JA. NO 1865

Agronomy & Crop Science 177, 129—138 (1996)

ISSN 0931-2250

Soils and Agroclimatology Division (SACD), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Asia Centre, Andhra Pradesh, India

Estimation of Nitrogen Fixation by the Natural ^{15}N-abundance Technique and Nitrogen Uptake by Pigeonpea Genotypes of Different Maturity Groups grown in an Inceptisol[1]

J. V. D. K. Kumar Rao, C. Johansen, T. Yoneyama, S. Tobita and O. Ito

Authors' addresses: J. V. D. K. Kumar Rao, Soils and Agroclimatology Division, ICRISAT Asia Centre, Patancheru 502 324, Andhra Pradesh, India; C. Johansen, Agronomy Division, ICRISAT Asia Centre, Patancheru 502 324, Andhra Pradesh, India; T. Yoneyama, National Agricultural Research Centre, Kannondai, 3-1-1, Tsukuba, Ibaraki 305, Japan; S. Tobita, Japan International Research Centre for Agricultural Sciences (JIRCAS), Ishigaki, Okinawa 907, Japan; and O. Ito, 1-2 Ohwashi, Tsukuba, Ibaraki 305, Japan.

With 2 figures and 5 tables

Received November 24, 1995; accepted February 5, 1996

Abstract

The nodulation, nitrogen fixation and nitrogen uptake of four pigeonpea genotypes belonging to extra short duration, short duration and long duration maturity groups grown on an Inceptisol were studied to examine why, despite the poor nodulation of pigeonpea in this soil, it still produces greater yields than in Alfisols and Vertisols. The percentage nitrogen derived from the atmosphere (%Ndfa) was estimated by ^{15}N natural abundance and N-difference methods using a long duration sorghum as the non-fixing reference crop. In general, nodulation of pigeonpea in the Inceptisol was much lower than that reported in Alfisols and Vertisols. The above-ground dry matter ranged from 3.1 to 17.1 t ha^{-1} while the N uptake ranged from 62.3 to 215 kg ha^{-1}. The fallen plant parts of pigeonpea genotypes ranged from 1.4 to 4.9 t ha^{-1} and their N contents ranged from 25 to 84 kg ha^{-1}. The estimates of percentage Ndfa obtained by the two methods were different. Those obtained by the ^{15}N natural abundance appeared more appropriate as the δ^{15}N of sorghum harvested along with short duration pigeonpea and later when it was mature did not change significantly. The extra short duration pigeonpea genotype ICPL 84023 contained very little N from atmospheric N_2, while the short duration pigeonpea cv. ICPL 151 had 17 % Ndfa and the long duration genotypes ICPL 366 and T7 had up to 36 % Ndfa. It can be concluded that one of the causes of high yields of pigeonpea on Inceptisols compared to Alfisols and Vertisols despite poor nodulation could be the high N supplying capacity of these Inceptisols. Strategies have been suggested as to how pigeonpea genotypes grown in Inceptisols could improve their nodulation and nitrogen fixation and thus better contribute to a sustainable agriculture.

Key words: *Cajanus cajan*, Inceptisol, maturity groups, nitrogen fixation, natural ^{15}N-abundance, pigeonpea

Introduction

Pigeonpea [*Cajanus cajan* (L.) Millsp] is an important grain legume of the semi-arid tropics. About 85 % of the worlds' production is contributed by India, where pigeonpea is the second most widely grown grain legume after chickpea. A wide range of maturity groups exists in pigeonpea which enables the crop to be adapted to diverse agroclimatic areas and cropping systems (Ali 1990). The crop is usually

Table 1. Chemical properties and pigeonpea *Rhizobium* populations of soil in the experimental field used for growing pigeonpea during 1990—91 rainy season

Soil depth (cm)	pH	EC (dS m^{-2})	NH_4-N	NO_3-N	Available P (mg kg^{-1} soil)	Available K	Rhizobium log 10 MPN g^{-1} dry soil
0—15	8.0	0.27	7.1	29.0	5.6	77	2.94
16—30	8.2	0.15	10.2	8.6	2.4	69	3.66
31—60	8.0	0.15	4.4	3.4	0.8	81	3.58
61—90	7.9	0.17	5.4	3.6	1.0	81	3.02
91—120	8.0	0.14	5.7	4.1	1.1	78	2.63

sown at the beginning of the monsoon season, in June or July, and harvested in about 3 months for extra short duration cultivars, 4—5 months for short duration, 5—6 months for medium duration, and 6—9 months for long duration cultivars. It is mostly a rainfed crop grown with minimal inputs — the first 3—4 months of growth takes place during the rainy season and subsequent growth is mostly dependent on stored soil moisture. It is important to know the ability of pigeonpea cultivars to nodulate and fix nitrogen as they are usually grown on marginal soils. Estimates of the amount of N_2 fixed by pigeonpea will allow a better understanding of the N economy of the cropping system and help in optimizing the use of N fertilizer. KUMAR RAO and DART (1987) studied pigeonpea cultivars of different maturity groups grown on Alfisol for nodulation and N_2 fixation. They reported that the short duration pigeonpea had relatively low nodulation and fixed less N_2 than the medium and long duration pigeonpeas. KUMAR RAO et al. (1987) estimated N_2 fixation by a medium duration pigeonpea grown on Vertisol by the ^{15}N-dilution method, using sorghum as a non-fixing control. They reported that more than 88 % of the N in pigeonpea was derived from N_2 fixation.

We observed over the years that pigeonpea (short and long duration) grown in Inceptisols in Central India had very low nodulation but produced greater biomass than in Vertisols and Alfisols in peninsular India. Furthermore, short duration pigeonpea was reported to benefit the succeeding cereal crop in a double-cropping system in that environment and the benefit was equivalent to application of about 40 kg N ha^{-1} (JOHANSEN et al. 1990). The present study aims at examining the contribution of N_2 fixation to the observed high yields of pigeonpea in these Inceptisols, using ^{15}N natural abundance method, and N uptake of extra short duration, short duration and long duration pigeonpea genotypes grown on an Inceptisol in Central India.

Materials and Methods

A field experiment was conducted on an Inceptisol (see Table 1 for chemical properties and *Rhizobium* counts) at the Jawaharlal Nehru Krishi Viswa Vidyalaya (JNKVV)-ICRISAT Cooperative Agricultural Research Station farm at Gwalior (26°N, 78°E), Madhya Pradesh, India, during the growing season of 1990—91. The crop was given a basal dressing of 17 kg P ha^{-1} as single superphosphate. Carbofuran (Furadon®) was applied at 2 kg a.i. ha^{-1}, for controlling soil-borne nematodes. Four high yielding and adapted pigeonpea cultivars, namely, ICPL 84023 [extra short duration (ESD)], ICPL 151 [short duration (SD)], ICPL 366 (long duration and resistant to sterility mosaic) and T7 [long duration (LD) were used. A long duration (about 200 days) and photosensitive sorghum [*S. bicolor* (L.) Moench] cv. IS 17820 was included in the trial as a non-nitrogen-fixing reference crop to estimate the ^{15}N enrichment of soil N (SHEARER and KOHL 1986) or to estimate soil N uptake by the pigeonpea plants (RENNIE and RENNIE 1983).

The trial was laid out in a randomized complete block design with five replications. Each plot measured 6 m × 4 m, with pigeonpea cultivars ICPL 84023 and ICPL 151 sown at a spacing of 30 × 10 cm (20 rows of 4 m length), while ICPL 366, T7 and sorghum were sown at 60 × 30 cm (10 rows of 4 m length). At sowing, pigeonpea seed was inoculated with two effective *Rhizobium* strains, IC 3195 and IC 3506. The peat-based *Rhizobium* cultures were suspended in water and applied in the furrow before sowing to supply about 10^6 rhizobia $seed^{-1}$. The trial was sown on 4 July 1990. The pre-emergence herbicide, pendimethalin

Table 2. Monthly rainfall (mm) and average maximum and minimum temperatures (°C) at Gwalior, Jun 1990—Apr 1991

Month	Rainfall	Temperature	
		Maximum	Minimum
Jun 90	23.3	38.5	29.7
Jul 90	204.6	32.0	25.3
Aug 90	158.4	32.3	25.3
Sept 90	465	31.1	24.4
Oct 90	0	32.6	17.3
Nov 90	0	27.8	10.5
Dec 90	15.5	22.5	7.0
Jan 91	0.2	20.9	4.3
Feb 91	25.7	25.9	9.8
Mar 91	0.2	31.5	13.9

(Stomp®) at 1.5 kg ha^{-1}, was sprayed for controlling weeds up to about 4 weeks after sowing. After this the plots were hand weeded until the crop was about 3 months old, when the canopy had closed. The crop was furrow irrigated whenever the top 10 cm soil became dry. The crop was irrigated mainly to rule out the possibility that the relatively low nodulation of pigeonpea grown in Inceptisol might be due to drought stress. The monthly rainfall and mean maximum and minimum temperatures during the growing period are given in Table 2. The crop was protected from pests (*Helicoverpa armigera* and *Melanagromyza obtusa* on pigeonpea and *Chilo partellus* on sorghum) and the mite-transmitted disease, sterility mosaic, by spraying appropriate insecticides.

All the pigeonpea cultivars were sampled for nodulation and dry matter at 23, 43, 70, 95, 139, 170, and 210 days after sowing (DAS), except short duration pigeonpea cultivars which were sampled only up to 95 DAS. At each sampling, representative plants from each plot [10 plants plot^{-1} when young (23 DAS) to 4 plants plot^{-1} at later growth stages (up to 210 DAS)] were cut at ground level, and the roots and nodules dug out and collected. Soil was dug out to capture most of the roots and nodules readily apparent in the soil profile — soil depth sampled ranged from about 20 cm at 23 DAS to about 150 cm at 210 DAS. That is, complete root recovery was not attempted for logistical reasons. Roots and nodules were washed free of soil, scored for insect damage, dried in an oven at 70 °C for about 48-h and weighed. Similarly, above-ground shoot material was dried and weighed. Fallen plant material was collected from two replications only from a net plot area of 3.6 m^2 rep^{-1} at weekly intervals from 11 September 1990 to 30 March 1991. It was also similarly dried and weighed. ICPL 84023 was mature and was harvested on 6 Nov 90 (125 DAS), ICPL 151 on 26 Nov (145 DAS), ICPL 366 and T7 on 30 Mar 1991 (259 DAS), and sorghum on 31 Jan 1991 (201 DAS). Sorghum was also sampled for above-ground dry matter and N uptake when ICPL 84023 and ICPL 151 were harvested. At maturity, pods were harvested by hand, air-dried and threshed. Grain, husk and top dry weight and N content were determined.

The N contents of plant material including fallen plant parts were determined by block digestion method and a Technicon Autoanalyser (Industrial Method No. 218-72A). The acid digest of the samples was used to measure the natural abundance of ^{15}N with a Finnigan MAT 251 mass spectrometer (YONEYAMA 1987). The natural ^{15}N abundance ($\delta^{15}N$) of the samples was expressed as follows:

$$\delta^{15}N\ (‰) = [(R\ sample/R\ standard) - 1] \times 1000 \quad (1)$$

where R is $^{15}N/^{14}N$ and atmospheric N_2 was used as the standard. The percentage of N derived from atmosphere (% Ndfa) in a N_2 fixing plant was calculated as follows using the natural ^{15}N abundance method:

$$\%\ Ndfa = [(\delta^{15}Nnp - \delta^{15}Nfp)/(\delta^{15}Nnp - \delta^{15}N_a)] \times 100 \quad (2)$$

where ^{15}Nnp is ^{15}N in a non-fixing plant, ^{15}Nfp is ^{15}N in a fixing plant, and $^{15}N_a$ is the ^{15}N value of a given legume grown in pot culture with atmospheric N_2 as the sole source of N. For this pigeonpea cv. ICPL 87 was grown in pots containing washed river sand. The seeds were inoculated with *Rhizobium* culture of IC 3195 at sowing and grown with nitrogen-free Arnon's nutrient solution (ARNON 1933) in a greenhouse. At maturity the plants were analysed for $^{15}N_a$. The percentage of N derived from soil (%Ndfs) was calculated using the equation: %Ndfs = 100 − %Ndfa.

The soil of the experimental site was analysed for pH (MCLEAN 1982), electrical conductivity, available N (KEENEY and NELSON 1982), available P (OLSEN and SOMMERS 1982) and available K (JACKSON 1967). The pigeonpea *Rhizobium* population of the soil was estimated by a serial dilution and plant infection method (KUMAR RAO et al. 1982). The soil N mineralization potential of the experimental site (0—15 cm depth) (Alfisol and Vertisol soils were included for comparison) was determined only once at the end of the experiment using an incubation assay conducted at 40 °C for 7 days under water-logged conditions (KEENEY 1982).

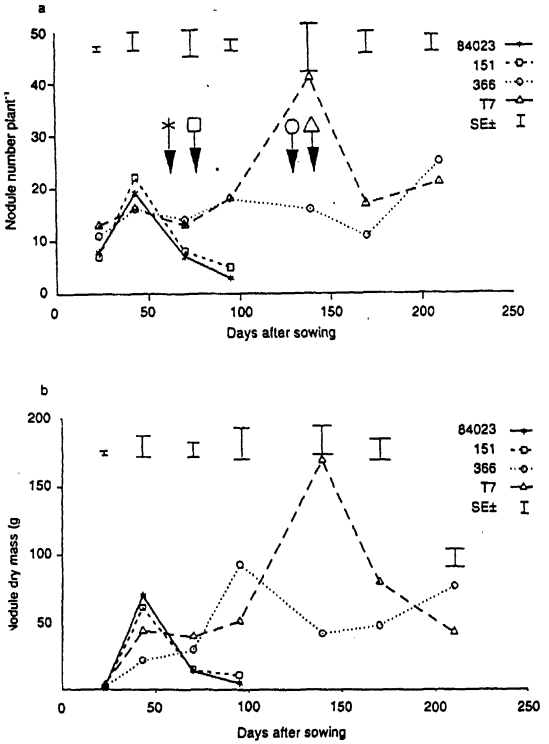

Fig. 1. (a) Nodule number plant^{-1} of pigeonpea genotypes of different maturity groups grown in an Inceptisol at Gwalior during the rainy season 1990—1991. Vertical bars indicate S.E. Arrows indicate 50% flowering. (b) Nodule dry mass (mg plant^{-1}) of pigeonpea genotypes of different maturity groups grown in an Inceptisol at Gwalior during the rainy season 1990—1991

Results

Nodulation

Pigeonpea formed about 10 nodules plant^{-1} by about 20 DAS (Fig. 1a). In extra short duration (ESD) and short duration (SD) pigeonpea, the nodules continued to form and reach a maximum of about 20 nodules plant^{-1} at 43 DAS, after which the number declined. This decline in nodulation occurred well before the two genotypes started flowering. In long duration (LD) pigeonpea, the nodule number increased with plant age up to 100 DAS in ICPL 366, while it reached a maximum of 40 plant^{-1} at 139 days after sowing in T7. The nodule mass followed the same pattern as nodule number in all genotypes (Fig. 1b).

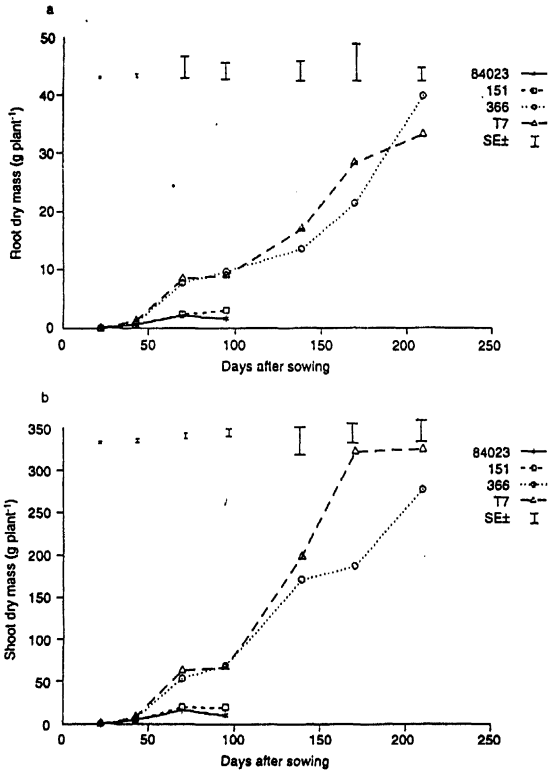

Fig. 2. (a) Root dry mass (g plant^{-1}) of pigeonpea genotypes of different maturity groups grown in an Inceptisol at Gwalior during the rainy season 1990—1991. (b) Shoot dry mass (g plant^{-1}) of pigeonpea genotypes of different maturity groups grown in an Inceptisol at Gwalior during the rainy season 1990—1991

Pigeonpea is a deep-rooted legume as its roots were seen even at a depth of 150 cm at later growth stages, particularly the long duration genotypes. However, nodules were not observed beyond a depth of 90 cm and most of the nodules were confined to 10—15 cm depth. Nodule damage by insects [which appeared similar to damage caused by *Rivellia* sp.; KUMAR RAO and SITHANANTHAM (1989)] was observed from 43 DAS to 210 DAS, however, it varied with plant age. The mean nodule damage by insects was about 1 % at 43 DAS, while it was as high as 70 % at 210 DAS. The level of damage increased significantly from 139 DAS.

Table 3. Shoot dry matter, seed yield and nitrogen yield and Ndfa[a] and Ndfs[b] (kg ha^{-1}) of pigeonpea and sorghum (as non-fixing control) at maturity grown in Inceptisol at Gwalior, 1990—91 season

Treatment	Dry matter (kg ha^{-1})			N yield (kg ha^{-1})				
	Shoot	Seed	Total	Shoot	Seed	Total	Ndfa	Ndfs
ICPL 84023	1922	1218	3140	20.1	42.2	62.3	0	62.3
ICPL 151	3303	1609	4912	24.4	53.6	78.0	13.3	64.7
ICPL 366	12 540	3201	15 741	93.1	118.0	211.1	76.0	135.1
T 7	13 806	3147	16 952	103.9	110.9	214.8	75.2	139.6
Sorghum (IS 17820)	11 851	822	12 672	107.3	16.1	123.4	0	123.4
SE	±690.4	±190.6	±860	±11.4	±6.83	±17.15		
CV%	17.8	21.3	18.0	36.6	22.4	27.8		

[a]Ndfa: Nitrogen derived from atmosphere calculated using %Ndfa estimated by δ^{15}N of seed (see Table 5); [b]Ndfs: Nitrogen derived from soil.

Dry matter production

The root and shoot dry matter increased to a greater extent and for a longer period in LD genotypes than in ESD and SD genotypes (Figs 2a and 2b). At maturity the shoot dry matter and grain yields of pigeonpea were proportional to growth duration — ESD yielded about 1.9 t ha^{-1} shoot and 1.2 t ha^{-1} grain compared to 13.9 t ha^{-1} shoot dry matter and 3.15 t ha^{-1} grain by LD (Table 3). Similarly, the amount of plant parts shed during growth increased with the growth duration (range 1.4 t ha^{-1} to 4.9 t ha^{-1}) (Table 4).

Table 4. Total dry matter and N yield (kg ha^{-1}) of fallen plant material of pigeonpeas grown on Inceptisol at Gwalior, 1990—91 season

Genotype	Dry matter	N Yield
ICPL 84023	1416	25.0
ICPL 151	2711	46.1
ICPL 366	4326	68.5
T7	4932	83.9

Nitrogen uptake and N_2 fixation

In general, N uptake by pigeonpea genotypes at maturity was also proportional to growth duration, i.e. the N uptake was 62.3 kg ha^{-1} in ESD while it was about 215 kg ha^{-1} in LD. Similarly, the N content of fallen plant parts was proportional to growth duration, e.g. ICPL 84023 had 25 kg N ha^{-1}, while T7 had 84 kg N ha^{-1} (Table 4).

In the present study we attempted to measure available soil N by growing a long-duration sorghum genotype IS 17820. On the assumption that N uptake by sorghum is an indication of the nitrogen available from the soil and that this was similar to N uptake by pigeonpea then N_2 fixation by pigeonpea would be the difference between N accumulated by pigeonpea and sorghum (RENNIE and RENNIE 1983). This may be true provided that the legume and the sorghum have explored similar soil volumes for N over the growing period. Using the N difference method it was estimated that ESD and SD pigeonpea genotypes did not fix atmosphere nitrogen, while LD genotypes (ICPL 366 and T7) fixed about 165 kg ha^{-1} (Table 5), equivalent to 57.3 % Ndfa with fallen plant parts included.

The δ^{15}N values for shoot and grain of pigeonpea and sorghum at maturity, and the estimates of the percentage of atmosphere-derived nitrogen and the percentage of soil derived N by δ^{15}N method using sorghum as the reference plant are given in Table 5. The δ^{15}N values of seed of both pigeonpea and sorghum were greater than the values of their respective shoots. However, the %Ndfa values estimated by equation (2) using either shoot or grain were similar. The LD cultivars ICPL 366 and T7 derived about 35 % of total N from atmosphere while SD cultivar ICPL 151 had

Table 5. Natural abundance of ^{15}N in pigeonpea cultivars and non-fixing sorghum grown in the 1990—91 rainy season in an Inceptisol at Gwalior, and the estimate of % Ndfs[a] by pigeonpea based on $\delta^{15}N$ method and N difference method

Cultivar	$\delta^{15}N$ (‰)		%Ndfs[a] estimated by $\delta^{15}N$[b]		%Ndfs by N difference (Fallen plant material included)	%Ndfs[c]
	Shoot	Seed	Shoot	Seed		
Pigeonpea						
ICPL 84023	+3.9	+5.8	4	0	0[d]	100
ICPL 151	+3.4	+4.4	12	17	0.6[d]	83
ICPL 366	+2.1	+3.0	35	36	55.9	64
T7	+2.3	+3.1	32	35	58.7	65
Sorghum						
IS 17820	+4.1	+5.6				
CV (%)	13.0	9.7				

[a]Per cent nitrogen derived from atmosphere; [b]The $^{15}N_a$ of a pigeonpea solely dependent on atmospheric N_2 was -1.6 ± 0.44 ‰; [c]Percent nitrogen derived from soil = 100 − %Ndfa, based on $\delta^{15}N$ of seed; [d]Sorghum sampled at the maturity of ICPL 84023 and ICPL 151 was considered for this.

about 15 % derived from atmosphere. ICPL 84023, the ESD pigeonpea cultivar had negligible N derived from N_2 fixation. Therefore, ICPL 84023 derived almost all of its N requirement from the soil, while ICPL 151 derived a substantial amount (up to 83 %) of N from soil. In the LD genotypes ICPL 366 and T7, the % Ndfs was relatively less (about 65 %).

Discussion

In the present study, the nodulation (nodule number and mass) of pigeonpea genotypes of different maturity groups (extra short duration, short duration and long duration groups) grown in Inceptisol was lower than that reported for Alfisol and Vertisol fields in peninsular India (Kumar Rao and Dart 1987, Kumar Rao et al. 1987). This may be due to several reasons: i) the native rhizobial population was relatively low and inoculation at sowing, although supplementing the population, did not apparently make much difference; ii) the available N in the soil profile, particularly in the 0—15 cm depth was relatively high (36.1 ppm N of which 29 ppm was NO_3-N) and such high concentrations (> 25 ppm N as NO_3) were reported to affect pigeonpea nodulation adversely (Kumar Rao 1990); iii) the high soil temperature (sometimes reaching ≈ 40 °C) during sowing and early vegetative growth stages in northern and central India might be another factor affecting nodule formation and development, although the lower and upper limits of temperature within which normal patterns of nodulation may be expected are still poorly understood for pigeonpea.

The nodulation was lower in ESD and SD pigeonpea genotypes compared to LD pigeonpea among the four genotypes tested. This is similar to the observation of Kumar Rao and Dart (1987) on pigeonpea genotypes grown in Alfisols. Although nodule number and mass reached a peak at around 40 DAS in the SD genotype and around 120 DAS in the LD genotype, the above-ground dry matter continued to increase up to around 70 DAS in (ESD and SD) and up to 170 DAS in T7 and 210 DAS in ICPL 366. A similar trend was seen in total N uptake in the above-ground plant parts of different pigeonpea genotypes.

In the present study, the ^{15}N natural abundance method and N difference methods were used to estimate the proportion of N derived from the atmosphere. Using the $\delta^{15}N$ method it was estimated that %Ndfa was negligible in ESD while it was 17 % in SD and 36 % in LD genotypes. These estimates were slightly lower when based on $\delta^{15}N$ of the shoot. Since much of the plant N is translocated to seed the estimates based on $\delta^{15}N$ of the seed could be considered realistic. The % Ndfa estimated by N difference method gave a different picture — N_2 fixation by

ESD and SD was negligible, while it was high in LD, up to 43 % when fallen plant parts were excluded or up to 59 % when fallen plant parts were included. However, the N-difference method is not universally valid, as it assumes that N_2 fixing and non-fixing plants contain the same amount of N derived from soil (RENNIE and RENNIE 1983). The data in Tables 3 and 5 indicate large differences in N derived from soil by sorghum and pigeonpea genotypes. This could explain why the N difference method cannot be used for estimation of N_2 fixation. In the present study the sorghum matured earlier than long duration pigeonpea, hence the estimate of percentage Ndfa of the LD based on N-difference could be an overestimate. However, the estimates of %Ndfa based on $\delta^{15}N$ can be considered more reliable because the $\delta^{15}N$ values of sorghum harvested along with SD and later when it was mature did not change significantly.

The %Ndfa varied considerably with the duration of the pigeonpea genotype, i.e. it increased with the crop duration as reported by KUMAR RAO and DART (1987) for pigeonpea grown on Alfisol. However, the %Ndfa of the pigeonpea genotypes grown on Inceptisol at Gwalior were low compared to those of pigeonpea (different genotypes) grown on Alfisol (6—51 %) or Vertisol (90 %). This can be explained in terms of relatively low nodulation observed at Gwalior in Central India compared to ICRISAT Centre in peninsular India. But the total biomass of the pigeonpea genotypes grown on Inceptisol at Gwalior are greater than that reported on Alfisol or Vertisol. The low nodulation and high biomass of pigeonpea at Gwalior may be due to the relatively high soil available N in 0—30 cm soil profile (see Table 1) while the available N level in Alfisol and Vertisols at ICRISAT Centre are usually low, generally less than 10 mg kg^{-1} soil (Dr T. J. REGO, pers. comm.). This point is further substantiated by the high N mineralization potential of Inceptisol compared to that of Vertisol and Alfisol. The N mineralization potential of the Inceptisol under study was estimated as 45.9 µg of N g^{-1} soil $week^{-1}$ compared to that of Vertisol (5.7 µg) and Alfisol (3.4 µg). Alternatively, the plants may be retrieving nitrogen from the deep soil layers (i.e. >1.2 m).

The low nodulation but high biomass production, by pigeonpea grown on Inceptisol poses a number of questions relating to the role of pigeonpea in various cropping systems. Firstly, ESD does not seem to derive nitrogen from the atmosphere and this plant type would not be expected to positively contribute to the N balance of a cropping system of which it is a component. Even though SD appeared to fix minimal N from the atmosphere, it was reported to benefit a succeeding wheat crop to an equivalent of about 40 kg N ha^{-1} in the same Inceptisol at Gwalior (JOHANSEN et al. 1990). The beneficial effect of SD may be because of rapid mineralization of N (about 46 kg N ha^{-1}) and other nutrients in the fallen plant parts and root residues as compared to the fallow or non-legume controls. A particular advantage of pigeonpea, whether N was derived from fixation or not, is that at harvest only pods and stems are removed from the field but leaf N returns to the soil. By contrast, in cereals most above-ground N is removed from the field.

From a sustainable agriculture point of view, it is necessary to make maximum use of natural resources such as atmospheric N and depend less on soil or fertilizer N. In the present study it is evident that pigeonpea genotypes particularly ESD and SD derived relatively little N from BNF. This might be because of their sensitivity to high levels of available N and also greater potential mineralizable N in the Inceptisol compared to Vertisol or Alfisol. However, the Inceptisols of farmers fields need to be studied for available N and also potential mineralizable N. If the farmers fields are similar to the Inceptisol under study and if the pigeonpeas grown on Inceptisol are to fix more nitrogen in symbiosis with *Rhizobium* and contribute more to sustain the cropping system, then NO_3 tolerant symbiotic pigeonpeas are needed. This can probably be achieved either by screening and selecting pigeonpeas that exhibit a greater %Ndfa when grown with high level of combined N or by very high rates of *Rhizobium* inoculation. The latter option needs to be tested with pigeonpea as rhizobia establishment, nodulation and N_2 fixation have been reported to increase in the presence of high nitrate by very high rates (100 times of normal inoculation) of *Rhizobium* inoculation in soybean (BERGERSEN et al. 1989, BROCKWELL et al. 1989).

Another alternative to improve nodulation and N_2 fixation by pigeonpea grown in Inceptisol is to use cropping strategy to reduce available N in soil either by crop rotation — ESD or SD pigeonpea in the rainy season followed by a non-legume (eg. wheat) in the post rainy season; or by

intercropping LD pigeonpea with sorghum or pearl millet. In the latter, the cereal crop utilizes available N and thus reduces the exposure of pigeonpea roots to the initial high mineral N, thereby increasing pigeonpeas dependency on nitrogen fixation.

Zusammenfassung

Abschätzung der Stickstoffixierung mit der Natur-^{15}N-Überschußtechnik und Stickstoffaufnahme bei Taubenerbsengenotypen unterschiedlicher Reifegruppen in einem Inceptisol

Die Nodulation, Stickstoffixierung und Stickstoffaufnahme von 4 Taubenerbsengenotypen als Vertreter einer sehr frühen, frühen und späten Reifegruppe wurden in einem Inceptisol angebaut, um zu untersuchen, warum trotz schwacher Nodulation der Taubenerbsen in diesem Boden höhere Erträge als in Alfisols und Vertisols gefunden werden. %-Stickstoff der Atmosphäre (% Ndfa) wurde mit Hilfe der Natur-^{15}N-Überschuß- und N-Differenzmethode unter Verwendung spätreifen Sorghums als nicht-N-fixierende Bezugspflanze bestimmt. Grundsätzlich war festzustellen, daß die Nodulation der Taubenerbse im Inceptisol geringer war als die in Alfisolen und Vertisolen. Die oberirdische Trockenmasse lag zwischen 3,1 bis 17,1 t/ha während die N-Aufnahme zwischen 62,3 bis 215 kg/ha betrug. Die abgefallenen Teile der Taubenerbsengenotypen lagen zwischen 1,4 bis 4,9 t/ha und ihre N-Gehalte zwischen 25 bis 84 kg/ha. Die Abschätzungen der % Ndfa war für die beiden Methoden unterschiedlich. Die der Natur-^{15}N-Überschußmethode erschien besser geeignet als die δ^{15}N Methode unter Verwendung einer Sorghumernte zusammen mit der frühreifen Taubenerbse; später, zur Reife, fand sich keine signifikante Änderung. Der sehr frühe Taubenerbsengenotyp ICPL 84023 wies nur sehr geringe Mengen von atmosphärischem N_2 auf, während der frühe Taubenerbsen cv.ICPL 151 17 % Ndfa und der spätreife Genotyp ICPL 366 und T 7 bis zu 36 % Ndfa aufwiesen. Es kann angenommen werden, daß einer der Ursachen für dje hohen Erträge von Taubenerbsen auf Inceptisols im Vergleich zu Alfisols und Vertisols trotz schwacher Nodulation die hohe Nachlieferungskapazität der Inceptisols ist. Es werden Vorschläge gemacht, wie Taubenerbsen-Genotypen ihre Nodulation und Stickstoffixierung verbessern und auf diese Weise zu einer nachhaltigen Landwirtschaft beitragen können.

Acknowledgements

The authors wish to acknowledge the administration of Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), College of Agriculture, Gwalior, in providing land and facilities for these studies as part of their cooperative arrangements with ICRISAT. We thank Dr H. S. Talwar, Mr V. N. Reddy, Mr K. C. Mouli and Mr P. V. S. Prasad for their help during the study. We would like to thank the staff of Soil Chemistry Laboratory of the Resource Management Program, ICRISAT, for soil and plant chemical analyses. We also thank Mr R. Narsing Rao and Mr P. Sai Ranga Rao for wordprocessing the manuscript.

References

Ali, M., 1990: Pigeonpea: Cropping systems. In: Y. L. Nene, S. D. Hall and V. K. Sheila (eds.), The Pigeonpea, pp. 279—302. CAB International, UK.

Arnon, D. I., 1933: Microelements in culture solution experiments with higher plants. Amer. J. Bot. 25, 322—325.

Bergersen, F. J., J. Brockwell, R. R. Gault, L. Morthorpe, M. B. Peoples, and G. L. Turner, 1989: Effects of available soil nitrogen and rates of inoculation on nitrogen fixation by irrigated soybeans and evaluation of δ^{15}N methods for measurement. Aust. J. Agril. Sci. 40, 763—780.

Brockwell, J., R. R. Gault, L. Morthorpe, M. B. Peoples, G. L. Turner, and F. J. Bergersen, 1989: Effects of soil nitrogen status and rate of inoculation on the establishment of populations of *Bradbyrhizobium japonicum* and on the nodulation of soybeans. Aust. J. Agric. Sci., 40, 753—762.

Jackson, M. L. 1967: Soil chemical analysis. Prentice-Hall (India), New Delhi.

Johansen, C., J. V. D. K. Kumar Rao, O. P. Rupela, and T. J. Rego, 1990: Contributions of pigeonpea to the nitrogen economy of different cropping system. Pages V.1: 259 in Abstracts. International Symposium on Natural Resources Management for a Sustainable Agriculture, New Delhi, India: Indian Society of Agronomy.

Keeney, D. R. 1982: Nitrogen availability indices. In: A. L. Page, R. H. Miller, and E. R. Keeney (eds.), Methods of Soil Analysis. Part 2. Agronomy 9, 711—733. Am. Soc. Agron., Madison, WI, USA.

— —, and D. W. Nelson, 1982: Nitrogen-inorganic forms. In: A. L. Page, R. H. Miller, and D. R. Keeney (eds.), Methods of Soil Analysis. Part 2. Agronomy 9, 643—698. Am. Soc. Agron., Madison, WI, USA.

Kumar Rao, J. V. D. K., 1990: Pigeonpea: nitrogen fixation. In: Y. L. Nene, S. D. Hall, and V. K. Sheila

(eds.), The Pigeonpea, pp. 233—256. CAB International, UK.

— —, P. J. DART, and M. USHA KIRAN, 1982: Cowpea group *Rhizobium* in soils of the semi-arid tropics. In: P. H. GRAHAM, and S. C. HARRIS (eds.), Biological nitrogen fixation technology for tropical agriculture, pp. 291—296. Proceedings of the workshop, 9—13 Mar 1981. CIAT, Colombia. Cali, Colombia: Centro Internacional de Agricultura Tropical.

— —, and P. J. DART, 1987: Nodulation, nitrogen fixation and nitrogen uptake in pigeonpeas [*Cajanus cajan* (L.) Millsp.] of different maturity groups. Plant and Soil **99**, 255—266.

— —, and S. SITHANANTHAM, 1989: Impact of nodule damage by *Rivellia angulata* on N_2 fixation, growth and yield of pigeonpea [*Cajanus cajan* (L.) Millsp] grown in a Vertisol. Biol. and Fertil. of Soils **7**, 95—100.

— —, J. A. THOMPSON, P. V. S. SASTRY, K. E. GILLER, and J. M. DAY, 1987: Measurement of N_2 fixation in field grown pigeonpea [*Cajanus cajan* (L.) Millsp.] using ^{15}N-labelled fertilizer. Plant and Soil **101**, 107—113.

MCLEAN, E. O., 1982: Soil pH and lime requirement. In: A. L. PAGE, R. H. MILLER, and D. R. KEENEY (eds.), Methods of Soil Analysis. Part 2, Agronomy **9**, 199—224. Am. Soc. Agron., Madison, WI, USA.

OLSEN, S. R., and L. E. SOMMERS, 1982: Phosphorus. In: A. L. PAGE, R. H. MILLER, and D. R. KEENEY (eds.), Methods of Soil Analysis. Part 2, Agronomy **9**, 403—430. Am. Soc. Agron., Madison, WI, USA.

RENNIE, R. J., and D. A. RENNIE, 1983: Techniques for quantifying N_2 fixation in association with non-legumes under field and greenhouse conditions. Can. J. Microbiol. **29**, 1022—1035.

SHEARER, G., and D. H. KOHL, 1986: N_2-fixation in field settings: estimations based on natural ^{15}N abundance. Australian J. of Plant Physiol. **13**, 699—756.

YONEYAMA, T., 1987: N_2-fixation and natural ^{15}N abundance of leguminous plants and *Azolla*. Bull. Nat. Instit. Agrobiol. Res. (Japan) **3**, 59—87.