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Dinitrogen Fixation by Pigeonpea of Different Maturity Types on Granitic Sandy Soils in Zimbabwe

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Abstract

N_2-fixation by pigeonpea (*Cajanus cajan* (L.) Millsp.) of different maturity groups was measured on coarse sand and sandy clay loam soils at Domboshawa and Murewa in Zimbabwe. Sorghum (*Sorghum bicolor* (L.) Moench) cultivars of corresponding growth duration, maize or a non-nodulating pigeonpea variety were used as non-fixing reference plants. The ^{15}N natural abundance method was used on-farm, with maize serving as the non-fixing reference plant, while the N difference method was used on-station at Domboshawa. The amounts of N_2 fixed by pigeonpea ranged from 6–43 kg ha^{-1} for short duration (about 100 days to maturity) and 18–183 kg ha^{-1} for the long duration (>150 days to maturity). Small amounts of N_2 fixed by pigeonpea grown on coarse sand soils were attributed to poor growth and biomass accumulation caused by poor soil fertility. All pigeonpea derived at least 81% of their N from N_2-fixation when grown on sandy soil, and at least 69% when grown on the moderately fertile sandy clay loam. The amount of N derived from fixation increased with decreasing soil N availability. The ^{15}N natural abundance method proved a useful tool in the appraisal of N_2-fixation in natural cropping settings, and gave comparable results with the N difference method. Amounts of N_2 fixed by pigeonpea under conditions of poor soil fertility were comparable to the

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amounts fixed by legumes with good N_2-fixation potential such as groundnut and soyabean. Pigeonpea could therefore contribute significantly to the N economy of smallholder cropping systems under marginal environments in the tropics. Our results show that BNF may be the only source of N in these farming systems. However, the quantities of N_2 fixed are often extremely low reflecting the poor productivity of legumes. Thus BNF technologies may not realize the claims often made under conditions where constraints are severe. Many soils on smallholder farms in the tropics are extremely poor in both physical and chemical fertility, and few technologies are available to ensure legume productivity. There is scope for improving BNF through the inclusion of stress-tolerant legume genotypes into the cropping system and strategic management of other nutrients.

Keywords: N_2-fixation, *Cajanus cajan*, maturity type, poor soil fertility, tropical environments, ^{15}N natural abundance, N-difference

1. Introduction

The beneficial effects of N_2-fixing legumes to soil fertility in crop production systems have long been recognised in ancient and modern agriculture (Belteky and Kovacs, 1984; Giller and Wilson, 1991). Legumes, through their symbiotic association with *Rhizobium* bacteria, can contribute up to 500 kg N ha^{-1} yr^{-1} to the nitrogen (N) economy of tropical and sub-tropical terrestrial ecosystems (FAO, 1993). This potential, however, has not been fully realised due to limiting environmental conditions (e.g. drought and low soil fertility) and under-exploitation of the diverse legume resource base that exists in tropical ecosystems (National Academy of Sciences, 1979). In recent years, the escalating costs and inaccessibility of 'green revolution' type agricultural inputs to smallholder farmers in developing countries have necessitated research into low-input agriculture. Sustainability of low-input cropping systems has become a major subject of research in Sub-Saharan Africa, where poor soil fertility has been identified as a key constraint to rural development (Sanchez et al., 1997). Increased manipulation and exploitation of soil biological processes, including biological nitrogen fixation (BNF), has been advocated (Swift, 1987; Woomer and Swift, 1994). The potential of BNF in cropping systems lies in the quantity of N fixed and its optimum utilization (Giller, 1998). The quantification of N fixed by legumes under a given set of environmental conditions and soil management practices is, therefore, a key step in the development of efficient agricultural and agroforestry systems.

Under favourable environmental conditions, exploitation of BNF can be enhanced through inclusion of more legumes in the cropping systems (Giller et al., 1994). This is applicable to countries like Zimbabwe where pigeonpea is being introduced as part of the strategy to increase the limited range of leguminous crops grown in the smallholder sector (Mapfumo et al., 1999) to improve both N and soil organic matter. Most of the locally derived organic fertilizer sources such as animal manure and composts do not provide sufficient N or are not readily available (Campbell et al., 1998). In this study, the quantities of N fixed by pigeonpea [*Cajanus cajan* (L.) Millsp.] of short, medium and long duration grown on sandy soils of poor to marginal fertility were determined in Zimbabwe. Pigeonpea was chosen for its adaptability to a wide range of environmental and agronomic conditions (Nene and Sheila, 1990). The crop is increasingly gaining importance in smallholder agricultural systems of Eastern and Southern Africa (Boehringer and Caldwell, 1989; Mapfumo et al., 1998; Sakala, 1998), particularly due to its versatility and tolerance to drought and low soil fertility. Several methods have been used to quantify the N fixed by legume plants, each one having its own advantages and disadvantages (Peoples et al., 1989; Giller and Wilson, 1991). Lack of suitable non-fixing reference crops, and the deep rootedness of the crop, have been cited as the main limitations to the quantification of N fixed by pigeonpea (Kumar Rao et al., 1987). However, there is a general paucity of information on BNF of pigeonpea (Kumar Rao, 1990) and particularly the quantities of N fixed in African soils. In this study, the N-difference and the ^{15}N natural abundance methods were both used to estimate pigeonpea BNF contributions to the N economy of depleted sands under smallholder management.

2. Materials and Methods

The experiments were conducted on two soil types at Domboshawa Training Centre (on-station), and on ten smallholder farms representing one soil type in Murewa Communal Area (on-farm). The two sites are in a sub-humid environment in north-eastern Zimbabwe, receiving 750–1000 mm of annual rainfall between November and March. Soils were of poor to moderate fertility (Table 1). The N-difference method was used at Domboshawa while the ^{15}N natural abundance method was used in Murewa. A very low natural abundance of ^{15}N ($\delta^{15}N < 2‰$) in Domboshawa soils made the use of the natural abundance method inappropriate.

At Domboshawa, five pigeonpea cultivars of short (cvs. ICPL87109 and ICPL87091), medium (cv ICP9145) and long (cvs. Ex-Marondera and Ex-Malawi) duration were planted on two soil types, sandy clay loam and coarse sand, on December 6 1996. The two soil types are herein after referred to as loam and sand respectively. Three sorghum (*Sorghum bicolor* L. Moench) cultivars of corresponding growth duration, namely Red Swazi (short), Sweetgraze (medium) and Jumbo (long), were included as non-fixing reference crops. Red

Table 1. Characteristics for soils at the Domboshawa and Murewa sites used for the pigeonpea experiments in Zimbabwe

Soil characteristic Textural class	Domboshawa 1 Loam	Domboshawa 2 Coarse sand	Murewa Coarse sand
Clay (%)	18	2	5
Sand (%)	76	92	90
Mineral N (mg kg^{-1}) [1]	42	20	24
Resin P (mg kg^{-1})	10	4	6
pH ($CaCl_2$)	4.4	4.2	4.3
Organic C (%)	0.59	0.29	0.34
Total N (%)	0.03	0.02	0.02
K (cmol+kg^{-1} soil)	0.19	0.08	0.07
Ca (cmol+kg^{-1} soil)	0.92	0.50	0.85
Mg (cmol+kg^{-1} soil)	0.53	0.36	0.34

[1] Mineral N after incubation; loam = sandy clay loam.

Swazi is a grain sorghum while the other two are forage varieties. A non-nodulating pigeonpea cultivar (P94090) of short duration was also included.

Plots measured 3.6 m × 2.7 m each, with a net plot of 1.8 m × 1.5 m available for sampling. Plant spacings of 0.9 m inter-row and 0.2 m within rows were used for both pigeonpea and sorghum. Three seeds were sown per planting station, and thinned to one per station two weeks after planting (WAP). All plants received a blanket application of 12.5 kg P ha^{-1} and 18 kg S ha^{-1} as single super phosphate. The fertilizer was banded into planting furrows at planting. All pigeonpea seed (except for the non-fixing control) was inoculated using a *Bradyrhizobium* strain MAR1510 obtained from Soil Productivity Research Laboratory, Marondera, Zimbabwe. A randomised complete block design with four replicates was used. Plots were kept weed-free through hand-hoeing. Soil moisture was adequate for a normal growing season. At 50% full flowering, 1 m row of above ground shoots was harvested from each plot. The shoots were air-dried on wire frames before being oven-dried to a constant mass at 60°C. Dried plant samples were ground to pass through a 1 mm sieve on a Wiley mill. Sub-samples were then taken for N determination using the semi-micro Kjeldahl method. The plant material was digested through wet oxidation and N determined colorimetrically. The quantity of N fixed was calculated as the difference between legume N uptake and N uptake by the corresponding non-fixing reference crop. Grain was harvested from a 1.5 m row per plot and yielded at 10% moisture content.

In Murewa Communal Area the pigeonpea cultivars ICPL87109, ICP9145 and Ex-Marondera were used with maize as the non-fixing reference. The experiment was part of a larger trial aimed at determining the effect of pigeonpea green manuring on subsequent maize (Mapfumo et al., 1998) and plots measured 18 m × 4.5 m per cultivar. The reference maize received 80 kg N ha^{-1} in form of ammonium nitrate. Treatments were replicated over the 10 farms, and a completely randomised design was used. Pigeonpea biomass was yielded at flowering stage while maize was harvested at physiological maturity. In each case 3 × 1.5 m rows were sampled. Above-ground biomass yields and N content were determined as described above, while ^{15}N natural abundance in plant samples and the ammonium nitrate fertilizer was determined by an automatic C/N analyzer (Roboprep) coupled to a 20–20 mass spectrometer (Europa Scientific, Crewe, UK) at Wye College, University of London. The proportion of N derived from atmospheric N_2 by pigeonpea was calculated through the following equation:

$$\%\text{N from fixation} = \frac{(\delta^{15}\text{N reference plant} - \delta^{15}\text{N fixing plant})}{(\delta^{15}\text{N reference plant} - \text{B})} \times 100$$

where B is the $\delta^{15}N$ of the same N_2-fixing plant when grown on N_2 as the only source of N. A B value of –0.90 was used (Peoples et al., 1991).

Statistical analysis

The data were subjected to analysis of variance. Mean comparisons for the Domboshawa data were based on LSD values, while Tukey's pairwise comparisons were employed for the Murewa data. For all mean comparisons significance was tested at $P<0.05$. Differences in productivity and N uptake by the reference crops used at Domboshawa were tested for significance in a separate analysis. Dependence of N_2-fixation on soil available N was investigated using linear regression analysis.

3. Results

Domboshawa

Reasonable synchrony in flowering was achieved between non-fixing reference crops and the pigeonpea of corresponding growth duration. Plant growth was generally poor on sandy soil, with the reference plants being severely stunted. Biomass yield for both pigeonpea (Table 2) and sorghum (Table 3) generally increased with lateness in crop maturity on both soil types.

There were no significant differences between medium and long duration pigeonpea cultivars for shoot N concentration (%N), total N yield and amount of N fixed on both soil types. This was also true for grain yield on loam soil. The short season cultivar ICPL87109 showed a significantly higher N concentration compared with both medium and long duration cultivars on loam. The other short duration cultivar (ICPL87091) performed relatively better on sand than on loam soil (Table 2; Fig. 1a). Grain yield was lowest in short duration pigeonpea and highest in the medium duration. There was a significant ($P<0.05$) linear relationship between grain and biomass yields (at flowering) for the short duration cultivars ($R^2=0.82$; df=6), but not for the medium and long duration cultivars ($R^2=0.22$; df=10).

The non-fixing references showed significant differences among the three maturity groups in terms of both shoot biomass and N uptake (Table 3). There was, however, no significant difference between the non-nodulating pigeonpea (P94090) and the short season sorghum (Red Swazi) for the two parameters on loam soil. On coarse sand soil amount of N accumulated by non-fixing pigeonpea was significantly higher than that for Red Swazi and similar to that for the medium duration sorghum. There were significant differences in N fixed by the

Table 2. The above ground biomass yield (kg ha^{-1}), the shoot N concentration (%) and shoot N yield (kg ha^{-1}), and grain yield (kg ha^{-1}) for five pigeonpea cultivars grown on two soils at Domboshawa in Zimbabwe

Cultivar (duration)	Biomass at flowering	% N at flowering	Shoot N	Grain at final harvest
(a) Sand clay loam				
ICPL87109 (short)	1329 a	3.79 a	43 a	413 a
ICPL87091 (short)	756 a	2.19 b	9 a	249 b
ICP9145 (medium)	6830 b	2.90 c	145 b	1279 c
Ex-Malawi (long)	7992 c	3.00 c	172 b	1223 c
Ex-Marondera (long)	9068 d	2.80 c	183 b	1178 c
SED	407	0.28	29	51
(b) Coarse sand				
ICPL87109 (short)	265 a	3.47 a	9 a	nd
ICPL87091 (short)	365 a	3.63 a	13 a	nd
ICP9145 (medium)	968 b	3.14 ab	30 b	nd
Ex-Malawi (long)	1173 c	2.86 b	34 b	nd
Ex-Marondera (long)	1094 b	2.74 b	30 b	nd
SED	78	0.25	3	nd

Figures in the same column followed by the same letter are not significantly different at $P<0.05$. nd = not determined.

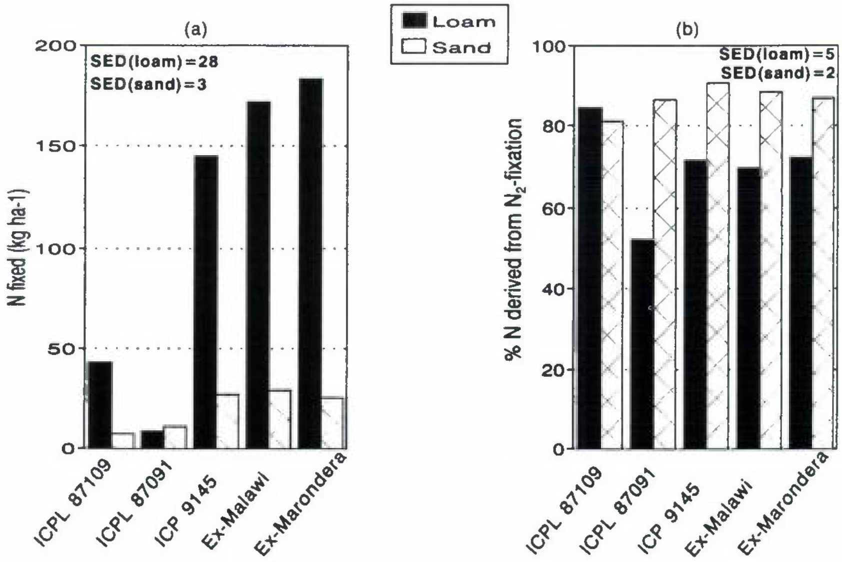

Figure 1. The amount of N (kg ha^{-1}) fixed (a) and the %N derived from N_2-fixation (b) by pigeonpea cultivars of different maturity types, as measured by the N difference method in two soils at Domboshawa in Zimbabwe.

Table 3. Above ground biomass yield and N uptake (kg ha^{-1}) for non-fixing reference plants grown on two soils at Domboshawa in Zimbabwe

Non-fixing reference plant	Sand clay loam		Coarse sand	
	Biomass	N uptake	Biomass	N uptake
Pigeonpea (P94090 - non-nodulating pigeonpea)	236 a	4 a	119 a	2.7 a
Sorghum (Red Swazi)	679 b	8 a	157 b	1.7 b
Sorghum (Sweetgraze)	3706 c	54 b	234 c	2.7 a
Sorghum (Jumbo)	4440 d	71 c	299 d	3.9 c
SED	162	6	13	0.3

Figures in the same column followed by the same letter are not significantly different at P<0.05.

different pigeonpea maturity types on both soil types. On average, long duration cultivars on loam soil fixed 23% more N than the medium duration and about seven times the amount fixed by the short duration varieties. On coarse sands there were no differences between amounts of N fixed by long and medium

Table 4. Biomass yield (kg ha^{-1}), δ^{15}N, %N, %N from N_2-fixation and N fixed (kg ha^{-1}) by three pigeonpea cultivars of different growth duration in a sand soil across ten farms in Murewa Communal Area, Zimbabwe

Farm	Cultivar	Biomass at flowering*	δ^{15}N** (‰)	%N	%N from N_2-fixation***	N fixed
1	ICP87109	834	−0.29	2.55	85	18
	ICP9145	2882	0.62	1.93	64	35
	Ex-Marondera	2939	0.39	1.90	69	39
	Maize	7809	3.28	1.05	–	(82)
2	ICP87109	314	−1.21	2.39	100	8
	ICP9145	224	−1.00	1.59	100	4
	Ex-Marondera	965	−1.28	1.33	100	13
	Maize	1298	4.16	0.88	–	(11)
3	ICP87109	169	−0.66	2.13	94	3
	ICP9145	965	−1.31	2.01	100	19
	Ex-Marondera	308	−0.98	1.86	100	6
	Maize	1245	2.88	0.91	–	(11)
4	ICP87109	43	−0.14	2.20	74	1
	ICP9145	364	0.34	2.11	58	4
	Ex-Marondera	355	−0.15	2.00	75	5
	Maize	2694	2.03	1.31	–	(35)
5	ICP87109	105	−0.64	2.38	96	2
	ICP9145	504	−0.49	1.85	93	9
	Ex-Marondera	546	−0.78	1.59	98	9
	Maize	3154	5.06	1.20	–	(38)
6	ICP87109	38	−0.31	2.43	91	1
	ICP9145	588	−1.15	1.79	100	11
	Ex-Marondera	476	−0.76	1.81	98	8
	Maize	1461	5.88	0.91	–	(13)
7	ICP87109	90	0.05	2.55	84	2
	ICP9145	168	−1.18	1.48	100	2
	Ex-Marondera	406	−0.52	1.51	94	6
	Maize	1935	5.02	1.17	–	(23)
8	ICP87109	222	−1.20	2.40	100	5
	ICP9145	406	−1.41	1.82	100	7
	Ex-Marondera	1250	−1.30	1.58	100	18
	Maize	4278	2.22	1.00	–	(43)
9	ICP87109	792	−0.41	2.16	85	14
	ICP9145	811	−2.78	1.35	100	11
	Ex-Marondera	2658	−1.82	1.33	100	35
	Maize	6823	2.33	0.72	–	(49)

Table 4. Continued.

Farm	Cultivar	Biomass at flowering*	$\delta^{15}N$** (‰)	%N	%N from N_2-fixation***	N fixed
10	ICP87109	30	−1.11	2.33	100	7
	ICP9145	414	−1.28	1.91	100	9
	Ex–Marondera	1133	−1.69	1.62	100	23
	Maize	1848	2.37	1.14	–	(21)
Means	ICP87109	264	−0.59	2.35 a	91	6
	ICP9145	733	−0.97	1.78 b	92	11
	Ex–Marondera	1104	−0.89	1.65 b	93	16
	Significance	NS	NS	0.001	NS	NS
	(Maize)	(3255)	(3.53)	(1.03)	(–)	(28)

*Maize biomass was measured at physiological maturity. **The $\delta^{15}N$ of the ammonium nitrate fertilizer applied to maize was +2.17 (SD=0.118; n=8). ***The discrimination value (B) value used was −0.90 (Peoples et al., 1989). Figures in parentheses under 'N fixed' indicate maize N uptake. Figures in the same column followed by the same letter are not significantly different at P<0.05, by Tukey's.

duration cultivars, both of which fixed about twice as much N as the short duration types. For all pigeonpea cultivars, significantly more N was fixed in loam than in sand soil (Fig. 1a). On loam soil short duration pigeonpea derived up to 84% of its N from N_2-fixation, while the medium and long derived 69–72%. The %N from N_2-fixation was higher on sand soil, with the short duration deriving 81–86% N from N_2-fixation compared with 86–90% for the medium and long duration (Fig. 1b). There was a significant ($P<0.01$) negative linear relationship between %N from N_2-fixation and soil available N, and a positive linear relationship ($P<0.01$) between N_2 fixed (kg ha^{-1}) and soil available N for all maturity groups. The highest regression coefficient was between soil N and N fixed by long duration pigeonpea ($R^2=0.72$; df=24).

Murewa

Results from Murewa Communal Area were comparable to those from the Domboshawa sand site. Crop biomass accumulation at Murewa was severely affected by waterlogging during early vegetative phase and pigeonpea, because of its slow growth, was more affected than maize. About 45% of the rainfall (total=1160 mm) at this site was received between January and February, about 4–10 weeks after crop planting. Chlorosis was evident on all plants. Although both biomass yield and N fixed generally increased with late maturity, the high variability between farms resulted in no significant differences between genotypes (Table 4). There were also no significant differences among the pigeonpea cultivars with respect to $\delta^{15}N$ and %N from N_2-fixation values. At least 91% of the N was derived from N_2-fixation, with calculated values for medium and late maturing pigeonpea approximated at 100% for some sites. Like at Domboshawa, the short season cultivar showed a larger shoot N concentration than the late maturing cultivars. The N concentration, however, was smaller than at Domboshawa for all cultivars.

4. Discussion

The small amounts of N fixed by pigeonpea cultivars in this study (Fig. 1; Table 4) were attributed to their low biomass productivity. At Domboshawa, shoot N concentrations (%N) between the moderately fertile loam and the relatively infertile sand soils were comparable, suggesting N_2-fixation per se was not the factor limiting production. While small N uptake by the reference crops is indicative of poor soil N availability, poor biomass accumulation by the N_2-fixing pigeonpea suggests that nutrients other than N and P were also limiting. Results from Domboshawa loam soil indicate that use of medium to long duration pigeonpea under moderate soil fertility may result in high biomass yields. Higher dependence of pigeonpea cultivars on N_2-fixation on the sandy soil than on the loam soil further suggests that N was a major limiting factor during the establishment phase. The relatively low shoot N concentration for the pigeonpea from Murewa was most likely due to waterlogging. Nodule number and mass in pigeonpea reaches a maximum about 60–80 days after planting (Kumar Rao and Dart, 1987), but the plants were under waterlogging for most of this period. Waterlogging during early legume growth decreases N_2-fixation and biomass accumulation (Sprent and Gallacher, 1976; Minchin et al., 1978). Higher shoot N concentration in short duration pigeonpea than medium and long duration types may be due to relative differences in their dry masses. The granitic sandy soils used in this study are typical of those that are widespread in smallholder farming systems of Zimbabwe and other parts of sub-Saharan Africa (Grant, 1981; Driessen and Dudal, 1991). Poor biomass accumulation may, therefore, undermine the optimum exploitation of BNF under these systems. This poses a great challenge in the development of BNF technological options for the farmers managing these extremely poor tropical soils. BNF researchers may need to take advantage of the diverse legume resources in tropical environments to come up with legumes that are tolerant to poor physical and chemical soil fertility.

The amount of N fixed ranged between 6–30 kg ha^{-1} on sand and 9–183 kg ha^{-1}

on loam, in the order short<medium<long duration. Studies conducted on an Alfisol in India (Kumar Rao et al., 1981; Kumar Rao and Dart, 1987) showed that different pigeonpea maturity groups could fix between 4 and 69 kg N ha^{-1} in one growing season. These values are within the range of our current findings, considering that the amounts of N_2 fixed by legumes may vary with different cultivars and environmental conditions (Rennie and Kemp, 1983; Giller and Wilson, 1991). In addition, our results show that under moderate soil fertility pigeonpea can fix up to 183 kg N ha^{-1}, an amount comparable to that observed for groundnut and soyabean (Toomsan et al., 1995). Less N was fixed at Murewa due to the pronounced effect of waterlogging. The significant negative linear relationship between %N from N_2-fixation and available soil N suggests that low soil N promotes high N_2-fixation in pigeonpea. Depressed N_2-fixation due to high soil nitrate has been reported in a number of studies (Rennie and Kemp, 1983; Danso et al., 1987; Papastylianou, 1988). Granite-derived sandy soils are prone to high N leaching loses (Kamukondiwa, 1995) and the high rainfall experienced during the experiment may have increased pigeonpea dependence on N_2-fixation. Given the inherently low levels of N in tropical agro-ecosystems (Sanchez and Logan, 1992), the amounts of N measured in this study may be large enough to justify inclusion of pigeonpea as a soil improving crop under marginal cropping environments. With modest inputs of other nutrients, pigeonpea BNF could contribute significantly to crop productivity in these marginal soils.

The use of non-fixing reference crops corresponding to each pigeonpea maturity group may have helped to minimise the problems of under- or over-estimating the amounts of N_2 fixed which often undermine the accuracy of the N-difference method (Kumar Rao et al., 1987; Witty and Giller, 1991). Lack of a significant difference between the non-fixing pigeonpea (cv. P94090) and a sorghum of similar growth duration (cv. Red Swazi) (Table 3) suggests the suitability of sorghum as a reference crop. The high %N from N_2-fixation values at Domboshawa sand and Murewa strongly suggest that the pigeonpea relied almost entirely on BNF. However, values of 100% (Table 4) at Murewa reflect some methodological problems. The ^{15}N natural abundance method has generally been regarded as a semi-quantitative method (Danso et al., 1986; Shearer and Kohl, 1986; 1988). Differential growth and uptake patterns between pigeonpea and maize is likely to have rendered the latter a poor reference, particularly with respect to medium and long duration pigeonpea. Isotopic discrimination by the N_2-fixing crop has also been identified as a potential source of error in ^{15}N natural abundance estimates (Shearer and Kohl, 1986; Witty and Giller, 1991), and in this case it appears the discrimination value (B) used was not appropriate. The B value used was probably too large particularly with respect to the medium and long duration pigeonpea genotypes, resulting in an over-estimation of the %N derived from N_2-fixation.

Calculations showed that a B value <–1.6 was necessary for all values (% N from N_2-fixation) to be less than 100%. We discounted the effect of the fertilizer applied to the maize since the results suggest that the fertilizer had a smaller $\delta^{15}N$ than the reference soil. Although our quantitative estimates based on ^{15}N natural abundance were most likely affected by the factors discussed above, we were able to demonstrate that the ^{15}N natural abundance technique is a useful tool in making rapid appraisals on N_2-fixation in cropping systems under natural settings.

5. Conclusions

Under marginal conditions of soil fertility, medium and long duration pigeonpea can fix N amounts that may influence the N economy of smallholder cropping systems. However, management and nutrient factors that promote high biomass productivity are critical determinants of the N quantities fixed by the crop. Although much has been claimed about the potential contribution of legumes to soil fertility, our study suggests that under the real farm situations exploitation of legume BNF may be severely limited by the extremely poor soils. Development of technical options that ensure increased legume productivity under conditions of poor soil fertility are therefore a prerequisite for implementation of BNF technologies. Our study complements current research efforts to quantify the potential N contributions by N_2-fixing legumes in tropical agro-ecosystems and to develop management options for optimal exploitation of legume BNF in smallholder farming systems.

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