SYMBIOTIC POTENTIAL AND N RETURNS IN FORAGE AND GRAIN LEGUMES FOR IMPROVING THE N ECONOMY OF TROPICAL CROPPING SYSTEMS

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ABSTRACT

There were marked cultivar and species differences in the amounts of N fixed and potential N returns in five forage legumes and ten groundnut (*Arachis hypogaea* L.) cultivars evaluated for symbiotic performance in both Guinea and Sahel savanna environments. Of the forage legumes, the *Crotalaria* and *Lablab* species accumulated greater symbiotic N and therefore showed higher potential N returns for improving the N economy of soils in both Guinea and Sahel savanna in Africa. However, *Lablab* appeared to be better adapted to the drier Sahel environment compared to the other species. When nutrient imbalances in the Guinea savanna soil were resolved by supplying plants with a moderate dose of a complete fertilizer (minus N), two of ten groundnut cultivars outperformed the rest in dry matter yield, N fixed and potential N returns in both fertilized and unfertilized conditions. These findings suggest that the two cultivars have the genetic potential for dry matter accumulation and enhanced N_2 fixation even under varying soil nutrient conditions. Another two groundnut cultivars showed evidence of soil N depletion with negative values of potential N returns, clearly indicating that their continued cultivation in a soil is likely to lead to mineral N exhaustion.

KEYWORDS

N fixed, N returns, forage legumes, groundnut cultivars

INTRODUCTION

The intrinsically low fertility of soils in Africa is a major constraint to increased agricultural productivity in the continent. Of all the nutrients, N is the single most limiting factor in agricultural soils in Africa. According to Borlaug (1990), about 90% of mineral N in African soils is found in living plants, with only a small mineralizable fraction left for plant uptake under agricultural conditions. As a consequence, N nutrition plays a major role in determing crop yields in the continent. To meet the nutrient demands of agricultural crops requires the use of chemical fertilizers and/or the exploitation of biological N from symbiotic legumes. The latter choice is cheaper than the former. Chemical fertilizers are not only expensive for routine use by most farmers, but also unavailable when needed. Additionally, their frequent application in agriculture is causing environmental degradation.

Consequently, N_2 fixation by legumes has become a significant alternative to chemical fertilizers in the provision of N for maintaining agricultural yields in Africa. This study examines the N_2-fixing capacity of forage and grain legumes and their potential contribution to the N economy of savanna soils.

Ten groundnut lines/cultivars were selected (Table 1) and seeded either in fertilized field plots containing a minimal dosage of a complete (N free) fertilizer (60 kg Ca, 26.2 kg P, 13.5 kg K, 6.1 kg Mg, 0.13 Na, 0.24 kg Cu, 0.03 kg Zn, 0.028 kg Mo, 50.7 kg S ha^{-1}) or in plots receiving no fertilizer. Maize (*Zea mays*) cv. TZE-3 was included as a non-N_2-fixing reference plant for assessing soil N uptake by groundnut. At flowering, four plants per plot were assessed for nodulation. At physiological maturity, plants were harvested from the innermost rows for yield determination, estimates of N_2 fixation and potential N returns. Five forage legumes (*Stylosanthes*, *Centrosema*, *Crotalaria*, *Lablab* and *Leucaena* species) were similarly assessed for N returns at Nyankpala within the Guinea savanna and Manga in the Sahel savanna, using maize and sorghum (*Sorghum* spp.) as reference plants.

In all cases, symbiotic N_2 fixation was assessed by subtracting total N of non-fixing cereal plant from total N of legume. This method agrees with standard ^{15}N techniques for estimating N_2 fixation (Kohl *et al*., 1980), especially under conditions of low soil N as obtained in these savanna soils. Potential N returns from legume were determined as the difference between total plant N and the sum of N harvested in seed and N taken up from soil.

RESULTS AND DISCUSSION

Except for the groundnut cultivar L1 and L2 which showed significantly ($P = 0.01$) greater accumulation of dry matter, plant growth (measured as total dry matter) was not different among the other eight lines in both fertilized and unfertilized plots (Table 1). Providing a complete fertilizer (minus N) to groundnut plants increased growth in L1 and L2 by 90% and 22% respectively compared to unfertilized counterparts.

There were marked cultivar differences in the levels of N fixed, with about 3.8-fold variation between the least and highest N_2-fixing cultivar. With fertilization, the cultivar L1 fixed the highest ($P = 0.01$) amount of N, followed by L2, which accumulated significantly ($P = 0.01$) more N than the remaining eight lines/cultivars (Table 1). Under natural unfertilized conditions, L1 and L2 were still the highest in N_2 fixation (Table 1), indicating that the two cultivars have the genetic potential for enhanced N_2 fixation, irrespective of the soil nutrient conditions. Except L1 and L2, which increased their levels of N fixed with nutrient supply, there was little effect of fertilization on the symbiotic performance of the other groundnut lines.

The values of potential N returns, calculated as the difference between total plant N and the N harvested in grain and N uptake from soil, showed strong variation with cultivar type. In general, more N was harvested in grain with nutrient supply than when plants were unfertilized. Consequently, the potential N returns were lower in residues of fertilized groundnut plants compared to unfertilized. Two groundnut lines (L8 and L9) showed evidence of soil N depletion, with negative values for potential N returns (Table 1), as observed for some symbiotic systems (Dakora and Keya, 1997). This suggests that the continued cultivation of such legumes is likely to lead to exhaustion of soil N.

Selected forage legumes were also evaluated for their N_2-fixing ability and potential N contribution to soil fertility in a Sahelian and Guinea savanna zone. Except *Leucaena*, which failed to nodulate, all the other species nodulated freely with native bacterial strains. Measures of N_2 fixation in each species were obtained using sorghum and maize as non-fixing reference plants. In each case, the values of symbiotic N in residue were similar, indicating that roots of the two cereals took up equal amounts of N from the same soil zone. Of these forage legumes, the *Crotalaria* species was the highest in N_2 fixation, followed by *Lablab* and *Centrosema* species. As shown in Table 2, annual contribution of symbiotic N_2 fixation to the N economy of soils ranged from 0.5 to 88 kg N ha^{-1} for these species. Except the *Lablab* species, which performed better in the drier Sahelian zone, the other species fixed more N in the wetter Guinea savanna soil. Inclusion of these forage legumes in cropping systems therefore has the potential for improving the N regime of agricultural soils, at least in the Guinea savanna environment. Lablab appeared to be better adapted to the drier soils of the Sahel savanna, and could serve as a covercrop against soil erosion and as a source of soil N enrichment.

CONCLUSION

Our data have therefore demonstrated the need to select legume cultivars for enhanced N_2 fixation and potential N returns if soil N improvement is to be a major objective in the cropping system.

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Table 1

Plant growth, N_2 fixation and potential N returns in ten groundnut lines

Groundnut line	Total dry matter (kg ha^{-1})		N fixed (kg ha^{-1})		Potential returns (kg ha^{-1})	
	Fert.	Unfert.	Fert.	Unfert.	Fert.	Unfert.
L1	5721a	3005a	113a	65a	59	35
L2	4183b	3420a	80b	69a	35	34
L3	2142c	2378ab	40c	49ab	8	16
L4	2207c	1613b	41c	32b	8	11
L5	2050c	1736b	39c	32b	6	14
L6	2283c	1759b	35c	33b	5	9
L7	1697c	1746b	30c	36b	3	12
L8	1301c	1468b	33c	28b	-2	9
L9	1571c	1426b	30c	29b	-1	8
L10	1696c	1380b	32c	27b	3	9

Values followed by dissimilar letters in a column are significantly different at P = 0.01.

L1 = Manipintar; L2 = NCACC2543 x NCACC293B; L3 = (Robot 33-1-13-6)B1 B1 B1 B1 B1; L4 = (Robot 33-1 x Ah8254)F2 B1 B1 B1 B1 B1; L5 = (Ah2105 x Chil)F2 P1 B1 B1 B1 B1; L6 = (Goldin Exfaizpurts)F2 P1 B1 B1 B1 B1 B1; L7 = (Robot33-1-7-6)B1 B1 B1 B1 B1; L8 = Robot33-1-10-3)B1 B1 B1 B1 B1; L9 = Robot33-1-1-5)B1 B1 B1 B1 B1; L10 = 79-2. Fert = fertilized; Unfert = unfertilized.

Table 2

Potential N returns from N_2 fixation by selected forage legumes grown in a Guinea savanna (Nyankpala) and a Sahel savanna (Manga) zone in Ghana

Species	Nodulation	Biological N in biomass (kg ha^{-1}) Nyankpala		Manga	
		sorghum*	maize	sorghum	maize
Crotalaria	+	87.7a	88.2a	ND	ND
Lablab	+	36.7b	37.2b	51.3a	56.1a
Stylosanthes cv. Verano	+	36.8b	37.3b	0.5b	5.3b
Stylosanthes cv. Cook	+	15.8c	16.3c	ND	ND
Centrosema	+	8.6c	9.1c	1.4c	6.2b
Leucaena leucocephala	-	0.0	0.0	0.0	0.0

*Biological N in legume residue was estimated by subtracting total N in cereal from that of legume. Values followed by dissimilar letters in a column are significantly different at P = 0.05.