Available online at www.sciencedirect.com

SCIENCE DIRECT®

Agriculture, Ecosystems and Environment 100 (2003) 231–240

Agriculture Ecosystems & Environment

www.elsevier.com/locate/agee

Soil N balance as affected by soybean maturity class in the Guinea savanna of Nigeria

A. Singh [a], R.J. Carsky [b,*], E.O. Lucas [c], K. Dashiell [d]

[a] Crop Science Department, Usmanu Danfodiyo University, P.O. Box 1754, Sokoto, Sokoto State, Nigeria
[b] International Institute of Tropical Agriculture, B.P. 08-0932, Cotonou, Benin
[c] Agronomy Department, University of Ibadan, Ibadan, Nigeria
[d] Department of Plant and Soil Science, Oklahoma State University, 368 Agricultural Hall, Stillwater, OK 74078-6028, USA

Abstract

Legume–cereal rotation may reduce the fertilizer requirement of the cereal crop and we hypothesize that the benefit depends on the maturity class of the soybean. Field trials were therefore conducted in 1995 in four Guinea savanna sites to monitor the effect of soybean (*Glycine max* (L.) Merrill) cultivation on the N balance of the soil. In trial 1, an early (TGx1485-1D) and a late (TGx1670-1F) soybean were grown to maturity along with a maize (*Zea mays* L.) reference plot. In trial 2, six varieties of soybean (early: TGx1485-1D, TGx1805-2E and TGx1681-3F; medium: TGx1809-12E and TGx923-2E; late: TGx1670-1F) were grown to maturity along with a reference maize plot. The total nitrogen (N) content, aboveground N_2 fixed, and N remaining in the stover were higher in the medium and the late varieties than in early varieties. Also, the early varieties had higher nitrogen harvest indices (81–84%) than medium and late varieties (74–79%). From the N balance calculation, it was found that medium and late maturing soybean resulted in an addition of 4.2 kg N ha^{-1} to the soil, whereas the early maturing varieties resulted in depletion of the soil N reserve by 5.6 kg N ha^{-1} ($P < 0.05$). On average, among the medium and late varieties, late maturing TGx923-2E resulted in an addition of 9.5 kg N ha^{-1} to the soil. When the stover was not returned to the field, early soybean resulted in more negative N balance than the medium and late soybean ($P < 0.05$). Therefore, planting an early variety of soybean for one season resulted in net depletion of soil N, even when the soybean residues were returned to the soil and N_2 fixed in the roots and N in the fallen leaf litter were included in the N balance calculations. Contrary to this, planting medium and late soybean for one season resulted in an addition of N to the soil. Therefore, medium and late soybean should be used as a preceding crop in legume–cereal rotation, if possible, to minimize or avoid depletion of soil N by early varieties of soybean.

Keywords: N_2 fixation; Nitrogen harvest index; N balance; Soybean (*Glycine max* (L.) Merrill); Guinea savanna; Nigeria

1. Introduction

Grain legumes have long been recognized as an important component of the traditional cropping system. Besides being a cheap source of protein to farm households, legumes fix atmospheric N that enables them to grow well on N-impoverished soils without the addition of fertilizer N and without depleting soil N reserves. Grain legumes have often been intercropped or rotated with cereals to reduce the fertilizer N requirement of the cereal crop in association or rotation with the legumes.

Beneficial effects of legumes on the yield of subsequent crops have been demonstrated in many studies

* Corresponding author. Present address: c/o W. Lambourn & Co., 26 Dingwall Road, Croydon CR9 3EE, UK.
Tel.: +229-30-61-12; fax: +229-35-05-56.
E-mail addresses: asingh@udusok.edu.ng (A. Singh), r.carsky@cgiar.org (R.J. Carsky).

0167-8809/$ – see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/S0167-8809(03)00193-2

(Carsky et al., 1997; Oikeh et al., 1998). It has been found that grain legumes release N through the roots during the growth period (Poth et al., 1986; Pate and Farquahar, 1988) or through their crop residues after decomposition (Giller and Cadisch, 1995). This N becomes available to the companion crop or the subsequent crop in rotation. Agboola and Fayemi (1972) reported that this N, after the decomposition of leaves, roots and nodules, might accrue more to the subsequent crop than to the companion crops. Others express the view that N benefit may be due to a 'sparing effect', whereby legumes, because of their ability to fix N, take up less N from the soil than the cereals (Peoples et al., 1995).

However, modern varieties of grain legumes, especially soybean, efficiently translocate N to the grain, thus leaving behind only a small portion of N in the stover. If legume stover is not returned to the soil at harvest, then there will be a significant removal of soil N from the system by the legume crop (Wani et al., 1995). Some grain legumes, such as soybean, have been reported to deplete N present in the soil (Jones, 1974). Giller and Cadisch (1995) reported that soybean should not be expected to leave a substantial amount of N for subsequent crops.

The effect of soybean on N balance depends on the difference between the inputs and outputs of N in the system. For a grain legume receiving no N fertilizer and with stover being incorporated into the soil, the N benefit to the soil can be assessed by calculating the difference between the percentage of N_2 fixed biologically from the atmosphere (Pfix) and the N removed in the harvested grain (NHI). Therefore, N balance will be positive as long as the NHI $<$ Pfix and it will be negative if NHI $>$ Pfix. In general, positive N balances are associated with the return of a greater amount of fixed N in crop residues compared with the removal of soil N in grain (McDonagh et al., 1993). Thus, grain legumes with high biomass N, low NHI, and high biological N_2 fixation have the greatest potential to contribute positively to the soil N pool (Chalk, 1998). We hypothesized that medium and late maturing varieties will produce more biomass, fix more N, and consequently contribute positively to the N balance of the soil. The objective of the experiment was to estimate the N balance of several soybean varieties to help guide their integration into legume–cereal rotation systems.

2. Materials and methods

2.1. Experimental sites

The experiments were researcher-managed and were established at Gidan Waya (9°28′N, 8°22′E), Mokwa (9°18′N, 5°04′E), Samaru Kataf (9°52′N, 8°22′E) and Yamrat (10°10′N, 9°49′E). The rainfall pattern and chemical and physical properties of the surface soil at the experimental sites are presented in Tables 1 and 2. Rainfall was higher in Gidan Waya and Samaru Kataf than Mokwa and Yamrat (Table 1). Mokwa, Samaru Kataf and Gidan Waya are located in the southern Guinea savanna (SGS) with an average net radiation of 80–85 kcal cm^{-2} per year and growing period ranging from 180 to 209 days. Yamrat lies in the northern Guinea savannna (NGS) with an average net radiation of 85–90 kcal cm^{-2} per year and a growing period ranging from 150 to 180 days (Kowal and Knabe, 1972; COMBS, 1995). Soils of the experimental sites were low in organic matter and total N content. Soil pH (H_2O) ranged from 4.8 to 6.5 with strongly acidic soils in Samaru Kataf and Gidan Waya and moderately acidic soils in Mokwa and Yamrat (Table 2). Fields with low N fertility were selected to assess the N_2 fixing potential of the soybean cultivars. Also, in low N soil, the N-difference method of estimating N_2 fixation is reported to agree with the standard ^{15}N dilution technique (Vasilas and Ham, 1984).

Table 1
Average monthly rainfall (mm) in 1995 and 1996 cropping season at the experimental sites

Month	Yamrat	Mokwa[a]	Gidan Waya[b]	Samaru Kataf[c]
April	25	31	na	70
May	75	189	48	180
June	137	199	282	223
July	134	191	420	214
August	255	207	367	310
September	147	134	156	287
October	39	83	100	57
Total	811	1033	1373	1363

[a] Source: National Cereal Research Institute (NCRI), sub-Station Mokwa, Niger State.
[b] Source: Rain gauge was not available in 1995 and before May in 1996. na: not available.
[c] Source: Agricultural Development Project (ADP), Samaru Kataf, Kaduna State.

Table 2
Physico-chemical properties of the surface soil (0–15 cm) at the experimental sites before planting in 1995 cropping season[a]

Properties	Yamrat	Mokwa	Gidan Waya	Samaru Kataf
pH (H_2O)	6.5 ± 0.10	5.6 ± 0.12	4.9 ± 0.15	4.7 ± 0.12
Bray-I P (mg kg^{-1})	1.5 ± 0.13	6.4 ± 0.41	3.0 ± 0.50	2.2 ± 0.41
Organic C (g kg^{-1})	4.9 ± 0.49	3.5 ± 0.23	7.3 ± 0.28	5.0 ± 0.23
Total N (g kg^{-1})	0.5 ± 0.04	0.4 ± 0.03	0.7 ± 0.03	0.5 ± 0.03
Exch. K (cmol kg^{-1})	0.2 ± 0.03	0.1 ± 0.02	0.2 ± 0.02	0.1 ± 0.02
Exch. Acid (cmol kg^{-1})	0.0 ± 0.00	0.4 ± 0.12	0.7 ± 0.14	0.9 ± 0.12
ECEC (cmol kg^{-1})	5.0 ± 0.30	2.3 ± 0.21	3.3 ± 0.26	2.7 ± 0.22
Sand (g kg^{-1})	770	770	590	870
Silt (g kg^{-1})	150	110	210	110
Clay (g kg^{-1})	80	120	200	20
Soil texture	Loamy sand	Sandy loam	Sandy clay loam	Sandy soil

[a] Values are the average of four samples in Yamrat and four samples and two trials in Gidan Waya, Samaru Kataf and Mokwa ± standard error of means.

2.2. Trial management

In trial 1, established at all the locations in 1995, an early maturing (TGx1485-1D) and late maturing (TGx1670-1F) soybean were grown to maturity along with non-N-fixing maize (open-pollinated TZB-SR, 120 days to maturity) as a reference crop. The treatments (soybean varieties and maize) were laid out in a randomized complete block design replicated three times at Gidan Waya and four times at Samaru Kataf, Mokwa, and Yamrat. The plots were 7 m × 4 m in size, large enough to contain five rows of soybean and maize at a row-to-row spacing of 0.75 m. Planting of the late soybean TGx1670-1F and maize was done in June at all locations while the early cultivar TGx1485-1D was planted in mid-July to avoid the rains at physiological maturity. No N fertilizer was applied to any of the treatments. However, 50 kg ha^{-1} of K and 16 kg ha^{-1} of P were applied as muriate of potash and single super phosphate, respectively, in all locations. Weeds were controlled with pre-emergence application of metachlor/metabromuron+paraquat applied at the rate of 0.5 + 0.2 kg a.i. ha^{-1} in Samaru Kataf, Gidan Waya, and Mokwa. Chemical weed control was supplemented by two manual weeding at 3 and 6 weeks after planting (WAP). Weeds were controlled manually at 3 and 6 WAP in Yamrat.

In trial 2, in 1995, established at Gidan Waya, Mokwa, and Samaru Kataf, six varieties of soybean of different maturity groups were grown to maturity along with a non-N-fixing maize reference plot (early: TGx1485-1D (95 days to maturity), TGx1805-2E (90 days to maturity) and TGx1681-3F (98 days to maturity); medium: TGx1809-12E (112 days to maturity); late: TGx923-2E (118 days to maturity), TGx1670-1F (120 days to maturity); K.E. Dashiell, personal communication, 18 April 1995, IITA, Ibadan). The treatments (soybean varieties and maize control) were laid out in a randomized complete block design replicated three times at Gidan Waya and four times at Samaru Kataf and Mokwa. Plot size was as in trial 1. Early varieties were planted in July while the medium and late varieties were planted in June as in trial 1. Fertilizer application and weed control were as in trial 1.

2.3. Sampling and analysis

At harvest, in both trials 1 and 2, three central rows 5 m long of soybean and maize were harvested for yield estimation. The grain was weighed and yields calculated on a 110 g kg^{-1} moisture basis (11%) in soybean and 150 g kg^{-1} moisture (15%) in maize. The mass of nodules, leaf litter, roots at podding, and grain and stover yield, and their N content were quantified. The amount of N_2 fixed by each soybean variety using the N-difference method and the dry matter yield and the N content in the maize reference plot were quantified; N_2 fixed by each soybean variety was calculated by subtracting the aboveground N content in the reference maize plot from that of soybean plots. Only one reference maize was used for estimating the N-difference. For the early soybean variety that was planted about 3 weeks later, it was assumed that maize took up very little N from the soil at the beginning of growth.

In the estimation of N_2 fixed in the roots and nodules, it was assumed that the fixed N constituted a similar proportion of the N in roots as in the aboveground plant parts and N content in the roots at podding was maintained at harvest. Fallen leaf litter was collected only once at harvest and its N content was included in the total aboveground N accumulation.

Analysis of variance (ANOVA) combined for sites and comparisons of treatment means were done using the general linear model (GLM) procedure in SAS (SAS Institute, 1996). The effect of growth duration in trial 2 was evaluated by group comparisons (medium and late varieties vs. early varieties) using the 'Estimate' statement in the GLM procedure.

3. Results

3.1. Trial 1

Results (Table 3) showed a significant effect of growth duration on the stover, litter, and total N content as well as N_2 fixed in the top and the roots of the soybean. Total N content (107 kg N ha^{-1}) and aboveground N_2 fixed (82 kg N ha^{-1}) in the late maturing TGx1670-1F were significantly higher than in the early maturing varieties ($P < 0.05$). Also, N_2 fixed in the roots (3.9 kg N ha^{-1}), leaf litter N (8.1 kg N ha^{-1}), and stover N content (16.8 kg N ha^{-1}) were significantly ($P < 0.05$) higher in the late maturing TGx1670-1F than in the early maturing TGx1485-1F. The early maturing TGx1485-1F had significantly higher nitrogen harvest index (84%) than the late maturing TGx1670-1F (77%) ($P < 0.05$). Soybean maturity had a significant ($P < 0.05$) effect on the grain yield of soybean, with late maturing TGx1670-1F (1446 kg ha^{-1}) higher yielding than early TGx1485-1F (1357 kg ha^{-1}).

From the N balance calculation where soybean stover was returned to the soil and the N removed in the grain was subtracted from N_2 fixed in the top, roots, and nodules, TGx1670-1F (3.8 kg N ha^{-1}) had a more positive N balance than TGx1485-1F ($P < 0.05$) (Table 3). When the soybean stover was exported from the field, late maturing TGx1670-1F had a less negative N balance (13 kg N ha^{-1}) than early TGx1485-1F (18 kg N ha^{-1}) ($P < 0.05$).

3.2. Trial 2

Results in Table 4 showed a distinct effect of growth duration on the stover, litter, and total N content, as well as N_2 fixed in the top and the roots of the soybean. Total N content (76 kg N ha^{-1}) and aboveground N_2 fixed (54 kg N ha^{-1}) in the medium and late maturing varieties were significantly higher than in the early maturing varieties ($P < 0.05$). N_2 fixed in the roots (6 kg N ha^{-1}), leaf litter N (5 kg N ha^{-1}), and stover N content (14 kg N ha^{-1}) were significantly ($P < 0.05$) higher in the medium and late maturing varieties than in the early maturing varieties. The only exception to this was that the early maturing TGx1805-2E took up more N and fixed more N from the atmosphere than the medium TGx1809-12E. The early maturing varieties had significantly ($P < 0.05$) higher NHI (81–84%) than the medium and late maturing varieties (74–79%) with the exception of late TGx1670-1F, which had NHI similar to early TGx1485-1D. With the exception of TGx1805-2E (1098 kg ha^{-1}) and TGx1681-3F (1018 kg ha^{-1}), there was a significant effect of growth duration on the grain yield of soybean varieties (Table 4). Late maturing TGx923-2E (1133 kg ha^{-1}) and TGx1670-1F (1180 kg ha^{-1}) had significantly ($P < 0.05$) higher grain yield than the early maturing TGx1485-1F (928 kg ha^{-1}) and medium maturing TGx1809-12E (893 kg ha^{-1}).

From the N balance calculation where soybean stover was returned to the soil and the N removed in the grain was subtracted from N_2 fixed in the top, roots, and nodules, the medium and late varieties had a more positive (or less negative) N balance than the early varieties ($P < 0.05$). When the varieties were averaged across locations, positive N balances were estimated with only TGx923-2E (9.5 kg ha^{-1}), TGx1809-12E (1.7 kg ha^{-1}) and TGx1670-1F (1.5 kg ha^{-1}). When the soybean stover was exported from the field, the medium and late maturing varieties had a less negative N balance (10 kg N ha^{-1}) than the early varieties (14 kg N ha^{-1}) ($P < 0.05$) (Table 4).

Results by location (Table 5) showed a more positive N balance with medium and late maturing varieties at all the locations and trials. The most positive balances were from growing TGx923-2E (24 kg N ha^{-1})

Table 3
Nitrogen fixed in the top and roots and nodules, stover and litter N uptake, N removed in the grain and calculated N balance in two soybean genotypes of different maturity groups grown in the Guinea savanna of Nigeria (trial 1)

Soybean genotypes	Maturity group	Grain yield (kg ha^{-1})	Total N uptake[a] (kg ha^{-1})	Fixed N (top) (kg ha^{-1})	Fixed N (root) (kg ha^{-1})	Litter N content (kg ha^{-1})	Grain N removed (kg ha^{-1})	NHI (%)	Stover N content (kg ha^{-1})	N balance (+stover)[b] (kg ha^{-1})	N balance (−stover)[c] (kg ha^{-1})
TGx1485-1D	Early	1357	92	67	3.2	4.5	77	84	10.6	−7.2	−18
TGx1670-1F	Late	1446	107	82	3.9	8.1	82	77	16.8	3.8	−13
S.E.M.		42.5	2.8	3.1	0.19	0.23	2.3	0.5	0.9	1.10	0.4

[a] Total N includes leaf litter N + stover and pod wall N (residue) + grain N.
[b] N balance = (N_2 fixed in top + N_2 fixed in root) − N removed in grain.
[c] N balance = (N_2 fixed in top + N_2 fixed in root) − N in grain − N in stover.

Table 4
Nitrogen fixed in the top and roots and nodules, stover and litter N uptake, N removed in the grain and calculated N balance in six soybean genotypes of different maturity groups grown in the Guinea savanna of Nigeria (trial 2)

Soybean genotypes	Maturity group	Grain yield ($kg\ ha^{-1}$)	Total N uptake[a] ($kg\ ha^{-1}$)	Fixed N (top) ($kg\ ha^{-1}$)	Fixed N (root) ($kg\ ha^{-1}$)	Litter N content ($kg\ ha^{-1}$)	Grain N removed ($kg\ ha^{-1}$)	NHI (%)	Stover N content ($kg\ ha^{-1}$)	N balance (+stover)[b] ($kg\ ha^{-1}$)	N balance (−stover)[c] ($kg\ ha^{-1}$)
TGx1485-1D	Early	928	63	43	2.5	2.5	51	81	9.5	−5.4	−15
TGx1805-2E	Early	1098	77	57	3.0	3.8	64	83	9.2	−3.9	−13
TGx1681-3F	Early	1018	63	43	2.9	2.0	53	84	7.5	−7.5	−15
TGx1809-12E	Medium	893	65	45	5.2	3.3	48	74	13.0	1.7	−11
TGx923-2E	Late	1133	83	63	7.5	6.2	61	74	16.2	9.5	−7
TGx1670-1F	Late	1180	81	62	4.4	4.3	64	79	12.7	1.5	−11
S.E.M.		49.6	3.5	3.6	0.24	0.21	3.3	1.0	0.74	0.95	0.4
Medium and late maturing soybean vs. early soybean (effect of growth duration)											
Estimate	54	8.8	8.6	3.0	1.8	1.8	−6.7	5.2	9.8	4.6	
Probability level	0.1925	0.0045	0.0051	0.0001	0.0001	0.5107	0.0001	0.0001	0.0001	0.0001	

[a] Total N includes leaf litter N + stover and pod wall N (residue) + grain N.
[b] N balance = (N_2 fixed in top + N_2 fixed in root) − N removed in grain.
[c] N balance = (N_2 fixed in top + N_2 fixed in root) − N in grain − N in stover.

Table 5
Calculated N balance in six soybean genotypes grown at different locations in the Guinea savanna of Nigeria (trials 1 and 2)

Soybean genotypes	Maturity group	N balance (kg N ha^{-1})[a]			
		Yamrat	Mokwa	Gidan Waya	Samaru Kataf
Trial 1					
TGx1485-1D	Early	−7	−17	−1	−4
TGx1670-1F	Late	18	−4	1	1
Trial 2					
TGx1485-1D	Early		−10	−6	1
TGx1805-2E	Early		−2	−7	−3
TGx1681-3F	Early		−13	−8	−1
TGx1809-12E	Medium		4	−3	3
TGx923-2E	Late		24	1	4
TGx1670-1F	Late		5	−3	2

[a] N balance = (N_2 fixed aboveground + N_2 fixed in root) − N removed in grain.

at Mokwa and TGx1670-1F (18 kg N ha^{-1}) at Yamrat. The most negative balances were from growing TGx1485-1D and TGx1681-3F at Mokwa.

Averaged over all varieties, Mokwa and Yamrat with moderately acid soil (pH 5.9–6.5) and rainfall ranging from 740 to 1050 mm had significantly higher N_2 fixed and grain and stover N accumulation than Samaru Kataf and Gidan Waya with high rainfall (1260–1370 mm) and strongly acidic soil (pH < 5.0). When the stover was returned to the soil, all locations had negative N balance values with Mokwa (6 kg N ha^{-1}) and Yamrat (5 kg N ha^{-1}) having more negative values than Samaru Kataf (2 kg N ha^{-1}) and Gidan Waya (5 kg N ha^{-1}) (Fig. 1). These values were more negative and followed the same trend when the stover was not returned to the soil.

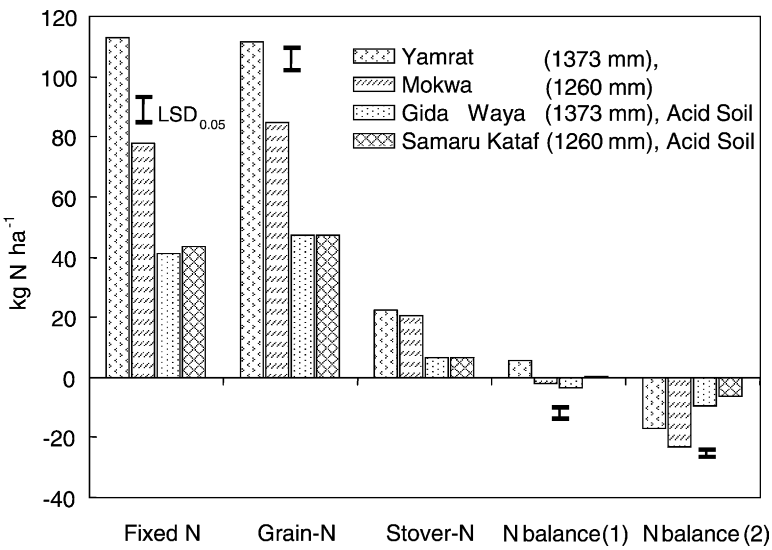

Fig. 1. Average amount of N_2 fixed, N removed in the grain, N in the stover and the calculated N balance in soybean grown at different locations in Guinea savanna of Nigeria. N balance (1) is with soybean stover returned to the soil = (N_2 fixed in top + N_2 fixed in root) − N removed in grain. N balance (2) is with soybean stover exported = (N_2 fixed in top + N_2 fixed in root) − N in grain − N in stover. Values in brackets are annual rainfall at sites in 1995.

4. Discussion

4.1. N_2 fixation

The potential contribution of grain legumes to the soil N balance will depend on the capacity of grain legumes to fix atmospheric N_2. However, the actual amount of N added to the soil will largely depend on the amount of N translocated to the grains at harvest (NHI) and the amount of N returned to the soil as crop residues (Giller and Cadisch, 1995). In this study, soybean fixed 43–82 kg N ha^{-1} across the locations, within the ranges of 26–188 kg N ha^{-1} reported by Giller et al. (1994) and 37–126 kg N ha^{-1} by Sanginga et al. (1997). Higher values of N_2 fixation reported by Giller et al. (1994) and Sanginga et al. (1997) may be due to inoculation with rhizobia. In this study, no inoculation was done because soybean varieties released from International Institute of Tropical Agriculture (IITA) usually nodulate well with the naturally occurring rhizobia in farmers' fields in Nigeria (IITA, 1994, 1996; Sanginga et al., 2000). Compared to early maturing varieties, N_2 fixation was higher in the medium and late maturing varieties (with one exception), largely as a result of higher biomass (Bushby and Lawn, 1993) and longer duration of stay in the field (Eaglesham et al., 1982). However, with the N-difference method of estimating N_2 fixation, the values for early varieties may be slightly underestimated because the maize reference crop was of 120 days duration. This underestimate may be only slight because maize takes up only about 2% of the total N in the first 3 weeks of the growth period (Hanway, 1962).

4.2. N balance

With a high NHI of 76–85%, similar to that reported by Eaglesham et al. (1982) and Toomsan et al. (1995), the N balance calculation indicated a N balance ranging from +9.5 to −8 kg N ha^{-1}. This range, however, varied with the cultivar. For example, planting late maturing TGx923-2E with a NHI of 76% resulted in an addition of 9.5 kg N ha^{-1} to the soil, while the early maturing varieties with high NHI resulted in the removal of 4–8 kg N ha^{-1}. Similar to this experiment, Sanginga et al. (1996) also obtained more negative N balance values for early maturing varieties. In medium maturing TGx923-2E, N_2 fixation was sufficient to offset the N harvested in the grain, therefore resulting in a positive N balance. In all the varieties, when the crop residues were removed, the N balance was more negative than that obtained when crop residues were returned to the soil. Peoples and Craswell (1992) and Toomsan et al. (1995) obtained similar results.

In most of the previous N balance estimates, the contribution of roots and nodules and the leaf litter that fell before harvest was not taken into account. In this study, when fixed N partitioned into leaves and roots was taken into consideration, N balance estimates were less negative than otherwise obtained. Fallen leaf litter and petiole-N (2–11 kg N ha^{-1}) contributed only 4–8% of the total N in the soybean crop. This was similar to 6 kg N ha^{-1} reported by Van Noordwijk and Purnomisid (1992) and lower than the 24% reported by Hanway and Weber (1971). However, Hanway and Weber (1971) started sampling leaf litter from the time of planting. In this study, leaf litter was sampled only once at harvest, therefore underestimating the potential contribution.

Roots and nodule N contributed 4–14% of the total N amounting to 3–8 kg N ha^{-1}. This was less than the estimate of 15% obtained by Armstrong et al. (1994). On the assumption that root N at podding is maintained at harvest, roots and nodules contributed 27% of N in the residues after the grain harvest. This was similar to the value (25%) that was obtained by Armstrong et al. (1994) with field pea in southwestern Australia. Furthermore, a study on lupine using ^{15}N indicated that root N may be 3-fold higher than that calculated using only N contained in recoverable root material (Peoples et al., 1995). Thus, the potential N benefits from the roots and nodules may still be underestimated.

4.3. Effect of soil characteristics

Due to the low N content of the soil at all the locations, nitrate accumulation did not hinder N_2 fixation from the atmosphere. The exceptionally low N_2 fixation and grain and stover N accumulation by soybean in Samaru Kataf and Gidan Waya may be attributed to a lower rhizobial population or an inability to form effective nodules (Sanginga et al., 2000). It has been reported by Sanginga et al. (1996) that rhizobial population is influenced by cropping sequence, i.e., plots cropped to a cereal in the previous season had fewer rhizobia than those cropped to legumes. In this regard, plots at Gidan Waya and Samaru Kataf may have had a low rhizobia density because they were cropped to maize and millet in the previous season.

Using a critical pH of 5.1 for soybean and 5.0 for maize (Aune and Lal, 1997), the soils at Yamrat and Mokwa were more suitable for soybean and maize cultivation than at Gidan Waya and Samaru Kataf. Acid soils are less productive because aluminum (Al) and manganese (Mn) toxicity and calcium (Ca) deficiency are often associated with low pH. Furthermore, phosphorus (P) availability is influenced by pH because relatively insoluble aluminum phosphate (Al-P) and iron (Fe-P) form under low pH (Sanchez, 1976). This conversion is reported to be most serious when soil pH is below 5.0 (Brady, 1990) as in Samaru Kataf and Gidan Waya. Aune and Lal (1997) observed a high negative correlation between soybean yield and Al-saturation. Low grain and stover N accumulation in Samaru Kataf and Gidan Waya may also be due to the sandy soil texture and high rainfall, which might have increased leaching of soil nitrate N and K beyond the plant roots.

5. Conclusions

Growing early maturing soybean for one season is estimated to result in a net depletion of soil N ranging from 4 to 8 kg N ha^{-1} even when the stover is returned to the soil and N_2 fixed in the roots and nodules and N in the fallen leaf litter were included in the N balance calculation. The most favorable N balance of 24 kg ha^{-1} was obtained with TGx923-2E (118 days) at Mokwa followed by 18 kg N ha^{-1} with TGx1670-1F (120 days) at Yamrat. When averaged over sites, TGx923-2E resulted in a net addition of 9.5 kg N ha^{-1}. On average, medium and late maturing soybean resulted in a net addition of 4.2 kg N ha^{-1}. Our data suggest that medium and late maturing soybean varieties would be a better preceding crop in a legume–cereal rotation.

Acknowledgements

The authors are grateful to Lekan Tobe, Adegbola Azeez, Rufus Ovom and Linus Ushie for assistance with fieldwork, Drs. G. Tian and N. Sanginga for providing laboratory facilities and several anonymous IITA scientists for technical review of the manuscript. This is IITA manuscript number IITA/00/CP/16.

References

Agboola, A.A., Fayemi, A.A., 1972. Fixation and excretion of nitrogen by tropical legumes. Agron. J. 64, 409–412.

Armstrong, E.L., Pate, J.S., Unkovich, M.J., 1994. Nitrogen balance of field pea crops in southwestern Australia, studied using the ^{15}N natural abundance technique. Aust. J. Plant Physiol. 21, 533–549.

Aune, J.B., Lal, R., 1997. Agricultural productivity in the tropics and critical limits of properties of Oxisols, Ultisols and Alfisols, Ultisols and Alfisols. Trop. Agric. 74 (2), 96–103.

Brady, N.C., 1990. The Nature and Properties of Soils, 10th ed. Macmillan, New York, USA, p. 621.

Bushby, H.V.A., Lawn, R.J., 1993. Nitrogen fixation by mungbeans and their role in sustainable agriculture. ACIAR Food Legume Newslett. 18, 8–11.

Carsky, R.J., Abaidoo, R., Dashiell, K.E., Sanginga, N., 1997. Effect of soybean on subsequent maize grain yield in the Guinea savanna zone of West Africa. Afr. Crop Sci. J. 5, 31–38.

Chalk, P.M., 1998. Dynamics of biologically fixed N in legume–cereal rotations: a review. Aust. J. Agric. Res. 49, 303–316.

COMBS (Collaborative Group on Maize-based Systems Research), 1995. Improvement of Soil Fertility and Weed Suppression Through Legume-based Technologies. IITA Research Guide 48, 2nd ed. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, p. 52.

Eaglesham, A.R.J., Ayanaba, A., Ranga Rao, V., Eskew, D.L., 1982. Mineral N effects on cowpea and soybean crops in a Nigerian soil. II. Amounts of N fixed and accrual to the soil. Plant Soil 68, 183–192.

Giller, K.E., Cadisch, G., 1995. Future benefits from biological nitrogen fixation: an ecological approach to agriculture. Plant Soil 174, 255–277.

Giller, K.E., McDonagh, J.F., Cadish, G., 1994. Can biological nitrogen fixation sustain agriculture in the tropics? In: Syers, J.K., Rimmers, D.L. (Eds.), Soil Science and Sustainable Land Management in the Tropics. CAB International, Wallingford, UK, pp. 173–191.

Hanway, J.J., 1962. Corn growth and composition in relation to soil fertility. II. Uptake of N, P, and K and their distribution in different plant parts during the growing season. Agron. J. 54, 217–222.

Hanway, J.J., Weber, C.R., 1971. Accumulation of N, P and K by soybean (*Glycine max* (L.) Merrill) plants. Agron. J. 63, 406–408.

IITA (International Institute of Tropical Agriculture), 1994. Natural technologies for sustainable food production. Annual Report. IITA, Ibadan, Nigeria, pp. 33–35.

IITA, 1996. Microbiology in the service of crops and soil: understanding nitrogen fixation in the promiscuous soybean. Annual Report. IITA, Ibadan, Nigeria, pp. 20–23.

Jones, M.J., 1974. Effects of previous crop on yield and nitrogen response of maize at Samaru, Nigeria. Exp. Agric. 10, 273–280.

Kowal, J.M., Knabe, D.T., 1972. Agroclimatological Atlas of the Northern States of Nigeria with Explanatory Notes. Ahmadu Bello University Press, Samaru, Zaria, Nigeria, p. 128.

McDonagh, J.G., Toomsan, B., Limpinuntana, V., Giller, K.E., 1993. Estimates of the residual nitrogen benefit of groundnut to maize in northeast Thailand. Plant Soil 154, 267–277.

Oikeh, S.O., Chude, V.O., Carsky, R.J., Weber, G.K., Horst, W.J., 1998. Legume rotation in the moist tropical savanna: managing soil nitrogen dynamics and cereal yields in farmers' field. Exp. Agric. 34, 73–83.

Pate, J.S., Farquahar, G.D., 1988. Role of the crop plants in cycling of nitrogen. In: Wilson, J.R. (Ed.), Advances in Nitrogen Cycling in Agricultural Ecosystems. CAB International, Wallingford, UK, pp. 23–45.

Peoples, M., Craswell, E.T., 1992. Biological nitrogen fixation: investments, expectations and actual contributions to agriculture. Plant Soil 141, 13–39.

Peoples, M.B., Herridge, D.F., Ladha, J.K., 1995. Biological nitrogen fixation: an efficient source of nitrogen for sustainable agricultural production. Plant Soil 174, 3–28.

Poth, M., La Favre, J.S., Focht, D.D., 1986. Quantification by direct ^{15}N dilution of fixed N_2 incorporation into soil by *Cajanus cajan* (pigeon pea). Soil Biol. Biochem. 18, 125–127.

Sanchez, P.A., 1976. Properties and Management of Soils in the Tropics. Wiley, New York, USA, p. 618.

Sanginga, N., Abaidoo, R., Dashiell, K., Carsky, R.J., Okogun, A., 1996. Persistence of effectiveness of rhizobia nodulating promiscuous soybeans in the moist savanna zones of Nigeria. Appl. Soil Ecol. 3, 215–224.

Sanginga, N., Dashiell, K., Okogun, J.A., Thottappilly, G., 1997. Nitrogen fixation and N contribution by promiscuous nodulating soybean in the Guinea savanna of Nigeria. Plant Soil 195, 257–266.

Sanginga, N., Thottappilly, G., Dashiell, K., 2000. Effectiveness of rhizobia nodulating recent promiscuous soybean selections in the moist savanna of Nigeria. Soil Biol. Biochem. 32, 127–133.

SAS Institute, 1996. SAS User's Guide: Statistics. SAS Institute, Cary, NC, USA.

Toomsan, B., McDonagh, J.F., Limpinuntana, V., Giller, K.E., 1995. Nitrogen fixation by groundnut and soybean and residual nitrogen benefits to rice in farmers' fields in northeast Thailand. Plant Soil 175, 45–56.

Van Noordwijk, M., Purnomisid, P., 1992. Litter fall in cassava-based cropping systems in Lampung. Agrivita 15 (1), 29–32.

Vasilas, B.L., Ham, G.E., 1984. Nitrogen fixation in soybean: an evaluation of measurement techniques. Agron. J. 76, 759–764.

Wani, S.P., Rupela, O.P., Lee, K.K., 1995. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. Plant Soil 174, 29–49.