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Agronomic benefits of rhizobial inoculant use over nitrogen fertilizer application in tropical soybean

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Abstract

This study compares the performance of inoculated soybean and the fertilized crop with a control. Soybean was cultivated with the use of inoculant or nitrogen (N) fertilizer application in five farmers' fields in the dry zone of Sri Lanka. Farmers' practices without the inoculant or fertilizer N served as the control. Plant density, nodule and plant dry weights were measured at flowering. Seed yield and seed N were measured at crop maturity. The study reveals that crop performance of tropical soybean could be increased by using greater plant density with inoculation. However, fertilizer application did not show such a trend. High plant densities reduced nodulation due to a limitation of native soil rhizobia to nodulate. This adversely affected seed yield. Both inoculation and fertilizer application increased plant growth and seed yield of soybean, as compared to the farmers' practices. Fertilizer application at the present rate did not suppress nodulation. This study shows the importance of biological nitrogen-fixation (BNF) even under fertilizer application in tropics. Future studies should be focused to evaluate optimal plant densities for maximum yields of soybean under inoculation. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Rhizobial inoculants; Tropical soybean; Nitrogen fertilizers; Agronomic benefits; Plant density

1. Introduction

The greatest success in terms of modified agricultural practices arising from scientific research on BNF has undoubtedly been the development of rhizobial inoculants (Giller and Cadisch, 1995). Soybean has been the only example where there has been widespread adoption, primarily due to the relative specificity of soybean for rhizobia. Inoculation of soybean is a significant agency for the manipulation of rhizobia for improving crop productivity and soil fertility (Keyser and Li, 1992). It can lead to the establishment of a large rhizobial population in the plant rhizosphere and to improved nodulation and N_2-fixation, even under adverse soil N conditions (Peoples et al., 1995). Sometimes, yields are not increased by inoculation, but N concentration in seed or plant parts may be increased over that of non-inoculated plants (Wani et al., 1995). In cases where both types of responses are not observed, the result might simply be a saving of soil N for succeeding crops.

Although BNF has long been a component of many farming systems throughout the world, its importance as a primary source of N for agriculture has diminished in recent decades as increasing amounts of fertilizer N are used for the production of food and cash crops (Peoples et al., 1995; Graham and Vance, 2000a). This has been caused by inadequate demon-

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stration of the technology, presence of adequate native rhizobia to nodulate, though they are inefficient, high soil mineral N levels suppressing BNF, inadequate quality control of inoculants and difficulties of inoculating under tropical conditions (Bantilan and Johansen, 1995). In Zambia, promiscuous soybean cultivars that nodulate abundantly with indigenous soil rhizobia have been selected and released to farmers (Jahaveri and Joshi, 1987). This has also contributed to the decline of demand for inoculants. It is also important to note that fertilizer N use also poses potential problems such as phytotoxicity, ammonia volatilization and nitrate accumulation (Bremner, 1995). In order to revive the role of BNF in agriculture, agronomic benefits of rhizobial inoculant use over fertilizer N application need to be demonstrated, because the impact of agronomic practices on the BNF is grossly understudied (Graham and Vance, 2000b). This study compares crop performance of tropical soybean under inoculant use and fertilizer N application.

2. Materials and methods

Sri Lanka has a tropical climate and is divided into wet, intermediate and dry zones, based on the intensity and distribution of precipitation (Domros, 1974). The present study was conducted in farmers' fields in Huruluwewa watershed situated in the Anuradhapura district of the dry zone. The mean annual rainfall in the zone is around 1300 mm, distributed in a major ('Maha') cropping season which extends from October to January and a minor ('Yala') cropping season that extends from April to June. Soybean is grown during the minor cropping season with irrigation in rice-based cropping systems. Soil in the watershed is a Rhodustalf, characterized by a pH (1:5 in H_2O) 6.4, 1.1% organic C and 0.096% total N. Five farmers' fields distributed in an area of ca. 125 ha were selected as replicates for the study. Two plots of $6\,m \times 4\,m$ were prepared in each farmer's field intended for soybean. A similar adjacent plot area served as the control (i.e. farmers' practices, without any treatment). Consistant with general practice, soybean was seeded on ridges 50 cm apart, at a spacing of ca. 5 cm. Treatments assigned to the two plots were coir dust-based inoculant of *Bradyrhizobium japonicum* TAL 102[1] (Seneviratne et al., 1999) and mineral fertilizer as recommended for soybean by the Department of Agriculture, Sri Lanka (urea 23 kg N/ha, triple super phosphate 69 kg P_2O_5/ha and muriate of potash 21 kg K_2O/ha as a basal application and urea 23 kg N/ha as a top dressing at the onset of flowering).

Soybean (cultivar Pb1, maturity at 80–85 days) seeds were soaked for 1–2 min in a diluted sugar solution for coating with inoculant. Previous studies have shown that this cultivar is a promiscuous genotype (Seneviratne et al., 1999). The crop in the two plots was maintained according to recommended practices of the Department of Agriculture, Sri Lanka (Crop recommendations technoguide, 1990). Leaving an area of $4\,m \times 3\,m$ in the middle of each plot, including the control for the harvest, 18 plants were removed carefully with soil still surrounding the root systems, at flowering. Number of plants were counted in three squares of $1\,m \times 1\,m$ in the harvest area of all plots to estimate plant densities. Soil was removed from the roots of the plants by soaking in water and nodules were carefully collected. Nodules and plants were over-dried at 65°C for 72 h and dry weights were recorded. At crop maturity, plants were removed from the harvest area of each plot where threshed and seed were sun-dried. Seed were weighed and ground subsamples were analyzed for total N by Kjedahl method. ANOVA, LSD test and correlation analysis of the data were performed using SAS (1987).

3. Results and discussion

Fig. 1 shows nodule and plant dry weights at flowering and seed yield of soybean in all five farmers' fields under inoculation, fertilizer application and the control. There is considerable variability between farmers' fields in those parameters, as reflected in their coefficients of variation (CV) (Table 1). In all fields, seed yields under inoculation and fertilizer application were greater than that of the control (Fig. 1). Plant densities were not significantly different among the treatment plots and the control (Table 1).

[1] Other names of the strain are USDA 110, 3I1b110 and RCR 3427. Authors received the strain from the Laboratory of Soil Fertility and Soil Biology, Catholic University of Leuven (KUL), Belgium.

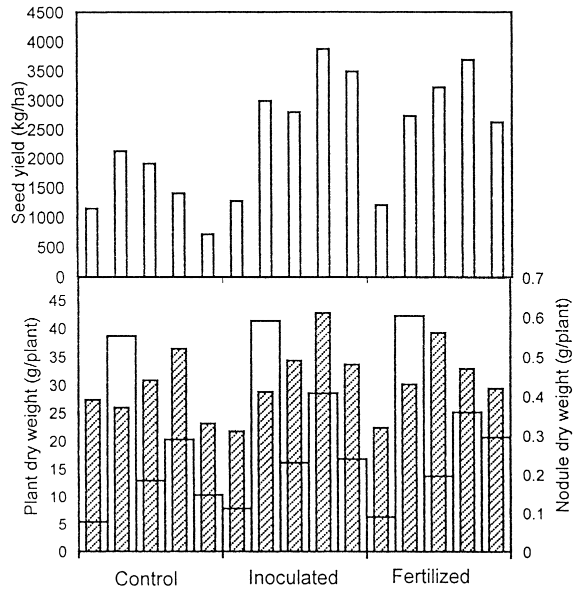

Fig. 1. Nodule (shaded columns) and plant dry weights at flowering and seed yield of soybean in all five farmers' fields (replicates) under inoculation, fertilizer application and the control (farmers' practices).

Plant dry weights of the two treatments were significantly greater than that of the control. However, nodule dry weight did not vary significantly among the treatments and the control. For the control, this is a result of promiscuity of the soybean cultivar used. It also infers that the level of fertilizer N used did not interfere with the nodulation by native soil rhizobia (Table 1). This is a result of relatively small amount of fertilizer N (46 kg/ha) applied in two equal splits (23 kg/ha per time) at seeding and at flowering, which would not normally be expected to suppress nodulation and N_2-fixation (Hardarson and Danso, 1990). Seed yield also followed a similar trend as of plant dry weight, the two treatments giving greater yields than the control. This implies that, the effect of inoculation on seed yield is comparable with that of fertilizer application plus any N_2-fixation with nodulation from native soil rhizobia. It has also been shown that grain legumes respond significantly to small doses of fertilizer N (20–30 kg N/ha) in semi-arid tropics, because the BNF does not function from the onset of plant growth and all the legume N requirement cannot be met from BNF, particularly under conditions of low soil N (Wani et al., 1995). Seed N concentration was not significantly different among the two treatments and the control.

Under inoculation, plant density and dry weight were positively correlated, which implied that higher plant densities produced higher plant dry weights (Table 2). Fertilizer application reduced nodule dry weight per plant under high plant densities. This could be due to a limitation of native rhizobia in this soil to nodulate, because their population is ca. 10^2 cells/g soil (G. Seneviratne, unpublished). Plant and nodule dry weights were positively correlated when the inoculant or fertilizer was used. This indicated the importance of N_2-fixation for improved plant growth even under fertilizer use in these fields. High plant densities produced large seed yields under inoculation, but not under fertilizer application. The yield increase associated with narrow row soybean production has traditionally been attributed to greater light interception (Taylor et al., 1982). However, later studies showed that other factors affect yield response to row width (Board et al., 1994). Bullock et al. (1998) observed enhanced early growth of soybean in narrow

Table 1
Nodule and plant dry weights at flowering and some yield parameters of soybean with a range of plant densities under rhizobial inoculation, fertilizer application and the control (farmers' practices) in farmers' fields[a]

Treatment	Plant density (no./m^2)	Plant dry weight (g/plant)	Nodule dry weight (g/plant)	Seed yield (kg/ha)	Seed N (%)
Control	24.6[a]	17.5[b]	0.41[a]	1458[b]	4.8[a]
Inoculated	28.4[a]	22.1[a]	0.46[a]	2882[a]	5.2[a]
Fertilized	27.6[a]	21.6[a]	0.44[a]	2693[a]	5.2[a]
LSD (0.05)	11.1	3.3	0.09	911	0.56
CV (%)	28.4	11.2	13.6	26.7	7.5

[a] Mean of five replicates. Values in the same column followed by the same letter are not significantly different at 5% probability level. LSD least significant difference. CV coefficient of variation.

Table 2
Correlation coefficients (r) between plant parameters at flowering and yield parameters of soybean under rhizobial inoculation (I), fertilizer application (F) and the control (C) (i.e. farmers' practices) in farmers' fields[a]

		Plant dry weight	Nodule dry weight	Seed yield	Seed N
Plant density	*C*	−0.22 (0.57)	−0.39 (0.30)	−0.15 (0.70)	0.64 (0.06)
	I	0.82 (0.01)	0.49 (0.18)	0.67 (0.03)	0.58 (0.08)
	F	−0.41 (0.27)	−0.66 (0.05)	0.25 (0.48)	0.21 (0.57)
Plant dry weight	*C*	–	−0.02 (0.95)	0.73 (0.03)	0.26 (0.50)
	I	–	0.79 (0.02)	−0.04 (0.92)	−0.46 (0.18)
	F	–	0.68 (0.04)	0.49 (0.15)	0.34 (0.34)
Nodule dry weight	*C*	–	–	0.24 (0.53)	0.22 (0.56)
	I	–	–	0.64 (0.06)	0.54 (0.09)
	F	–	–	0.52 (0.10)	0.12 (0.78)
Seed yield	*C*	–	–	–	0.17 (0.67)
	I	–	–	–	0.77 (0.02)
	F	–	–	–	−0.10 (0.79)

[a] Values within parentheses are probability levels.

row spacing without fertilizer application, which contributed to a yield increase. This was also recorded in the inoculated treatment of the present study (Table 2). Under farmers' practices, plant dry weight was the best determinant of seed yield, however, this was not the case in the treatment plots. High plant densities under inoculation and the control were associated with high seed N concentrations, as was reflected by their positive correlations among plant and seed parameters. This could be attributed to a favourable microclimate provided by shading under the closed canopy, improving the efficiencies of both native and introduced rhizobia, because it has been observed that soil temperature could increase even up to ca. 45°C during the day time in bare soil in this region (J. Senanayake pers. comm.). Seed yield and seed N increased together in the inoculated crop because field conditions which promote seed yield also enhance seed protein content (Vollmann et al., 2000). It is also apparent from these positive correlations of the inoculated treatment as compared to corresponding poorly-correlated parameters of the control, that the efficiency of N_2-fixation of the introduced strain may be higher than that of native rhizobia, although plant N data are absent.

This study revealed that only rhizobial inoculation achieved seed yield response to plant density and nodulation. Crop performance of inoculated tropical soybean can be increased by denser planting (Table 2). However, fertilizer application does not show such a trend, rather high plant densities reduce nodulation and adversely affect seed yield, although the yields are not significantly different between the inoculated and fertilized treatments, when averaged across all sites (Table 1). These results show the importance of BNF even with fertilizer applications in the tropics. Future studies should evaluate optimal plant densities for maximum yields of soybean under inoculation.

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