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Understanding variability in soybean yield and response to P-fertilizer and rhizobium inoculants on farmers' fields in northern Nigeria

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ABSTRACT

Soybean yields could benefit from the use of improved varieties, phosphate-fertilizer and rhizobium inoculants. In this study, we evaluated the results of widespread testing of promiscuous soybean varieties with four treatments: no inputs (control); SSP fertilizer (P); inoculants (I) and SSP plus inoculants (P + I) among smallholder farmers in northern Nigeria in 2011 and 2012. We observed a strong response to both P and I, which significantly increased grain yields by 452 and 447 kg ha^{-1} respectively. The additive effect of P + I (777 kg ha^{-1}) resulted in the best average yields. Variability in yield among farms was large, which had implications for the benefits for individual farmers. Moreover, although the yield response to P and I was similar, I was more profitable due to its low cost. Only 16% of the variability in control yields could be explained by plant establishment, days to first weeding, percentage sand and soil exchangeable magnesium. Between 42% and 61% of variability in response to P and/or I could be explained by variables including year, farm size, plant establishment, total rainfall and pH. The predictive value of these variables was limited, however, with cross-validation R^2 decreasing to about 15% for the prediction between Local Government Areas and 10% between years. Implications for future research include our conclusion that averages of performance of technologies tell little about the adoption potential for individual farmers. We also conclude that a strong agronomic and economic case exists for the use of inoculants with promiscuous soybean, requiring efforts to improve the availability of good quality inoculants in Africa.

1. Introduction

The population of sub-Saharan Africa is projected to double in the next 40 years (Cleland, 2013) and increases in food production are much needed (FAO, 2014b; World Bank, 2014). As the potential to expand agricultural land is limited in many areas with high population densities, sustainable intensification of agricultural production is crucial (Pretty et al., 2011; Garnett et al., 2013; Vanlauwe et al., 2014a). A potential pathway for sustainable intensification is the integration of grain legumes in farming systems (Giller and Cadisch, 1995; Peoples et al., 1995). Legumes have the capacity to fix nitrogen from the air in symbiosis with *Rhizobium* bacteria. Legumes can therefore contribute to improved soil fertility in cereal-dominated cropping systems in Africa, including the savannahs of West Africa (Osunde et al., 2003a; Sanginga, 2003; Franke et al., 2008). Legumes can be grown in rotation with other crops, with the additional advantage of reducing the need for N fertilizer for subsequent cereals in the context of Integrated Soil Fertility Management (ISFM) (Vanlauwe et al., 2010). In addition legume rotations assist in reducing pest and disease incidence (Sanginga, 2003; Yusuf et al., 2009), or are grown as inter- or relay crops, often without compromising the yield of the main crop (Baldé et al., 2011). Grain legumes also have important nutritional value in terms of protein, amino acids and micro-nutrients (Gibson and Ferguson, 2008). The short growing period of some legumes ensures availability of food during the hunger period in the middle of the cropping season (Franke et al., 2004; Rubyogo et al., 2010).

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Legume yields in African smallholder farming systems are often far below their potential. Numerous studies have shown that legume yields can be enhanced with the use of improved legume varieties (Okogun et al., 2005; Buruchara et al., 2011), phosphate (P) based fertilizers (Weber, 1996; Kamara et al., 2007; Kolawole, 2012), rhizobial inoculants (Sanginga et al., 2000; Osunde et al., 2003b; Thuita et al., 2012), or their combination (Snapp et al., 1998; Ndakidemi et al., 2006). Despite increases in the use of inputs among African smallholders on specific crops in some regions (Sheahan and Barrett, 2014), the use of inputs with legumes remains limited (Chianu et al., 2011; Franke and De Wolf, 2011). Moreover, many African countries lack the facilities to produce, store and distribute high quality inoculants (Pulver et al., 1982; Bala et al., 2011).

Since the early 1980s, research has focused on breeding soybean (*Glycine max* (L.) Merrill) varieties that can nodulate with rhizobia indigenous to African soils—so-called 'promiscuous' varieties (Sanginga et al., 2000; Giller, 2001). A breeding programme was initiated at the International Institute for Tropical Agriculture (IITA) in Nigeria to cross promiscuous soybean varieties of Asian origin with varieties from the USA with greater yield potential and better disease resistance (Kueneman et al., 1984; Pulver et al., 1985). The developed varieties had a greater ability to nodulate without inoculation (Sanginga et al., 2000) and they have been widely adopted in West Africa (Sanginga et al., 2003). Despite this success, more recent studies report yield responses to inoculants in these promiscuous varieties (Osunde et al., 2003b; Thuita et al., 2012). Hence, the need to inoculate promiscuous soybean varieties is still under discussion (Thuita et al., 2012), even more so because previous studies did not involve large scale testing of these varieties with and without inoculation under farmers' management.

Nigeria is the largest producer and consumer of soybean in sub-Saharan Africa. Demand continues to grow both as source of feed for the poultry industry and for human consumption. Production is mainly done by smallholders on farms of less than five ha (ACET, 2013). Average soybean productivity in Nigeria is around 1 t ha^{-1} (three-year average 2011–2013 (FAO, 2014a)), way below the yields of around 3 t ha^{-1} achieved on research stations in Nigeria (Tefera, 2011). Soybean production is mainly constrained by poor soil phosphorus availability (Kamara et al., 2007; Kolawole, 2012), diseases such as soybean rust (Twizeyimana et al., 2008) and moisture stress (Tefera, 2011). Other constraints are the high costs or limited availability of good quality inputs (fertilizer, inoculants, herbicides and pesticides (ACET, 2013)). Although many farmers in Nigeria use fertilizers, most is applied to maize and at rates well below what is recommended (Manyong et al., 2001; Sheahan and Barrett, 2014).

Legume yields are determined by the effects of legume genotype (G_L), the rhizobium strain(s) nodulating the legume (G_R), the biophysical environment (E), agronomic management (M) and their interactions, as expressed by the relation (Giller et al., 2013):

$$(G_L \times G_R) \times E \times M$$

Understanding the relation between these variables to enhance legume yields requires analysis of the performance of legume/rhizobium combinations under a wide range of environments and management decisions.

In this paper, we describe the results of the widespread testing of phosphate-based fertilizer (P-fertilizer) and rhizobial inoculants in soybean on farmers' fields in northern Nigeria, with the aim to understand the effects of the different variables in the $(G_L \times G_R) \times E \times M$ relationship on soybean yields and response to input application. We also evaluate the consequences of variability in yield for the distribution of the (economic) benefits of input application. Finally, we explore the ability to predict soybean yields and response to inputs for targeting of technologies based on relevant environmental and management factors.

2. Materials and methods

2.1. Study area

The study was carried out in two states: Kaduna and Kano in northern Nigeria, located between 6°50 and 9°15 East and 9°00 and 12°30 North. Kaduna State was split into two regions (North and South, with the latitude of Kaduna City as the border between North and South) to reflect the high diversity in agroecological conditions and agricultural intensification within the state. Rainfall falls in a single season between May and October. Kano State is the northernmost region with the driest climate (about 800 mm annual rainfall) and the shortest growing season (Table 1) and is more densely-settled than Kaduna State. Kaduna South receives about 1400 mm annual rainfall and has the longest growing season, but soils are highly variable and farming tends to be less intensive (e.g. in terms of fertilizer use and use of animal draught power). Erratic rainfall, poor soil fertility and weed infestation generally limit agricultural production in northern Nigeria (Manyong et al., 2001; Sanginga, 2003). Major crops in all three regions are cereals (maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench) and millet (*Pennisetum glaucum* (L.) R. Br.)). Yam (*Dioscorea* spp.) and ginger (*Zingiber officinale* Roscoe) are important next to cereals in Kaduna South (Franke and De Wolf, 2011). Soybean is an emerging crop in northern Nigeria, with about 30% of the households in Kano State to 50% in Kaduna State cultivating soybean in 2010 (Franke and De Wolf, 2011).

2.2. On-farm try-outs of improved soybean technologies

Around 6,000 households in 2011 and 13,800 households in 2012 participated in a dissemination campaign of improved soybean technologies in Kano, Kaduna North and Kaduna South. In each of these regions, Local Government Areas (LGAs) were selected (Fig. 1) based on their potential for soybean cultivation and in consultation with local partners. An LGA typically covered several villages that were managed by one extension agent. Within each village, participating farmers were selected by extension agents based on the farmer's interest in soybean cultivation and the accessibility of the farm (for visibility of the plot and possibility for other farmers to visit the plots, as the try-outs also served as demonstrations).

Farmers were organized in groups of 20–25 people, consisting of one lead farmer (trained directly by the project) and 19–24 satellite farmers (trained by the lead farmer). Each farmer received a package with seed of an improved soybean variety, single super phosphate (SSP) fertilizer and rhizobial inoculant. Farmers tested the package on their own field in a simple, non-replicated try-out whereby each farm formed a replicate. Lead farmers had try-outs measuring 20 × 30 m, with four treatments on sub-plots of 10 × 15 m; satellite farmers had try-outs of 20 × 20 m with four sub-plots of 10 × 10 m. The four treatments were: no inputs (control); SSP only (P); inoculants only (I) and a combination of SSP and inoculants (P + I). Soybean varieties used came from the IITA soybean breeding programme. All were promiscuously-nodulating varieties but they differed in maturity period, potential grain yield and harvest index (Table 2). Varieties were targeted to particular regions; hence not all varieties were assessed in all regions.

SSP (18% P_2O_5) was applied at a rate of 20 kg P ha^{-1} at planting. Recommendations were to band the fertilizer 10 cm away from the planting line in a 2–5 cm deep trench, covered after application. Actual application methods may have varied but were not