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Residual benefits of promiscuous soybean to maize (*Zea mays* L.) grown on farmers' fields around Minna in the southern Guinea savanna zone of Nigeria

A.O. Osunde [a,*], A. Bala [a], M.S. Gwam [a], P.A. Tsado [a], N. Sanginga [b], J.A. Okogun [b]

[a] *Department of Soil Science, Federal University of Technology, PMB 65, Minna, Niger State, Nigeria*
[b] *International Institute of Tropical Agriculture (IITA), PMB 5320 Ibadan, Nigeria*

Abstract

Biological nitrogen fixation (BNF) by promiscuous cultivars of soybeans (*Glycine max* (L.) Merr.) in cereal-based cropping systems of Nigeria's moist savanna zone offers a potential for minimizing the investment made by resource-poor farmers on nitrogen fertilizers. A 3-year trial was conducted on five farmers' fields in the southern Guinea savanna zone of Nigeria to assess the residual effects of two successive crops of promiscuous soybean cultivars on the yield of a following maize (*Zea mays* L.) crop. The soybean cultivars, TGX1456-2E (medium maturity) and TGX1660-19F (late maturity), were grown in 1996 and 1997. Treatments, imposed only in the first year of the trial, were: (i) uninoculated, (ii) inoculated with a mixture of two *Bradyrhizobium* strains, and (iii) fertilized with 60 kg N ha^{-1}. A fourth treatment was a plot left to fallow. In 1998, all the previous soybean and fallow plots were sown to maize without any fertilizer application. Results in 1996 and 1997 showed a soybean response to inoculation in the first year, but differences due to the residual effect of inoculation in the second year were not significant. Both cultivars showed a similar response to inoculation but responses at the five sites were varied. Soybean cultivar 1456-2E fixed 43–52% of its N amounting to 56–70 kg N ha^{-1} and cultivar 1660-19F derived 39–54% of its N from N_2-fixation which amounted to 51–78 kg N ha^{-1}. Both cultivars had a high N harvest index resulting in a net removal of 52–95 kg N ha^{-1} when both grain and stover were exported. Even when the stover was returned, there was a depletion of 23–65 kg N ha^{-1}, with 1456-2E removing more N than 1660-19F. Arbuscular-mycorrhizal infection on maize roots was 11–27% and dependent on previous soybean treatments and farmers' fields. Plant height, shoot biomass, grain yield, and N uptake of maize were significantly greater in plots previously sown to soybean than in the fallow plots. In general, plots sown to the late maturing cultivar 1660-19F exhibited better residual effect, producing larger yield parameters than the plots planted with medium maturing 1456-2E.

Keywords: Promiscuous soybean; Maturity class; Inoculation; N_2-fixation; N contribution

1. Introduction

Nutrient deficiencies, especially those of N and P, are among the major constraints to crop production in the Nigerian savanna. Although this problem could be tackled using fertilizers, these are often inaccessible to most resource-poor farmers because of their high cost and inadequate supplies. Cultivation of leguminous crops in rotation with other food crops has been recognized as one of the cost-effective ways by which farmers can maintain soil fertility. The legumes meet some of their N requirement through N_2-fixation, thus sparing some of the soil N to the subsequent crops

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[*] Corresponding author. Tel./fax: +234-66-221286.
E-mail address: aoosunde@skannet.com (A.O. Osunde).

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(Giller et al., 1991) in addition to the residual N that accrues due to nodule senescence and fallen leaves (Ledgard and Giller, 1995).

Tropical grain legumes such as soybean (*Glycine max* (L.) Merr.) are efficient in translocating the bulk of the fixed N to the grain, and even when the residues are returned to the soil, there may be a net removal of N from the field (Peoples and Craswell, 1992; Giller et al., 1994). This, however, depends on the cultivar and the field history (Peoples et al., 1995). Some promiscuous soybean cultivars have indeterminate growth habit and have relatively lower grain and N harvest indices, and hence have greater potential to add N to the soil than the specifically nodulating commonly grown commercial varieties (Mpepereki et al., 1996, 2000).

In Nigeria, the soybean crop is being increasingly cultivated within the savanna agro-ecological zone, where it is well adapted (Smith et al., 1993), especially with the introduction of the promiscuous soybean cultivars developed by IITA. Studies conducted in this region on soybean–maize (*Zea mays* L.) rotation have shown that the net N contribution of the soybean crop to the soil increases with growth duration, and ranges between −8 and 47 kg N ha^{-1}, provided the soybean stover is not harvested from the plots (Sanginga et al., 1997, 2001; Singh et al., 2000). However, the usual practice of most farmers in this region is to harvest the soybean crop without returning the stover to the soil. Carsky et al. (1997) observed that even when the stover was exported, maize grain yield increase following soybean that was given a basal application of 20 kg N ha^{-1} was similar to that from 40 kg N ha^{-1} applied to maize preceded by maize. For many farmers in the Nigerian savanna, access to N fertilizer that will allow for even a basal application is limited. This trial was set up to simulate the usual farmers' practice of harvesting both the soybean grain and stover. The objectives of this study were to: (i) determine the response of two promiscuous soybean cultivars of varying maturity classes to bradyrhizobial inoculation without a basal fertilizer application, (ii) determine the relationship between maturity classes of soybean and their N_2-fixation patterns and yield, and (iii) evaluate the residual effect of a previous promiscuous soybean crop on the yield of a subsequent maize crop.

2. Materials and methods

2.1. Site description

Field trials were carried out during the cropping seasons of 1996–1998 on five farmers' fields within 60 km radius of Minna (9°40′N, 6°30′E), located in the southern Guinea savanna ecological zone of Nigeria. Minna has a subhumid climate with a mean annual rainfall of 1200 mm concentrated almost entirely within the months of June and August. Temperature rarely falls below 22 °C, with a wet season average of 29 °C. Soil properties in the five farmers' fields are presented in Table 1.

Table 1
Selected physical and chemical properties of soils (0–15 cm) in the five experimental sites around Minna, southern Guinea savanna zone of Nigeria

Soil parameter	Experimental sites				
	Bosso	Shakodna	Vemu	Numui	Gidan Kwanu
pH (KCl)	5.33	5.18	5.44	5.14	5.87
Organic carbon (%)	0.42	1.20	0.62	0.54	0.53
Total N (%)	0.04	0.09	0.05	0.04	0.05
Available P (μg g^{-1})	1.46	1.14	1.65	6.88	3.27
Exchangeable K (cmol kg^{-1})	0.20	0.10	0.22	0.11	0.22
Exchangeable Ca (cmol kg^{-1})	1.51	3.52	1.84	3.31	3.91
Exchangeable Mg (cmol kg^{-1})	0.32	0.93	0.44	0.43	0.63
Exchangeable acidity (cmol kg^{-1})	0.15	0.06	0.10	0.08	0.07
Sand (%)	83	57	75	75	71
Silt (%)	11	27	13	17	14
Clay (%)	6	16	12	8	10

2.2. *Soybean trials*

During the 1996 and 1997 cropping seasons, promiscuous soybean cultivar TGX1456-2E, a medium maturity cultivar (100 days), and TGX1660-19F, a late maturity cultivar (120 days), were cultivated under the following treatments imposed in 1996: uninoculated control, inoculated with two *Bradyrhizobium* strains (R25B and IRj2180A), fertilized with 60 kg N ha^{-1} as urea, and a fallow as a check for the maize trial. Soybean seeds were inoculated with peat inoculant containing an approximate density of 10^7 viable rhizobia per seed (Vincent, 1970). In 1997, soybean was repeated on the same plots but without a second application of inoculants or fertilizers. Planting was done in both years in mid-July by hand-drilling on ridges, followed by thinning 2 weeks after sowing at a spacing of about 10 cm between plant stands. The nitrogen fertilizer treatment that was imposed in 1996 was band-applied as urea immediately after thinning at about 2 cm away from the soybean stands. Apart from this treatment, no other fertilizer was applied to either the soybean or fallow plots. Weeding was carried out as when necessary. The experiment was farmer-managed, designed as a split-plot with each field serving as a replicate. The promiscuous soybean cultivars were assigned as the main plot and the imposed treatments as subplots. Each sub-plot was made up of six hand-made ridges 25–30 cm high and 6 m long with 70 cm between ridges.

The soybean grain and stover were both removed from the field in the two cropping seasons, in line with farmers' practice in the region. The N balance (Tables 2 and 3) was estimated as the difference between the N fixed and the total N exported in the grain (+stover) or in total aboveground biomass (−stover).

2.3. *Maize trials*

In 1998, the previous soybean plots and the fallow plots were sown to maize without any fertilizer application. Seeds were sown on ridges at a within-row spacing of 30 cm and with 70 cm between ridges.

2.4. *Soil and plant sampling and analyses*

Soil samples were collected (0–15 cm) from each field for routine soil analyses (IITA, 1989) before

Table 2

N_2-fixation, N accumulation, and net N input by two promiscuous soybean cultivars, with or without inoculation, across five sites in the Nigerian southern Guinea savanna during the 1996 cropping season

Treatments	Stover N (kg ha^{-1})	Grain N (kg ha^{-1})	Total N[a] (kg ha^{-1})	%N from N_2-fixation	N fixed (kg ha^{-1})	Net input of N from N_2-fixation (kg ha^{-1})	
						(+) stover	(−) stover
N source							
Inoculated	35.49	130.51	166.00	49.70	82.50	−48.01	−83.50
Uninoculated	31.92	121.21	153.13	46.00	70.44	−50.77	−82.69
60 kg N ha^{-1}	26.07	97.83	123.91	25.90	32.09	−65.74	−91.82
LSD (5%)	4.41	20.93	24.55	9.65	10.72	12.11	6.44
Cultivar							
TGX1456-2E	29.62	134.96	164.58	42.51	69.95	−65.00	−94.63
TGX1660-19F	32.70	98.08	130.77	38.56	50.48	−47.64	−80.29
LSD (5%)	NS[b]	27.14	31.19	NS	15.34	10.11	10.52
Farmers' fields							
Bosso	29.25	106.27	135.51	46.27	62.70	−43.56	−72.81
Shakodna	31.93	115.08	147.02	50.28	73.95	−36.76	−73.07
Vemu	30.22	115.05	145.28	43.89	63.78	−51.29	−81.15
Numui	37.57	145.07	182.64	45.55	83.28	−61.86	−99.36
Gidan Kwanu	26.83	101.13	127.95	50.38	64.49	−36.64	−63.46
LSD (5%)	6.76	34.66	40.01	NS	9.23	11.05	15.90

[a] Total N of aboveground dry matter.

[b] Not significant.

Table 3
N_2-fixation, N accumulation, and net N input by two promiscuous soybean cultivars, with or without inoculation, across five sites in the Nigerian southern Guinea savanna during the 1997 cropping season

Treatments	Stover N (kg ha^{-1})	Grain N (kg ha^{-1})	Total N (kg ha^{-1})	%N from N_2-fixation	N fixed (kg ha^{-1})	Net input of N from N_2-fixation (kg ha^{-1})		Total N deficit in 2 years (kg ha^{-1}) with stover exported
						(+) stover	(−) stover	
N source								
Inoculated	28.49	99.67	128.16	49.22	63.05	−36.6	−65.11	149
Uninoculated	26.70	89.97	116.67	48.66	56.82	−33.19	−59.85	143
60 kg N ha^{-1}	31.08	102.84	133.92	45.96	61.60	−41.28	−72.32	164
LSD (5%)	NS	NS	NS	NS	NS	NS	NS	NS
Cultivar								
TGX1456-2E	13.60	93.40	107.36	51.97	55.83	−37.79	−51.53	147
TGX1660-19F	43.55	101.58	145.14	53.92	78.23	−23.34	−66.91	147
LSD (5%)	18.43	NS	23.44	NS	15.30	11.06	14.23	NS
Farmers' fields								
Bosso	18.95	75.72	94.67	32.47	30.77	−44.98	−63.90	137
Shakodna	34.94	111.95	146.89	56.04	82.25	−29.63	−64.63	138
Vemu	18.40	62.12	80.53	47.91	38.57	−23.55	−41.96	123
Numui	59.09	124.79	164.65	59.85	98.63	−14.71	−66.02	165
Gidan Kwanu	31.08	112.89	144.51	76.25	110.26	−3.10	−34.25	98
LSD (5%)	18.16	32.78	41.51	7.38	17.74	10.28	21.32	28

ridging in 1996. Composite samples were obtained from 20 points per field, air dried and passed through a 2 mm sieve. For both soybean and maize trials, plant samplings were confined to the four inner ridges of each subplot with 10 plants destructively sampled for measurements of the various plant parameters. Soybean plants were sampled at mid-podding stage for the estimation of N_2-fixation using the ureide-N technique (Herridge and Peoples, 1990), while shoot dry weight and N content were measured at physiological maturity. Maize plants were sampled at mid-silking stage for mycorrhizal infection counts, while measurements of height, shoot biomass, and N content were done at physiological maturity.

All plant samplings were by cutting the shoots at soil level. Maize cobs were harvested at physiological maturity and dried before shelling. A subsample of the grain was oven dried, ground, and analyzed for N and P contents. Tissue analyses were conducted according to the methods of IITA (1989). Assessment of mycorrhizal colonization of maize roots was carried out using Trypan blue staining (Philips and Hayman, 1970) and examination of the roots at 100× magnification using the intersect method (Giovannetti and Mosse, 1980).

2.5. Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the GLM package (SAS, 1989). Where there was a significant effect ($P \leq 0.05$) of the main factors or their interaction, the least significant difference (LSD) was used to evaluate differences between treatment means.

3. Results

3.1. Soybean shoot biomass and grain yield

The main effects of N sources, cultivars, and site, but not their interactions, affected differences in soybean shoot biomass in one or both seasons (Fig. 1). During the 1996 season, inoculated plants produced over 5 t ha^{-1} of shoot dry matter compared to 4 t ha^{-1} from the uninoculated treatment and 4.5 t ha^{-1} from the N-fertilized treatment (Fig. 1(i)). Differences among these treatments were, however, not significant in the 1997 season. Cultivar 1456-2E produced larger biomass than 1660-19F in both seasons. Shoot biomass of 1456-2E averaged 5.5 t ha^{-1} during the

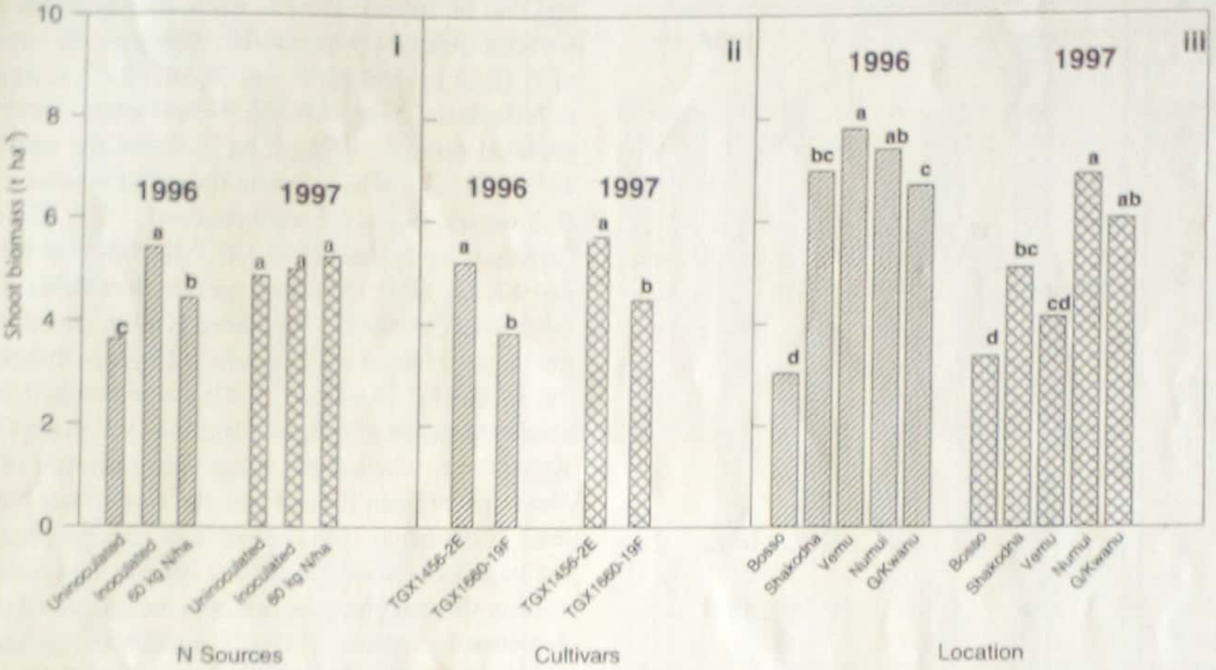

Fig. 1. Effect of N sources, cultivar and location on the shoot biomass of promiscuous soybean in the southern Guinea savanna of Nigeria. Bars with the same letter are not significantly different.

two seasons compared to 4.2 t ha^{-1} for 1660-19F (Fig. 1(ii)). The largest shoot biomass yields produced across the five sites in the 1996 season was at Vemu (average 7.8 t ha^{-1}) and Numui (average 7.4 t ha^{-1}) (Fig. 1(iii)). The smallest yield (3.04 t ha^{-1}) was produced at Bosso. In the 1997 season, Numui again had the biggest yield (6.9 t ha^{-1}) and Bosso the smallest (3.4 t ha^{-1}).

Differences in soybean grain yields were significant only due to the effects of sites. Total grain yield ranged from 1.9 to 2.4 t ha^{-1} in the 1996 season, and from 1.2 to 2.4 t ha^{-1} in the 1997 season (Fig. 2). In both years, the largest yield was obtained from the Numui site, while the Bosso site had the smallest yield.

3.2. N_2-fixation and N balance

The main effects of N sources, cultivars, and location significantly affected differences in N accumulation, N_2-fixation, and net N input of soybean in both 1996 (Table 2) and 1997 (Table 3). The effects due to the interaction of these factors were not significant. During the 1996 season, total N contents were greater in both the inoculated and uninoculated soybean treatments than in the N-fertilized control (Table 1). The proportion of N derived from N_2-fixation (%Ndf) was similar (46–50%) for the inoculated and uninoculated plants, amounting to 83 kg N ha^{-1} of N fixed (inoculated) and 70 kg N ha^{-1} (uninoculated). The N-fertilized soybean, on the other hand, had a significantly smaller %Ndf (26%) with 32 kg N ha^{-1} fixed. This treatment also led to more N deficit than the other two treatments, whether or not the stover was removed from the field. A similar proportion of the N (39–43%) in both cultivars 1660-19F and 1456-2E was derived from N_2-fixation. This amounted to 70 kg N ha^{-1} of fixed N for 1456-2E and 50 kg N ha^{-1} for 1660-19F. However, as the total N content of 1456-2E was greater, it also derived more N from the soil than 1660-19F. The proportion of the plant N removed in the grain (N harvest index) was greater in 1456-2E (82%) than in 1660-19F (75%). Both cultivars led to a negative net N input (−48 to −95 kg N ha^{-1}) even if the stover were to be returned. However, 1660-19F caused less N deficit than 1456-2E, especially if the stover was returned. Although the %Ndf at the five sites was similar (44–50%), the total N contents of the soybean plants differed widely across the sites (128–183 kg N ha^{-1}). The amount of N input from N_2-fixation also varied,

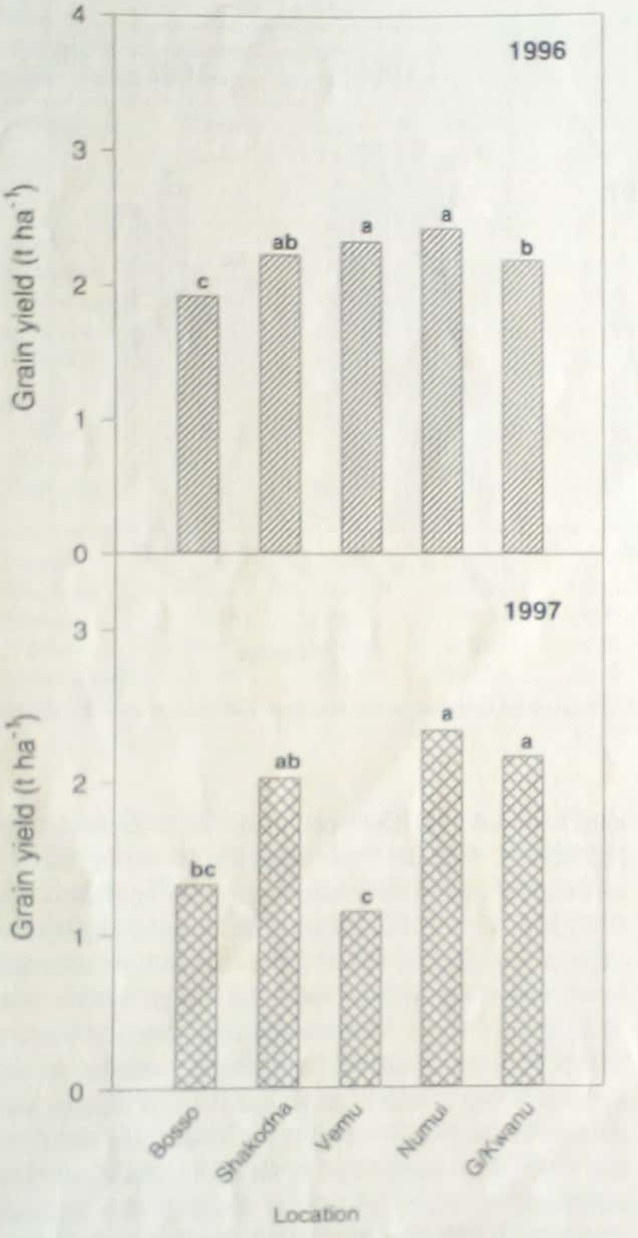

Fig. 2. Location effect on the grain yield of promiscuous soybeans grown for two seasons at five sites in the southern Guinea savanna of Nigeria. Bars with the same letter are not significantly different.

with the Shakodna and Numui sites deriving more N inputs (74–83 kg N ha^{-1}) than the other three sites (63–65 kg N ha^{-1}). The Numui site also had the most N depleted from the soil (99 kg N ha^{-1}) and the Gidan Kwanu site the least (63 kg N ha^{-1}).

In the 1997 season, differences in N input due to the main effects of N sources were not significant (Table 2). The %N harvest index for 1456-2E was 87% and that of 1660-19F 70%, while the %Ndf for both soybean cultivars was similar, although the amount of N fixed by 1660-19F was 78 kg N ha^{-1} compared to 56 kg N ha^{-1} for 1456-2E. Nevertheless, 1660-19F depleted more N (67 kg N ha^{-1}) from the soil than 1456-2E (52 kg N ha^{-1}) when the stover was removed. If, however, the stover were returned, 1456-2E would deplete more N than 1660-19F. The %Ndf at the Gidan Kwanu site (76%) was greater than those of the other sites (33–60%). The Gidan Kwanu site also had the largest N input (110 kg N ha^{-1}) and the Bosso site the smallest (31 kg N ha^{-1}). This also resulted in the smallest amount of N uptake from the soil at the Gidan Kwanu site, whether the stover was removed or not. Next to the Gidan Kwanu site, the Numui site had the least N depletion if the stover was returned, but also the largest N removal when the residue was removed.

Over the two cropping seasons, the estimated soil N depletion by cultivars 1456-2E and 1660-19F was the same (147 kg N ha^{-1}) with the removal of the stover (Table 2). The amount of N removed by the inoculated soybean treatments (149 kg N ha^{-1}) was also similar to that of the uninoculated plants (143 kg N ha^{-1}) over the two seasons. However, the N-fertilized treatments depleted slightly more N from the soil (164 kg N ha^{-1}) than the two inoculation treatments. There was also a slight variation in soil N depletion across the five sites. The least N was removed at the Gidan Kwanu site (98 kg N ha^{-1}) and soil at the Numui site was depleted the most (165 kg N ha^{-1}).

3.3. Production in maize following soybean

Differences in maize height (Fig. 3a) and shoot biomass (Fig. 3d) were not affected by inoculation treatment of the previous soybean crop. However, maize plants in plots previously sown to soybean were significantly taller, with more shoot biomass, than those in the fallow plots (Fig. 3a and d). Site effect on maize height and shoot biomass was also significant. Maize shoot biomass at the Bosso site was about half the biomass at each of the four other sites (Fig. 3e). Maize shoot height was also significantly less at the Bosso site than at the other sites (Fig. 3b). Plant height and shoot biomass of maize in plots previously sown to the late maturing cultivar 1660-19F were also greater than those of maize plants in plots sown to the medium maturing cultivar 1456-2E (Fig. 3c and f).

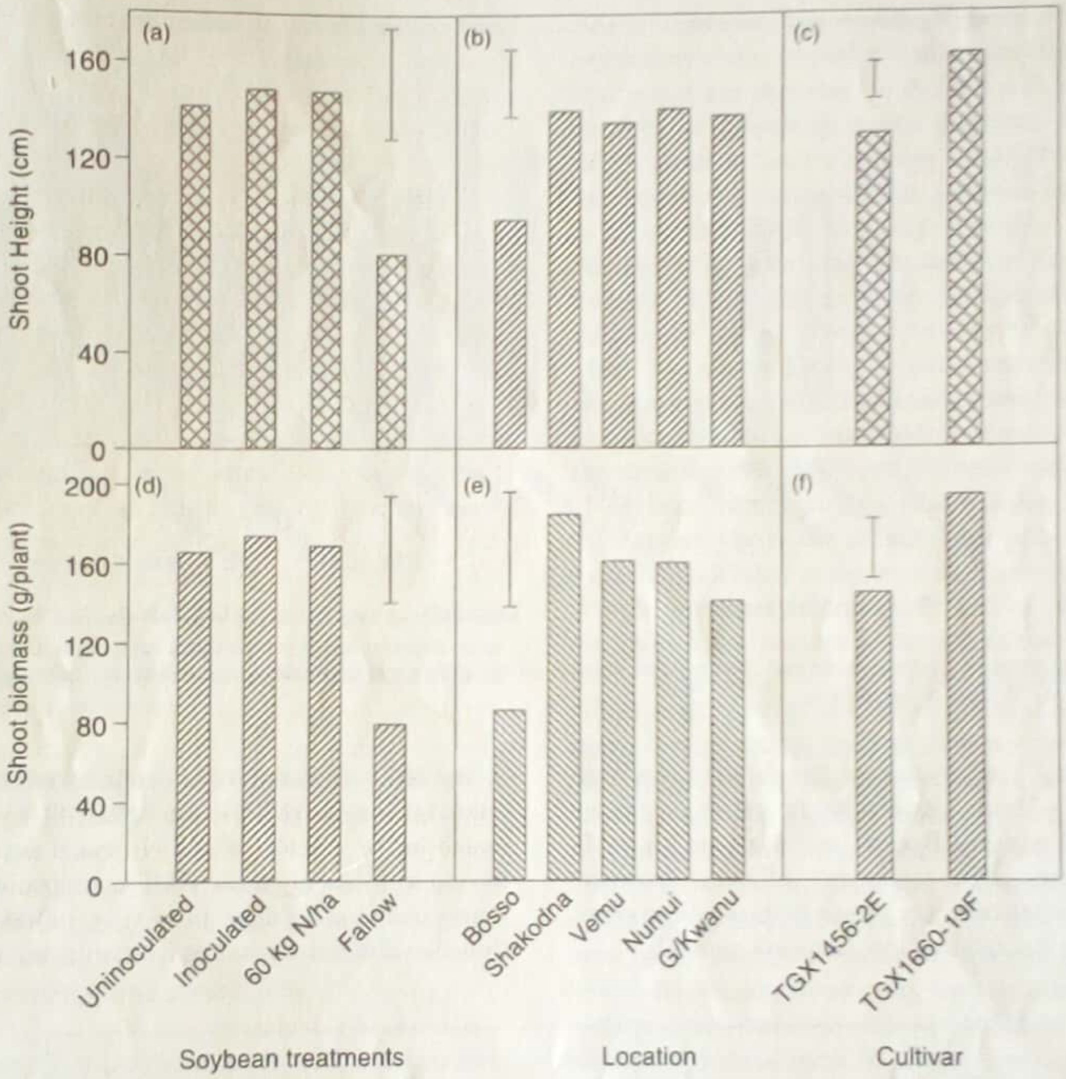

Fig. 3. Effect of previous soybean treatments, location and cultivar on height and shoot biomass of a maize crop following soybean. Vertical bars represent LSD at 5% level of significance.

Maize grain yields did not vary with soybean treatments; however, yields in plots previously sown to soybean were significantly larger than yields in the fallow plots (Fig. 4a). Grain yields of about 3 t ha^{-1} were produced in the soybean-treated plots as against an average yield of about 0.5 t ha^{-1} in the fallow plots. There was also a site effect on grain yield (Fig. 4b) with yield at the Bosso site being the lowest (0.7 t ha^{-1}), while the Shakodna site had the best grain yield (3 t ha^{-1}). Plots previously sown to soybean cultivar 1660-19F had more grain yield (2.6 t ha^{-1}) than the 1456-2E-treated plots that had 2.1 t ha^{-1} (Fig. 4c).

The amount of N yields in maize grain differed across the various sites with grain from the Shakodna site having the largest N yield (60 kg N ha^{-1}) and the Bosso site the least (10 kg N ha^{-1}). Maize from the other three sites had N yields of 35–40 kg N ha^{-1} (Fig. 5a). Maize grain N yield also differed between plots sown to different soybean cultivars, with maize plants in the 1660-19F-cropped plots yielding more grain N (40 kg N ha^{-1}) than plants in the 1456-2E plots (30 kg N ha^{-1}) (Fig. 5b). The N content of maize grain grown in plots that were previously sown to soybean was almost twice that of maize in the fallow plots (Fig. 5c). Grain N yield in the soybean plots was

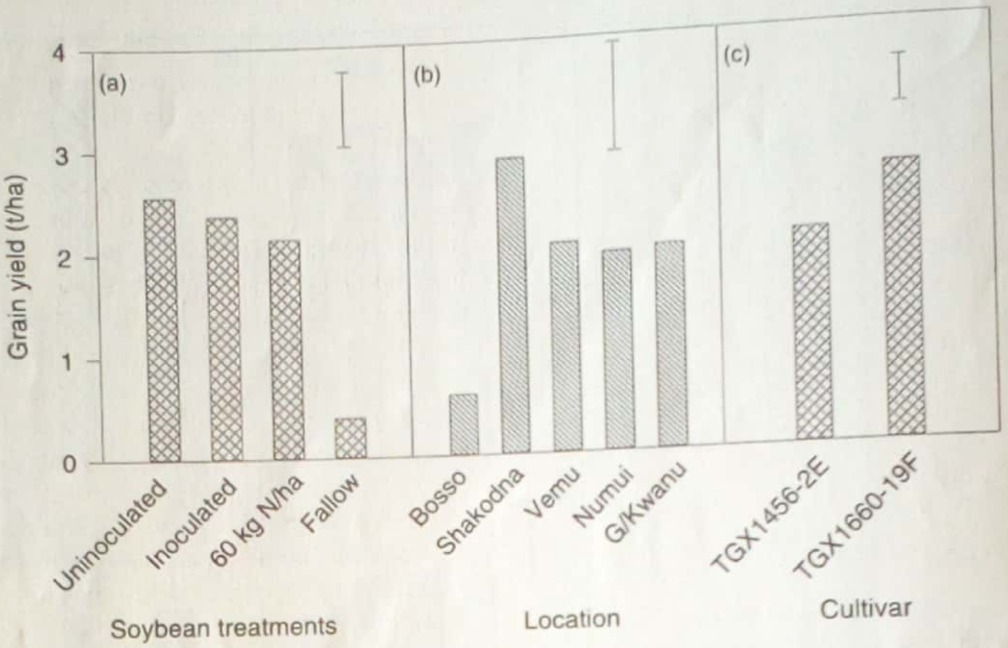

Fig. 4. Effect of previous soybean treatments, location and cultivar on the grain yield of a maize crop following soybean. Vertical bars represent LSD at 5% level of significance.

35–38 kg N ha^{-1} while that of the fallow plots was 21 kg N ha^{-1}. There was also a site effect on maize grain P yield with the Bosso site having the lowest P yield, but there was no significant difference between the grain P yields of maize grown in the soybean plots and maize in the fallow plots (data not shown).

The level of maize root infection by arbuscular-mycorrhizal fungi (AMF) ranged from 11 to 27% with maize in the inoculated and N-treated soybean plots having significantly more AMF colonization than the uninoculated and fallow plots (Fig. 6a). AMF infection also differed across the five farms with the Gidan

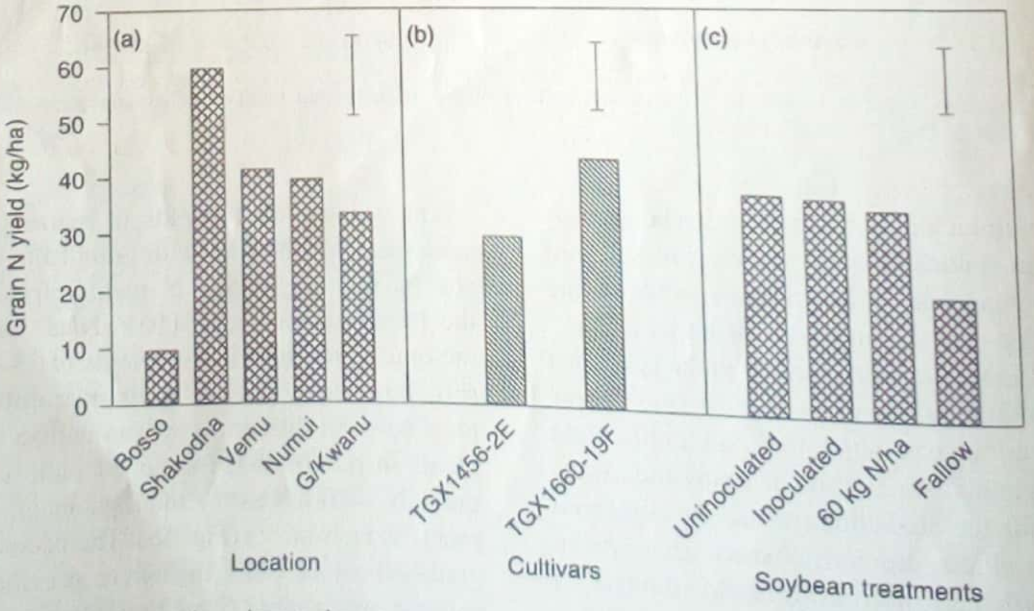

Fig. 5. Effect of location, cultivar and previous soybean treatments on the seed N content of maize grown after a 2-year soybean cultivation. Vertical bars represent LSD at 5% level of significance.

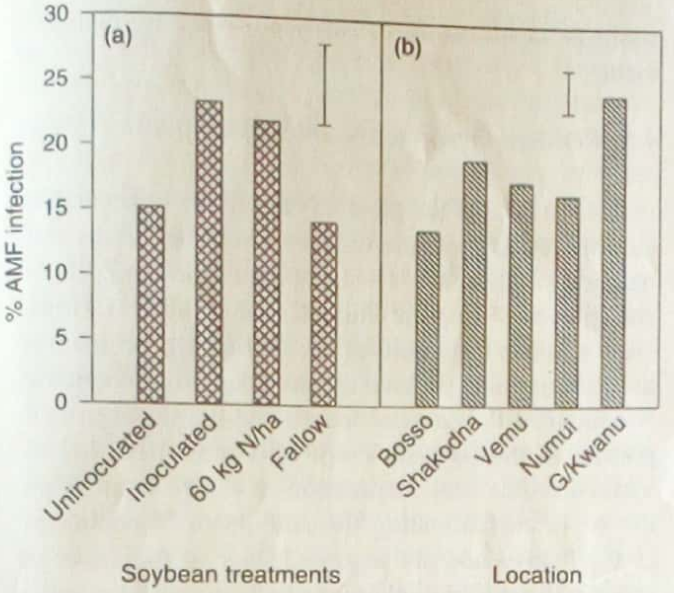

Fig. 6. Effect of previous soybean treatments and location on percent arbuscular-mycorrhizal fungi (AMF) infection of the roots of maize grown after a 2-year soybean crop. Vertical bars represent LSD at 5% level of significance.

Kwanu site having the highest infection (25%), and the Bosso site the lowest (13%) (Fig. 6b).

4. Discussion

4.1. Soybean dry matter production

Inoculation of the soybean seeds resulted in greater shoot dry matter than those of the uninoculated or even the N-fertilized plants in the first year. However, this was not translated into more grain yields for the inoculated plants. Nevertheless, this shows that the potential exists to increase yields of promiscuous soybean by artificial inoculation. By the second season, there was no yield difference among the previously inoculated, uninoculated, and N-fertilized treatments, suggesting that the inoculant strains were persistent and had perhaps spread to the uninoculated plots. This was confirmed by the recovery of the inoculant strains from the nodules of the second year soybean plants grown in the uninoculated and N-fertilized plots (Osunde et al., unpublished results). One major limitation of the use of inoculants by smallholder farmers in sub-Saharan Africa is the high cost because of the requirement for repeated applications (Mpepereki et al., 2000). However, our result suggests that identifying and selecting superior and competitive rhizobial strains that are persistent in the soil will help in minimizing the frequency, hence the cost, of inoculant use to farmers. Such a strategy could form the basis for inoculant formulation for resource-poor farmers in the continent. The lack of a cultivar × inoculation interaction indicates the similarity in the symbiotic response of 1456-2E and 1660-19F to indigenous rhizobial populations. This is contrary to other reports which had shown 1660-19F to be more promiscuous (Sanginga et al., 1997, 2000), suggesting that the symbiotic characters of these promiscuous cultivars are site-dependent. Both shoot dry matter and grain yield of soybean exhibited strong site dependence. Several authors who made similar observations attributed such site variability to the previous cropping sequence (Peoples et al., 1995), number and effectiveness of the indigenous rhizobia in the soil (Thompson et al., 1991; Sanginga et al., 1996), and available nutrients (Thies et al., 1991; Giller et al., 1998). In a previous study, Gwam (2000) showed that the size of indigenous rhizobial populations in the five sites we used for this study was highly variable, with the Shakodna site having the highest counts, and the Bosso site the lowest. It is also apparent that the yield differences observed across the farms in our trial could have been partly due to the variation in initial soil nutrient levels. Hence, the Bosso site, with a relatively lower nutrient level than the other sites (Table 1), had the smallest values of most of the yield parameters. This site also recorded the lowest soybean yield.

4.2. N_2-fixation and accumulation by soybean

The proportion of N derived from fixation (%Ndf) was similar in the two promiscuous soybean cultivars with both estimated to have fixed 39–54% of their N. This amounted to 56–70 kg N ha^{-1} in cultivar 1456-2E and 51–78 kg N ha^{-1} in 1660-19F (Tables 2 and 3). As a result, there was no obvious difference in yield performance between the two cultivars. The %Ndf values obtained for the two cultivars were below the range (77–84%) reported by Abaidoo et al. (1999) for 10 soybean cultivars that included 1456-2E and 1660-19F. However, Sanginga et al. (1997) recorded a %Ndf value of 52% for 1660-19F, similar to the values obtained in our study, although their estimates of the total N fixed (130 kg N ha^{-1}) was almost twice the values we observed.

The N harvest index of the medium maturing cultivar 1456-2E (82–87%) was higher than that of the late maturing cultivar 1660-19F (70–75%). These values are slightly above the 76–80% range recorded by Singh et al. (2000) for medium and late maturing promiscuous soybean varieties, but are consistent with their observation that the longer maturing varieties have a lower proportion of N in the grain than cultivars of shorter duration. Ogoke et al. (2000), on the other hand, recorded no difference in N harvest between cultivars of different maturity classes.

Where the %Ndf of a legume is greater than its %N harvest index, a positive net residual N benefit could be expected, provided the legume stover is not removed (Giller et al., 1994; Toomsan et al., 1995). In both 1456-2E and 1660-19F, the %Ndf was less than the %N harvest in all cases, and there was a negative net N input from N_2-fixation even if the stover were to be returned (Tables 2 and 3). When stover was returned, the net N input from 1660-19F was greater than that of 1456-2E. For grain legumes such as soybean, even when the residues are returned to the soil, there is generally a net removal of N from the field (Peoples and Craswell, 1992; Giller et al., 1994, 1997). However, Singh et al. (2000) observed that when the stover was returned, medium and late duration promiscuous soybean cultivars had a positive net input as against a negative net input by the early duration varieties. On the other hand, Ogoke et al. (2000) reported that both the early and medium varieties depleted soil N, while the long duration varieties made a net contribution of N to soil. In terms of the linkage of N input to maturity classes, our result is in agreement with these reports. However, contrary to their findings, our results showed a negative net N input, irrespective of maturity classes.

Both reports (Ogoke et al., 2000; Singh et al., 2000) also showed that exporting the stover resulted in N depletion for all maturity classes, with the early varieties causing a larger negative N balance than the longer duration types. Our results have also confirmed these observations. However, Carsky et al. (1997) observed that the long duration cultivar, 1660-19F, when given a basal application of 20 kg N ha^{-1}, resulted in a net N contribution even with the stover exported, thus indicating the importance of supplementary fertilizer application in soybean residue management.

4.3. Residual benefit to the subsequent maize crop

At least 80% of the plant's N requirement needed to be from N_2-fixation and the stover returned to the soil before a positive net N balance could be realized, as shown by the value for Gidan Kwanu (Table 3). However, a major limitation of the N balance estimation used in this study is that it did not take into account the N contained in senesced leaves and the underground portion of the soybean crop. This must have led to a considerable underestimation of the N input from the soybean. Estimating the amount of N contained in the below- and aboveground litter of the soybean crops will help in explaining the better yield parameters observed for maize in the soybean plots than in the fallow plots. The aboveground N content at maturity in the 1996 season was 165 kg ha^{-1} for 1456-2E and 131 kg ha^{-1} for 1660-19F (Table 2). Based on studies involving several soybean varieties, years and fertilizers, Hanway and Weber (1971) reported that 20–30% of total aboveground N is contained in the senesced leaves. Using the average of this range, we may, therefore, estimate the N content of the senesced leaves to be approximately 41 kg N ha^{-1} for 1456-2E and 33 kg N ha^{-1} for 1660-19F. The N content in roots of promiscuous soybean cultivars at maturity is estimated to be 10–19% of total aboveground N (Sanginga et al., 1997; Abaidoo et al., 1999). For the 1996 season, therefore, the total N content of above- and belowground litter can be estimated at 66 kg N ha^{-1} for 1456-2E and 53 kg N ha^{-1} for 1660-19F. The estimates for the 1997 season will be 43 kg N ha^{-1} for 1456-2E and 58 kg N ha^{-1} for 1660-19F.

Based on the above figures, the total net N deficit after two successive croppings of soybean, with the stover exported, would have been substantially reduced from the 147 kg N ha^{-1} value calculated (Table 3) to between 36 and 38 kg N ha^{-1} for both soybean cultivars. Hence, it appears that any soil N benefit accruable to the subsequent maize crop after soybean may be due to a "sparing effect" with the soybean fixing a fraction of its N requirement, thus saving some of the soil N for the subsequent crop (Giller et al., 1991). Nonetheless, this does not entirely account for the better yield of maize in the soybean plots than in the fallow plots. Yield increases in maize following soybean do occur, even in situations where the net N contribution of the soybeans is negative (Sanginga et al., 2001). Such increases are hypothesized to be due to rotational effects, such as a reduction in *Striga hermonthica* parasitism (Carsky et al., 2000) and reduced incidence and severity of nematode damage (Weber et al., 1995) on the maize plants; or probably due to other effects that enable the maize crop to exploit the soil better when preceded by legumes rather than cereals (Sanginga et al., 2001).

The significant variation in arbuscular-mycorrhizal fungi (AMF) infection among the soybean treatment plots could be due to differences in the soil P level following soybean harvest. Although the soil P content was not measured after the cultivation of the promiscuous soybean, the plots with the highest AMF infection were also the plots that had the largest soybean biomass. The requirement for and incorporation of P in plant tissues would have been greater in the plants with larger biomass. This could have led to more P harvested in those plots. The depletion in P could have induced a greater need for mycorrhizal colonization of the maize roots than from plots with smaller yields of soybean dry matter.

In general, maize height, shoot biomass, grain yield and N yield in grain were greater in plots previously sown to the late maturing cultivar, 1660-19F than to the medium maturing cultivar, 1456-2E. Two possible reasons could be responsible for this result. First, 1456-2E had a shorter duration in the field, and thus the amounts of dry matter from its senesced leaves and root turnover are likely to be less than those of 1660-19F; hence its N input is also likely to be lower. Secondly, the N input from the senesced leaves and underground biomass of 1456-2E could also be smaller because it had a greater N harvest index than 1660-19F. The combined effect of these two features could result in a bigger residual effect for 1660-19F. This, in turn, could have translated into greater yields for maize plants grown in plots previously cropped to 1660-19F.

5. Conclusions

The soybean crop responded to bradyrhizobial inoculation in terms of shoot biomass. Although this response was not translated into increased grain yield, it nonetheless indicates that the potential exists to increase yields of promiscuous soybean by inoculation. There was no significant difference in the response to inoculation shown by both cultivars 1456-2E and 1660-19F; rather, the inoculation effect was site-dependent. Both cultivars fixed 39–54% of their total N requirement, which amounted to 56–70 kg N ha^{-1} in cultivar 1456-2E and 51–78 kg N ha^{-1} in 1660-19F. Hence, there was no obvious difference in the yield performance between the two cultivars. The 1660-19F cultivar appeared to have a better residual effect, possibly because it had a greater turnover in dry matter and a lower N harvest index than 1456-2E. Even without fertilizer application, a maize grain yield of about 3 t ha^{-1} was realized, suggesting that the contribution from the 2-year soybean crop was substantial. Thus it appears that growing promiscuous soybean in rotation, even without the residues being returned to the field, will be beneficial to the subsequent maize crop. This will mean greater yields for smallholder farmers at minimal costs.

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