Plant and Soil **241**: 223–231, 2002.

The contribution of nitrogen by promiscuous soybeans to maize based cropping the moist savanna of Nigeria

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Received 14 November 2000. Accepted in revised form 25 January 2002

Key words: ^{15}N isotope dilution, N contribution, ^{15}N recovery, Southern Guinea Savanna, Rotation

Abstract

Agronomic results indicate that maize grain yields generally are higher when the crop is planted following soybean than in continuous maize cultivation in the moist savanna agroecological zones of West Africa. Many factors have been hypothesized to explain this phenomenon, including enhanced N availability and the so-called 'rotational effect'. There is, however, hardly any quantitative information on the residual N benefits of promiscuous soybeans to subsequent cereal crops grown in rotation with soybean. Three IITA promiscuous soybean breeding lines and two Brazilian soybean lines were grown in 1994 and 1995 at Mokwa in the southern Guinea savanna, Nigeria, to quantify the nitrogen contribution by soybeans to a succeeding crop of maize grown in rotation with soybean for two consecutive years, 1996 and 1997 using two methods of introducing ^{15}N into soil (fresh ^{15}N labelling and its residual ^{15}N) and three maize cultivars (including one cultivar with high N use efficiency) used as reference plants. The nodulating soybeans fixed between 44 and 103 kg N ha^{-1} of their total N and had an estimated net N balance input from fixation following grain harvest ranging from −8 to 43 kg N ha^{-1}. Results in 1996 and in 1997 showed that maize growing after soybean had significantly higher grain yield (1.2 – 2.3-fold increase compared to maize control) except for maize cultivar Oba super 2 (8644-27) (a N-efficient hybrid). The ^{15}N isotope dilution method was able to estimate N contribution by promiscuous soybeans to maize only in the first succeeding maize crop grown in 1996 but not in the second maize crop in 1997. The first crop of maize grown after soybean accumulated an average between 10 and 22 kg N ha^{-1} from soybean residue, representing 17–33% of the soybean total N ha^{-1}. The percentage ^{15}N derived from residue recovery in maize grown after maize was influenced by the maize cultivars. Maize crop grown after the N-efficient hybrid cultivar Oba Super 2 (844-27) had similar ^{15}N values similar to maize grown after soybeans, confirming the ability of this cultivar to use N efficiently in low N soil due to an efficient N translocation ability. The maize crop in 1997 grown after maize had lower ^{15}N enrichment than that grown in soybean plots, suggesting that soybean residues contributed a little to soil available N and to crop N uptake by the second maize crop. The differential mineralization and immobilization turnover of maize and soybean residues in these soils may be important and N contribution estimates in longer term rotation involving legumes and cereals may be difficult to quantify using the ^{15}N labelling approaches. Therefore alternative methods are required to measure N release from organic residues in these cropping systems.

Introduction

Farmers' perceptions of crop importance in improving or depleting soil fertility were investigated in a recent survey conducted in the northern Guinea savanna in Nigeria, to get a firsthand indication on farmers' potential to accept new technologies that could enhance soil nutrient stocks (Manyong et al., 2001). Cereals, particularly maize and sorghum, were regarded as depleting soil nutrients while legumes (soybean, groundnut, and cowpea in that order) were regarded as not depleting soil. Soybean is a relatively new crop for smallholders to most African countries but in recent times its cultivation in the moist savanna agroecological zone has gained popularity as a consequence of the increasing need for food and fodder. It is also important as a cash crop. Increased attention is also being paid to improving the N_2 fixation of promiscuous soybeans in an attempt to develop sustainable cropping systems in the moist savanna (Mpepereki et al., 2000; Sanginga et al., 1997).

Recent research results have shown that maize yields increase when grown in crop rotations with soybeans compared to maize grown after maize in the northern Guinea savanna (Carsky et al., 1997; Kaleem, 1993). Many factors have been hypothesized to explain these results including enhanced N availability following soybean and other rotational effects such as a reduction of diseases and higher mycorrhizal colonization rate and diversity (Sanginga et al., 1999). There is, however, a dearth of reliable estimates of N_2 fixation by these legumes, and hardly any quantitative information is available on their N contribution to subsequent or associated crops such as maize in moist savanna cropping systems.

Even though many early reports have indicated that the cultivation of legumes results in the enrichment of soil N, this has often been dependent on the proportion of the legume's N that is fixed and N harvest index. For such a beneficial residual effect to occur after legumes compared to non-legumes, it is expected that the amount of fixed N_2 returned by the legumes to the soil must be greater than the amount of soil N in the harvested grain.

Earlier field studies performed in Nigeria have shown that soybeans derived less than 60% of their N from fixation with a negative contribution to the N balance in the cropping systems (Eaglesham et al., 1982). Sanginga et al. (1997), however, demonstrated that the N contribution depended on the soybean genotype and maturity period. However, the method of calculation used (net contribution of legume residue N to soil N is equal to the amount of N fixed minus N removed in seeds in kg ha^{-12}) fails to estimate the exact amounts of N taken by the succeeding cereal crop.

Various ^{15}N methodologies have been used to trace the fate of N from leguminous plant material incorporated into the soil (Ladd and Amato, 1986), and to estimate the availability of N to a crop after a legume compared to a crop after a non-legume (Suwanarit et al., 1986). It is disputed whether the beneficial effect of legumes to subsequent crops is due to a N contribution from fixation or is a net 'rotation contribution' (Heichel, 1987) which is a complex effect combining N availability, disease control, and improvement in soil structure (Papastylianou and Puckridge, 1983). The uses of direct and indirect ^{15}N methods have, most of the time, been confined to the first crop; limited information is available on the usefulness of this method to estimate the N contribution after several sequences of rotation.

In this study, we compared the N benefits by five soybean lines to subsequent two maize crops using three independent estimates. The first estimate was obtained by constructing an N balance based on the total N difference method between maize grown on previous soybean and maize plots, i.e., by attributing increased yield and N uptake in the maize crop to the legumes (Estimate 1). The second and the third estimates were made by the ^{15}N dilution method (Fried and Middleboe, 1997). Fresh ^{15}N-labelled fertilizer is added to soil, which contains unlabelled organic residues of soybean and maize (Estimate 2) and the residual ^{15}N of the previous ^{15}N application (Estimate 3).

Materials and methods

The field experiments were conducted between 1995 and 1997 at Mokwa, located in the southern Guinea savanna in Nigeria (longitude 6°5′; latitude 9°48′) with a mean rainfall of 1100 nun per annum. The soil is characterized as an Alfisol.

Before clearing, soil samples were collected at 0–20 cm depth (composite of 20 cores for each of the four blocks). These had low total N (0.06%) and about 32 soybean bradyrhizobial cells per gram of soil. The population of infective soybean bradyrhizobia was estimated by the plant infection technique using two promiscuous soybean lines TGX 1456-2E and TGX 1660-19F (Weaver, 1970). A basal application of 15 kg P as single superphosphate and 15 kg K ha^{-1} as muriate of potash was applied to the soil by broadcasting before planting.

The investigation had two parts. In the first, N_2 fixed by five promiscuous soybeans was measured (Sanginga et al., 1997) and in the second, the N residual effects were estimated.

Seed sources and preparation

Five soybean lines were selected from a screening trial for promiscuity done by the Grain Legume Improvement Program (GLIP) at IITA: three early maturing lines IAC 100 (Brazilian line), TGX 1456-2E (IITA) and TGX 1519-1D (IITA) and two late maturing lines

TGX 1660-19F (IITA) and Br 17060 (Brazilian line). Three maize cultivars Oba Super 1 (902 1-18) (early maturing), TZE Comp (medium maturing) and Oba Super 2 (8644-27) (a late reputedly N-efficient hybrid) were used as reference plants to estimate N_2 fixation in soybeans and its contribution to subsequent maize crops. All seeds were surface sterilized with H_2O_2 (3%) for 3 min and alcohol for 10 s to avoid rhizobia contamination.

Rhizobial inoculation

In 1995, soybean lines were inoculated with a mixture of rhizobia isolates, IRJ 2180 (*Bradyrhizobium japonicum* isolated from soybean in 1979) and R25 (*Bradyrhizobium* sp. isolated from promiscuous soybean in 1994) following the practice described by Vincent (1970). These two strains were selected from an earlier study conducted to reassess the promiscuity and effectiveness of rhizobia nodulating IITA breeding lines (Sanginga et al., 2000). Seeds were mixed with peat containing rhizobial inoculant at a population density of approximately 10^7 cells of rhizobia per seed.

Labelled nitrogen fertilizer

Nitrogen fertilizer (urea) enriched with 5 a% ^{15}N excess was applied to soil as a solution at 20 kg N ha^{-1} in unconfined microplots with maize growing on all previous soybean and maize treatments in 1996. The remaining plot area received unlabelled urea at the same rate. For the 1997 maize crop, two procedures of ^{15}N labelling were used: the fresh ^{15}N labelling as in 1996 with 20 kg N ha^{-1} with 5 a% excess, and the residual ^{15}N of the 1996 fresh application.

Experimental layout

The experimental design was a randomized complete block design with four replications. Treatments were the previous soybean lines and maize reference plants grown in 1994 and 1995. In 1996, maize was grown on all plots. In 1997, maize was again grown in all plots but these were subdivided according to the ^{15}N labelling approach. One half of the plots received a fresh application of ^{15}N while the other part received the same rate of unlabelled fertilizer. Each subplot corresponded to each soybean cultivar consisted of eight rows, 10 m long, with an interrow spacing of 0.75 m and 50 mm within rows. Maize was planted in 1996 and 1997 at the inter-row spacing of 0.75 and 0.25 m within rows. Plot size allowed for destructive sampling during the first harvesting period for shoot biomass and grain yield harvests. ^{15}N microplots were centrally located within each subplot and measured 0.5×1.5 m. Immediately after sowing and thinning (about 1 week after germination) the labelled N fertilizer was applied at the rate given above and dissolved in water at 200 ml/m^2.

Harvest

Harvests were made by gathering all aboveground plant material within the innermost 1.2 m of the two central rows of each subplot. Harvested plant samples were chopped into 10–20-mm pieces weighed and sub-sampled, and about 500 g of fresh weight were oven-dried at 70 °C before being ground to pass through a 0.5-mm sieve. For the last harvest, plant samples were separated into reproductive (grain) and vegetative parts (shoots) before subsampling. Total N and the N isotope ratios were determined with the Automatic Nitrogen Analyser (1500 Carlo Erba), coupled to a SIRA mass spectrometer (Axmann, 1990). The proportion of N derived from the atmosphere in 1994 and 1995 was calculated using the isotope dilution equation. The percentage of N in maize derived from soybeans was estimated by the same principle as that for the calculation of N_2 fixation (Seranatne and Hardarson, 1988). Here the previous three maize cultivars were used as controls. These maize cultivars were expected to have the same $^{15}N/^{14}N$ ratio if there was no residual fixed N from promiscuous soybean lines supplied to the succeeding maize crop. However, if there was any residual N effect, it would result in a lower $^{15}N/^{14}N$ ratio of maize following soybean compared to maize following maize. The extent to which the ratio decreases relative to the control indicates the proportion of the N derived from fixed N_2 in the preceding crop, plus its conserving effect, if any, which can be determined by the equation:

$$\%\mathrm{Ndfr} = 1 - \left(\frac{\%^{15}\mathrm{Na.e \ in \ the \ maize \ following \ soybean}}{\%^{15}\mathrm{N.a.e \ in \ the \ maize \ following \ maize}} \right)^{*} 100,$$

where % Ndfr refers to the percentage of N in the maize derived from an unlabelled source which consists of N derived from fixed biologically fixed N in the legume residue. Hence, the amount of N derived from the unlabelled source is:

$$\frac{\%\mathrm{Ndfr} \times \mathrm{total \ N \ yield \ of \ maize \ following \ soybean}}{100}$$

Statistical analysis

Statistical analyses were done using SAS (Statistical Analysis System Institute Inc., 1989). Analysis of variance were done using PROC GLM to determine the statistical differences between the treatments and their interactions. Specific pair-wise comparisons of treatment levels were done using the Duncan tests or the least significant difference (LSD) test at $P = 0.05$.

Results

Total N, N fixed, and N balance in promiscuous soybeans

The plant total N accumulation in soybeans in 1994 and 1995 ranged from 137 to 199 kg N ha^{-1}. Cultivar IAC 100 accumulated less total nitrogen than the other soybean lines and had the highest N harvest index (Table 1).

Soybean lines fixed an average amount of 77 kg N ha^{-1} representing about 42% of their total N. The proportion and amount of N derived from atmosphere (Ndfa), however, varied between soybean lines with the late maturing TGX 1660-19F and Br 17060 deriving on the average 103 kg N ha^{-1} (57% Ndfa) and 92 kg N ha^{-1} (53% Ndfa). These lines were closely followed by the early maturing TGX 1456-2E and TGX 15 19-1D. Soybean line IAC 100 fixed the least amount of N (44 kg N ha^{-1}).

The net N balance (calculated as the total amount of N_2 fixed minus N removed in seeds) was small for the early maturing lines TGX 1519-1D and TGX 1456-2E (13 kg N ha^{-1}, average) and even negative for cultivar IAC 100 (−8 kg N ha^{-1}). The late maturing lines TGX 1660-19F (30 kg N ha^{-1}) and Br 17060 (43 kg N ha^{-1}) contributed more residual N than the early maturing lines. These lines also had the lowest N harvest index.

Maize total N and grain yield

The five soybean lines and the three maize cultivars had different effects on the total N and grain yield of the following maize. Maize after maize gave lower yields than maize after soybeans. The percentage increases over the maize after maize ranged from 22% for maize after soybean IAC 100 to 139% for TGX 1456-2E (Table 1). The N content in maize was highest on plots previously grown to soybeans. The N uptake in maize after maize was on the average 41 kg N ha^{-1} equivalent to 65% of the total plant N accumulated by maize after soybeans. There were significant differences in total N in maize depending on the soybean line in the previous soybean plots.

Atom % N enrichment and N derived from residue in maize

The percent ^{15}N atom excess in shoots, roots, and grain of the two maize crops following grown in soybean or maize is shown in Table 2. ^{15}N percent atom excess in shoots decreased sharply (1.462%) between the first maize crop in 1996 and second maize crop in 1997 (0.079%). The average value for the fresh ^{15}N application in 1997 was 0.817% compared to 1.462% for the fresh application in 1996.

The first crop of maize in 1996, grown on plots previously cropped to soybeans showed a significantly lower ^{15}N enrichment than that following the two reference maize plants (Oba super 1 (9021-18) and TZE comp). The percent ^{15}N atom excess values observed for maize Oba super 2 (8644-27) were lower than those of the two other maize cultivars and similar to those of maize grown in previous soybean plots. The second maize crop grown on previous maize plots in 1997 had slightly lower a% ^{15}N values than that growing on previous soybean plots.

In determining the percentage and amount of N derived from the previous soybean crop residue, three maize cultivars were used as reference control plants. The values observed for maize cultivar Oba super 2 (8644-27) were negative (Table 3) due to the fact that the percent ^{15}N atom excess values for this treatment were lower than those for most of the plots where soybean had previously been grown (Table 2). The values for the other two maize cultivars, Oba super 1 (9021-18) and TZE comp, were positive and not statistically different.

Using the average values of the two positive reference maize plants, the estimated values of percent N derived from residues in maize grown in plots previously grown to soybeans varied depending on the soybean lines (Table 3). In 1996, they averaged 27% (range 20–43%) in shoots, 22% (range 14–32%) in roots, and 19% in grain (range 14–24%). The total residual N estimates in maize grown in previous soybean plots ranged from 10 to 22 kg N ha^{-1} and more of it was recovered in shoots and grain (Table 4). Total N uptake in roots was small. The highest estimate (15 kg N ha^{-1}) was in maize grown in former soybean

Table 1. Grain yield, total N and N_2 fixed (means of uninoculated and inoculated treatment) measured by the isotope dilution of five soybean lines grown in the field at Mokwa, southern Guinea savanna, Nigeria (Mean values of 1995 and 1996 for soybean and 1996 and 1997 for maize)

Soybean lines/Maize	Soybean					Maize		
	Grain yield (kg ha^{-1})	Total N (kg ha^{-1})	N_2 fixed (kg ha^{-1})	Net input from fixation (kg ha^{-1})^{a}	N harvest Index^{b}	Maize grain yield (kg ha^{-1})	Maize^{d} total N (kg ha^{-1})	Soybean^{c} N input (kg ha^{-1})
Soybeans								
IAC 100	1314^{b}	137^{b}	44^{c}	−8^{d}	0.57^{a}	1541^{b}	57^{b}	16^{b}
TGX 1519-1D	1340^{b}	168^{ab}	78^{bc}	11^{c}	0.50^{b}	2425^{ab}	68^{a}	27^{a}
TGX 1456-2E	1494^{a}	199^{a}	69^{b}	15^{bc}	0.51^{ab}	3021^{a}	67^{a}	26^{a}
TGX 1660-19F	1493^{a}	182^{a}	103^{a}	30^{ab}	0.49^{bc}	1458^{b}	58^{b}	17^{b}
BR 17060	1136^{c}	174^{a}	92^{ab}	43^{a}	0.43^{c}	1986^{ab}	64^{a}	23^{a}
Maize								
Oba super 2 (8644-27) (Ref 1)						1326^{c}	35^{c}	ND
Oba super 1 (9021-18) (Ref 2)						1131^{c}	40^{c}	ND
TZE comp (Ref 3)						1200^{c}	47^{c}	ND

^{a}Net input from fixation:net contribution of soybean N residue to soil N is equal to amount of N fixed minus N removed in grain in kg ha^{-1}.
^{b}Nitrogen harvest index total N in seed divided by total crop N.
^{c}Nitrogen input in maize is calculated by the total N difference method using means of the three reference maize cultivars. ND, not determined.
^{d}Whole aerial tissue.
Means followed by the same letter within the same column are not statistically different at $P<0.05$ (ANOVA).

Table 2. Percent ^{15}N atom excess in maize grown after five soybean lines and the maize cultivars at Mokwa, southern Guinea savanna, Nigeria

Soybean lines	1996 Fresh ^{15}N application			1997 Fresh ^{15}N application		1997 Residual ^{15}N		
	Shoot	Roots	Grain	Shoot	Grain	Shoot	Grain	Weeds
IAC-100	1.445^{abc}	0.449^{b}	0.408^{a}	0.810^{a}	0.295^{b}	0.078^{a}	0.052^{a}	0.049^{bc}
TGX 1519-1D	1.355^{abc}	0.509^{b}	0.411^{a}	0.875^{a}	0.347^{a}	0.081^{a}	0.047^{abc}	0.051^{bc}
TGX 1456-2E	1.390^{abc}	0.510^{b}	0.447^{a}	0.676^{b}	0.362^{a}	0.084^{a}	0.051^{a}	0.050^{bc}
TGX 1660-19F	1.418^{abc}	0.542^{ab}	0.443^{a}	0.878^{a}	0.322^{ab}	0.075^{a}	0.049^{abc}	0.064^{a}
Br 17960	1.025^{c}	0.430^{b}	0.393^{a}	0.907^{a}	0.342^{ab}	0.088^{a}	0.046^{abc}	0.056^{ab}
Maize								
Oba super 2 (8644-27) (Ref 1)	1.299^{bc}	0.511^{b}	0.379^{a}	ND	ND	ND	ND	ND
Oba super 1 (9021-18) (Ref 2)	1.839^{a}	0.760^{a}	0.521^{a}	0.815^{a}	0.316^{ab}	0.075^{a}	0.042^{c}	0.042^{c}
TZE comp (Ref 3)	1.786^{ab}	0.535^{ab}	0.515^{a}	0.761^{a}	0.326^{ab}	0.074^{a}	0.044^{bc}	0.045^{c}

ND, not determined. Means followed by the same letter within the same column are not statistically different $P<0.05$ (ANOVA).

line Br 17060. The residual N estimates after the other soybean lines did not differ greatly (Table 4).

In 1997, the percentage ^{15}N atom excess values for the two maize reference plants (Oba super 1 and TZE comp) were similar to those for plots where soybeans were previously growing with both the fresh ^{15}N application and the residual ^{15}N applied in 1996 (Table 2), and therefore it was not possible to use the ^{15}N isotope dilution method to estimate any residual effects of soybean on the second maize crop.

In the first maize crop N derived from fertilizer averaged 27% in shoots, 8% in roots and 10% in grain (Table 5). In contrast to percentage N derived from the soybean residues, the N derived from fertilizer did not

Table 3. Effect of the preceding soybean crop and maize reference on N derived from residue (%) by maize grown after five soybean lines at Mokwa, southern Guinea savanna, Nigeria

Soybean lines	Shoot			Roots			Grain		
	Ref 1	Ref 2	Ref 3	Ref 1	Ref 2	Ref 3	Ref 1	Ref 2	Ref 3
IAC-100	-11^{c}	21^{c}	19^{c}	12^{a}	41^{a}	16^{a}	-8^{a}	22^{a}	21^{a}
TGX 1519-1D	-03^{b}	30^{ab}	25^{b}	0^{b}	33^{b}	5^{b}	-8^{a}	21^{a}	20^{a}
TGX 1456-2E	-07^{b}	24^{ab}	22^{bc}	0^{b}	33^{b}	5^{b}	-18^{b}	14^{b}	13^{b}
TGX 1660-19F	-09^{b}	23^{bc}	21^{bc}	-6^{b}	29^{c}	-1^{b}	-17^{b}	15^{b}	14^{b}
Br 17060	21^{a}	44^{a}	43^{a}	16^{a}	43^{a}	20^{a}	-4^{a}	25^{a}	24^{a}

Means followed by the same letter within the same column are not statistically different at $P<0.05$ (ANOVA). Ref 1 = Oba super 2 (8644-27); Ref 2 = Oba super 1 (9021-18); Ref 3 = TZE Comp.

Table 4. Estimates of residual N (kg ha^{-1}) in maize grown after five soybean lines at Mokwa southern Guinea savanna, Nigeria using the isotope dilution method (mean values of the two maize references R_2: Oba super 1 (9021 and R_3: TZE comp.)

Soybean lines	Total N (kg ha−1)				N derived from soyybean residues (kg ha^{-1})			
	Shoots	Roots	Grain	Total	Shoots	Roots	Grain	Total
IAC-100	29^{b}	5^{a}	19^{b}	53^{b}	6.0^{b}	1.3^{a}	4.4^{b}	11.7^{b}
TGX 1519-1D	28^{b}	6^{a}	34^{a}	68^{a}	7.0^{b}	0.8^{a}	7.0^{a}	16.0^{b}
TGX 1456-2E	27^{b}	4^{a}	35^{a}	66^{a}	6.0^{b}	0.8^{a}	5.0^{b}	12.0^{b}
TGX 1600-19F	35^{a}	5^{a}	14^{b}	58^{ab}	8.0^{b}	0.6^{a}	2.0^{b}	10.6^{b}
Br 17060	34^{a}	5^{a}	25^{b}	64^{a}	15.0^{a}	2.0^{a}	6.0^{a}	22.0^{a}

Means followed by the same letter within the same column are not statistically different at $P<0.05$ (ANOVA).

Table 5. Estimates of N derived from fertilizer N in maize grown after five soybean lines at Mokwa, southern Guinea savanna, Nigeria

Soybean lines	N derived from fertilizer (%)			N derived from fertilizer (kg ha^{-1})			
	Shoot	Grain	Root	Shoot	Grain	Root	Total
IAC–100	29^{b}	8^{a}	9^{b}	8.4^{a}	0.4^{a}	1.7^{b}	10.5^{b}
TGX 1519-1D	27^{b}	8^{a}	10^{b}	7.5^{a}	0.5^{a}	3.5^{a}	11.4^{b}
TGX 1456-2E	28^{b}	9^{a}	10^{b}	7.5^{a}	0.4^{a}	3.6^{a}	11.4^{b}
TGX 1660-19F	28^{b}	9^{a}	11^{b}	9.9^{a}	0.4^{a}	1.5^{b}	11.9^{b}
Br 17060	21^{b}	8^{a}	9	7.0^{a}	0.4^{a}	2.2^{b}	9.5^{b}
Maize							
Oba super 2 (8644-27) (Ref 1)	25^{b}	8^{a}	10^{b}	Nd	Nd	Nd	8.6^{b}
Oba super 1 (9021-18) (Ref 2)	37^{a}	10^{a}	15^{a}	Nd	Nd	Nd	14.8^{a}
TZE comp (Ref. 3)	36^{a}	10^{a}	11^{b}	Nd	Nd	Nd	17.0^{a}

Means followed by the same letter within the same column are not statistically different at $P<0.05$ (ANOVA).

differ significantly between maize grown in the previous soybean plots. Maize grown following two of the three maize crops had a higher recovery of N from fertilizer than maize sown in plots previously grown to soybean. Fertilizer N accounted for approximately 11% of the plant total N or about 20 kg N ha^{-1}. The amount of N derived from fertilizer following soybean averaged 10 kg N ha^{-1}.

Discussion

It is a misconception that legumes will always lead to an improvement of the soil N status. For such a beneficial residual effect, to occur, it is expected that the amount of fixed N_2 returned by legumes to the soil should be greater than the amount of soil N in the harvested grain (Giller and Wilson, 1991). Depletion of soil-N by growing soybeans has been reported before, in a crop, which fixed 48% of its N-requirement (Eaglesham et al., 1982).

In current study, assuming that only seeds of soybean were removed from the plots, it was estimated that the net N accrual to soil ranged between −8 kg N ha^{-1} (IAC 100) and 47 kg N ha^{-1} (Br 17060). The average for IITA promiscuous lines was 19 kg N ha^{-1} with cultivar TGX 1660-19F contributing 30 kg N ha^{-1}. Soybean lines such as IAC 100 having high harvest indices for N (Sanginga et al., 1997) are unlikely to add appreciable amount of N to the soil through the non-harvested residue. Due to the greater N deficiency in the moist savanna, attempts are now being made by the soybean breeders to reduce the harvest index of N in order to increase the contribution of soybean to soil-N since lines within one crop will give different values of residual N. This is illustrated in this study (Table 1). Soybean lines such as Br 17060 and TGX 1660-19F have a relatively low harvest index for N and contributed relatively greater amount of N to the soil and subsequent nutrient crop. Thus, it might be dangerous to generalize as done by Eaglesham et al. (1982) and Johnson et al. (1974) who indicated, that a net depletion of soil N following grain harvest. The estimates made for these promiscuous soybeans do not, however, take into consideration N contribution from roots, which was shown to be small (Sanginga et al., 1997). However, the recovery of roots from soil is always incomplete so that the full carry-over effect of N will be underestimated, There is also the question of root decomposition and root exudates released before harvest of roots. These quantities can now at least approximately estimated using the technique of McNeil et al., 1997). The so-called rotational effect and the shortcoming of the methodology for estimating the N balance based on the difference between N fixed and N exported through seed also were not estimated.

Although it is traditional to attribute the increases in cereal yield following legume cultivation to greater N accumulation, our data show that the relative increase in maize N following soybeans was smaller than the relative increase in dry-matter yield (Table 1). It is apparent that the 26 kg N ha^{-1} difference between maize after soybean line TGX 1456-2E, for example, could not have accounted fully for the 1802 kg ha^{-1} grain yield difference in maize after maize. Also, yield increases occurred even in situations where the calculated N contribution of soybean was estimated to be negative, such as with soybean line IAC 100. Hence, the increased yields of maize following soybean were not due entirely to the carry-over of N from the soybean residue and to the soil N-conserving effect (Keatinge et al., 1988) but probably also due to 'other effects' which enabled the subsequent crop to exploit the soil more when preceded by legumes than by a cereal. Highly variable results have been reported, however, and the quality of the residue is clearly important. Sisworo et al. (1990) found recoveries in rice (^{15}N-based) ranging from 11.4 to 27.5% of the N applied in cowpea residues. Nitrogen recoveries in alley cropped maize with *L. leucocephala* as low as 5–10% have been reported (Sanginga et al., 1995; Vanlauwe et al., 1998). These 'other effects' merit careful investigation so that the mechanism by which legumes benefit a succeeding crop can be understood. For the subsequent crop, it is important that the residual N benefit after legumes should be evident in the mineral (available) N pool. The availability N for a subsequent crop will be influenced by the amount of plant residues left, the availability of N from the plant residues, mineralization of soil organic matter, and the extent to which soil N was depleted by the preceding crop.

In this study, we compared three methods of estimating N contribution by soybean to a subsequent maize crop. Estimates based on the differences between the proportion of N in the whole plants which derived from fixation and the N removed from harvested seeds (Herridge and Bergersen, 1988), gave values of net N balance ranging from −8 to 43 kg N ha^{-1}. Residual N values of 10.6–24.3 kg were obtained by the indirect ^{15}N labelling method in the first crop, while the total N difference method gave values varying between 16 and 23 kg N ha^{-1}. Senaratne and Hardarson (1988) reported that the N benefit to subsequent crops after grain legumes was due to a lower uptake of soil N by legumes relative to cereals, and a carry-over of N from the legume residue, both leading to a greater uptake of soil N by the subsequent crop compared to crops grown after non-legumes. However, the ^{15}N methods could not estimate any carry-over N contribution of soybeans to maize in the second crop of maize in 1997 either by the fresh application of ^{15}N or from the residual ^{15}N applied a year before in 1996. This was due to the similar ^{15}N enrichment of the maize grown after maize than that of maize following soybean. We attribute this anomaly to possible methodological limitations sometimes encountered with ^{15}N methods.

The differential mineralization and immobilization turnover between maize and soybean residues could also contribute to the observed differences in maize ^{15}N, i.e., there was a N priming effect or an added N interaction (ANI). However, as the soils had low amounts of N and organic matter, it initially seems unlikely that these effects could have been so large. An alternative explanation is that the residual ^{15}N estimate was an underestimate of the residual N in the maize and that 'pool substitution' occurred to create an apparent ANI (Fox et al., 1990; Jenkinson et al., 1985). This is when N mineralization from the residue is taken up in the place of soil-N by a process such as immobilization, resulting in a dilution of the ^{15}N concentration of the residue N available for uptake by a subsequent crop. It is difficult to prove that this occurred, but the consistency and magnitude of the discrepancy between estimates of the fresh ^{15}N application and its residual effect across treatments in 1997 initially suggest that apparent ANIs may have been a factor in this experiment.

Due to its high quality residue and its fast decomposition, there was probably a greater mineralization of native and thus unlabelled soil N beneath the soybeans than in the rhizosphere of maize in the first maize crop, and this was reflected in a greater dilution of the ^{15}N enrichment and thus in a lower ^{15}N enrichment in soil N where the preceding crop was soybeans compared to maize in the first year. In the second year, the same phenomenon was probably in favour of maize, because of its low quality, release of N was slow and reached its peak during the second maize crop. Generally, plant residues with an N content of less than 1.2–1.3% (C/N ratio of about 30) will immobilize soil-N (and fertilizer N, if present) throughout the early weeks and often months of incubation, but if the percentage N is more than 1.8–2.0 (corresponding to a C/N ratio of about 20) considerable net mineralization usually occurs within a week or so, if not immediately (Jenkinson et al., 1985). The percentage N contents in stover of soybean was 2.8% and in maize was 0.7%. It is, therefore, likely that there had been immobilization of soil N following the incorporation of maize stover. The time course of N availability from decomposing residue of promiscuous soybean and maize when in a cropping system rotation as practiced in the Guinea savanna needs to be investigated. However, Vanlauwe et al. (1998) found with *Leucaena leucocephala* (a legume) and *Dactyladenia* (a non-legume) grown in alley cropping that the percentage N recovered by two successive maize crops from the residue was as low as 10% from *L. leucocephala* and 5% from *Dactyladenia*. It is thus evident that the rate of mineralization is greatly influenced by the type of residue.

In conclusion, soybean lines such as IAC 100 which have a high harvest index for N can make only a marginal contribution to the N-status of the soil compared to those with high N_2 fixation and low N harvest index such as TGX 1660-19F and Br 167060. It was also demonstrated that maize growing on previous soybean plots including IAC 100 took up less soil and fertilizer-N than maize grown after maize, thus giving rise to an apparent soil-N conserving effect. However, the total amount of N calculated to be contributed by the soybean residue (10 and 22 kg N ha^{-1} average) could not explain the greater yield increase in maize grown after soybeans. Hence, the increased yields of maize following soybeans were not entirely due to the carry-over of N from the soybean residue and to the soil-N conserving effect but also include other rotational effects. These 'other effects', merit further investigations so the mechanism by which soybeans benefit a succeeding maize crop can be better understood.

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Section editor: F.R. Minchin