application of rhizobium inoculant and phosphorus fertilizer, selection of sites, good agronomic practices and data collection.

2.4. Mobilization of farmers

Northern and Upper West regions were selected for the study due to the predominance of soybean cultivation in those two regions. Farmers in the selected locations within each district had been previously introduced to legume-inoculant technology by non-governmental organizations and therefore understood the demands of the technology. Mobilization of farmers was done through community sensitization and education about improved soybean technologies with the AEAs. Interested farmers were selected by the AEAs, organized into groups of 20–25 people. Within farmer groups, lead farmers were selected and trained on the handling and application of *Bradyrhizobium* inoculant, phosphorus fertilizer application and good agronomic practices. Each farmer received an improved soybean variety, rhizobium inoculant (Nodumax) and triple super phosphate (TSP). As a requirement, farmers were asked to set up the trials at locations visible to others especially non-participating farmers.

2.5. Field preparation, layout, inoculation and sowing

Each field was ploughed and harrowed to a depth of 15 cm and divided into 4 plots measuring 10 m x 10 m with an alley of 1 m. The soybean seeds were sown at a distance of 75 cm x 10 cm. The soybean cultivar, Jenguma (TGx series) was used. Five grams of the *Bradyrhizobium* inoculant was added to 1 kg of seeds and applied using the two-step method (Somasegaran and Hoben, 2012). Planting between the districts were done in a week interval and within a week for each district with the help of AEAs. In the Northern region, planting was done between 7 – 13th July 2015. In the Upper West region, planting was done between 15–21 August 2015.

2.6. Treatments and experimental design

There were four (4) treatments: inoculant only (I), TSP (only) (P), no input (control) and a combination of TSP and inoculant (P + I). The treatments were tested in a simply non- replicated trial where each farm within a district was considered a replicate. The rhizobium inoculant (Nodumax) contained 10^9 cells g^{-1} of *Bradyrhizobium japonicum* strain USDA 532c. The TSP (46% P_20_5) was applied at a rate of 30 kg P ha^{-1}. The mode of application was band placement. About 136 and 45 demonstration trials were established in the Northern and Upper West

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