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Nitrogen Requirements at Different Growth Stages of Short-duration Pigeonpea (*Cajanus cajan* L. Millsp)[1]

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With 4 figures and 9 tables

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Abstract

The response to N fertilization of a short-duration pigeonpea genotype, ICPL 87, was studied in the field to assess the scope for genetically improving symbiotic N_2 fixation by pigeonpea. The field study was undertaken during 1985, 1986 and 1987 growing seasons on Vertisol and Alfisol at ICRISAT Center (peninsular India), Inceptisol at Gwalior (central India) and Entisol at Hisar (northern India) in as non-limiting environmental conditions as possible. Nitrogen fertilizer was applied to the soil at various growth stages to determine when N becomes most limiting. There was a significant response in grain yield to fertilizer N applied at flowering in Vertisol but not in Alfisol, Inceptisol or Entisol. This suggests that biological N_2 fixation by short-duration pigeonpea was not adequate to meet N requirements of the crop grown in Vertisol but that it was probably adequate in the other three soil types. These results are discussed in relation to the nodulation and acetylene reductase activity of pigeonpea and also N mineralization potential of different soils. It can be concluded that there is a need for genetic improvement of N_2 fixing ability of short-duration pigeonpea grown on heavy textured soils such as Vertisols.

Key words: Fertilizer nitrogen, biological nitrogen fixation, short-duration pigeonpea, nodulation, plant growth stage

Introduction

Pigeonpea (*Cajanus cajan* (L.) Millsp) is an important grain legume of the semi-arid tropics. Most production of pigeonpea is from long-duration genotypes (7—10 months) normally grown in intercropping or mixed cropping systems. However, in recent years, short-duration pigeonpea grown as a monocrop in rotation with a winter crop, such as wheat, has become increasingly popular in northern India (ALI 1990). In tropical environments, with winters warm enough to allow continued growth of pigeonpea, short-duration pigeonpea genotypes can be ratoon harvested. For example, ICPL 87, which was released for cultivation in India during 1986, has a yield potential of up to 5 t ha^{-1} in multiple harvests when grown as a sole crop in peninsular India (CHAUHAN et al. 1987). Although these cultivars have a high yield potential, the yield levels in farmers fields are often well below that potential. One of the reasons for this variation may be N nutrition. The nodulation and N_2 fixation of short-duration pigeonpea was reported to be lower than that of medium- and long-duration pigeonpea cultivars (KUMAR RAO and DART 1987). In order to assess the necessity and appropriate procedure for genetically improving symbiotic N_2 fixation capacity of pigeonpea, knowledge is required of the extent to which the plant is ever limited by N and at what growth stages

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this limitation occurs. If N responses are found it is then necessary to evaluate whether genetic or agronomic manipulations, such as inoculation with *Rhizobium*, addition of N fertilizers, addition of other nutrients that may be limiting the symbiosis, alleviation of water stress, etc, provide most scope for overcoming the limitation.

Responses of pigeonpea growth and seed yield to N fertilizer are sometimes found, even where there is no response to rhizobial inoculation (ROJOA 1980, KUMAR RAO et al. 1981, KULKARNI and PANWAR 1981, SRIVASTAVA and VERMA 1986). Thus use of a starter dose of about 20 kg ha^{-1} N is often recommended for pigeonpea. It is usually observed that nodule mass of pigeonpea declines by the time of flowering, when the soil is normally drying out. It is, therefore, uncertain as to whether N limits plant growth and yield from this growth stage. This is difficult to assess under dryland conditions because of the difficulty of making fertilizer N available to the plant from dry soil. Foliar application of N fertilizer to pigeonpea has been tried, however, with conflicting reports of the benefits. Foliar application of 2 % diammonium phosphate at flowering and pod formation stages of the crop increased the grain yield significantly (YELAMANDA REDDY et al. 1987), while foliar spray of N just after flowering did not increase yield (RAO, ICRISAT, unpublished observations, LOPEZ et al. 1994).

The present study on the N response of a short-duration pigeonpea genotype was carried out under good environmental conditions to determine conditions under which N limits pigeonpea so as to guide N_2 fixation improvement. Nitrogen was applied to the soil at various growth stages to determine when N becomes most limiting. The short-duration cultivar ICPL 87 was used as the test cultivar as this has previously shown a greater response to N in a Vertisol field than two medium-duration cultivars (ICRISAT 1986).

Materials and Methods

The experiment was conducted on an Alfisol (Udic Rhodustalf) and a Vertisol (Typic Pellustert) field — two major soil types of semi-arid tropics — at ICRISAT Center, Patancheru (17 °N 78 °E, 545 m elevation) during the rainy seasons of 1985/86, 1986/87 and 1987/88 (Vertisol only). Similar experiments were conducted on an Entisol (Typic Camborthids) at Hisar (29 °N 75 °E, 221 m elevation) in northern India and on an Inceptisol at Gwalior (26 °N, 78 °E, 211 m elevation) in Central India during the rainy seasons of 1986/87 and 1987/88.

The annual rainfall at ICRISAT Center, Patancheru in 1985 was 557 mm, 27 % less than the average of 764 mm. The rainy season total (June—October) was 477 mm as compared to the normal 653 mm. Annual rainfall in 1986 at Patancheru was 713 mm, 51 mm below the long-term mean. The start of the rainy season was quite favourable. Rainfall in June and July was nearly normal and in August 56 % more rain fell than in an average year. However, only 58 mm rain fell in September and October, compared with a long-term mean of 253 mm, resulting in drought conditions. At Hisar, the annual rainfall was 383 mm, 14 % below normal. Of this, 33 % fell in June. At Gwalior, 498 mm rainfall was received during the rainy season (June—October), 41 % below the average. The annual rainfall in 1987 at Patancheru was 879 mm, 12 % above average. Rainfall during the rainy season was 24 % below average but October and November were exceptionally wet. At Hisar, annual rainfall was 205 mm, 54 % below average. Rainfall during June—October was only 63 mm, 83 % below average. At Gwalior the annual rainfall was 481 mm, 46 % below average.

The soils of experimental sites were analysed for pH (MCLEAN 1982), electrical conductivity, organic carbon (NELSON and SOMMERS 1982), total N (DALAL et al. 1984), available N (KEENEY and NELSON 1982) and available P (OLSEN and SOMMERS 1982) and the results are given in Table 1. The soil N mineralization potential of the representative soils was determined only once at the end of all field experiments using incubation assay method conducted at 40 °C for 7 days under waterlogged conditions (KEENEY 1982) and the results are presented in Table 2.

Treatments and experimental details are given in Table 3. All experiments were conducted in randomized block design with four replications. The crop was planted on ridges spaced at 60 cm with 2 rows per ridge to give an interrow spacing of 30 cm. Plant-to-plant spacing was 10 cm. The crop was given a basal dressing of 20 kg ha^{-1} P as single superphosphate, 20 kg ha^{-1} K as KCI and 40 kg ha^{-1} $ZnSO_4$ (applied only in Vertisol). Nitrogen was added as urea. $ZnSO_4$ was applied at land preparation, while the other fertilizers were mixed and applied as a band below the seed. For N application during growth, urea was placed in furrows between ridges at a depth of 5—10 cm. At sowing the seed of inoculated treatments was treated with a peat culture of an effective *Rhizobium* strain IC 3195 to provide about 10^5 rhizobia per seed. Two seeds were sown per hill and seedlings were thinned to one per hill 2 weeks after sowing. The crop was hand weeded intensively during the first 2 months. In the trials receiving supplemental irrigation the crop was furrow irrigated

Table 1. Chemical properties of soils (0–15 cm depth) at experimental sites

	Soil Type						
	1985		1986			1987	
	Alfisol	Vertisol	Vertisol	Entisol	Inceptisol	Vertisol	Inceptisol
pH	5.6	8.0	8.2	8.3	8.1	8.2	7.8
Electrical conductivity ($dS\ m^{-1}$)	0.07	0.43	0.26	0.25	0.19	0.43	0.23
Organic carbon (%)	0.38	0.55	0.29	NA	0.33	0.75	0.34
Total N	420	509	NA	NA	NA	464	536
Available N $mg\ kg^{-1}$ soil	16.9	27	NA	38.1	15	5.0	6.6
Available P	6.3	8.4	1.5	27.9	7.3	8.1	10.3

NA Not available

Table 2. Nitrogen mineralization potential (μg of $N\ g^{-1}$ soil $week^{-1}$) of the four soil types used for studying the response of short-duration pigeonpea genotype, ICPL 87 to fertilizer N

Soil type/location	
Inceptisol/Gwalior	45.9
Entisol/Hisar	19.4
Vertisol/Patancheru	5.7
Alfisol/Patancheru	3.4

whenever the top 10 cm of soil profile dried out. The crop was protected from pod borer (*Helicoverpa armigera*) infestation by spraying endosulphan (35 EC) at $2\ l\ ha^{-1}$.

During crop growth, plant samples were collected from selected treatments for nodulation, acetylene reduction assay (only in Alfisol and Vertisol fields) and dry matter determination. During 1985/86 the samplings were done at 18, 26, 38, 49, 63, 88, 101 and 145 days after sowing (DAS) in Vertisol; and at 28, 39, 50, 67, 84, 98, 141 and 182 DAS in Alfisol. For acetylene reduction assay the roots and nodules were carefully excavated and assayed as described by Kumar Rao and Dart (1987).

Shoot samples taken with root and nodules at 49, 63 and 88 DAS in Vertisol and 50, 67 and 84 DAS in Alfisol were also analysed for N. A tip sample, comprising the main shoot tip cut below the third expanded leaf, was separated from each plant and analysed separately. At the first flush harvest, shoot samples were also taken for analysis of N content of seed, pod husk and the remaining shoot material.

At maturity, pods were harvested from a net plot area of 3.5 × 3.6 m. For multiple harvests, the first and second flush of pods were hand picked. After sun-drying the pods were threshed and grain yield recorded. The shoot dry matter (5 plants $sample^{-1}$) and yield components were also estimated at each harvest.

Several mini-plot (4 m × 1.2 m, 4 rows of 4 m length) replicated trials were conducted in Alfisol and Vertisol fields at ICRISAT Center during rainy season 1986 to study the response of pigeonpea to phosphorus (14 kg P ha^{-1} as single super phosphate as basal), nitrogen fertilizer (50 kg N ha^{-1} as urea at sowing and 75 kg N ha^{-1} just before flowering) and *Rhizobium* (IC 3195) inoculation.

Results

Plant dry matter and grain yield

In Vertisol, shoot dry matter reached maximum at about 100 days after sowing and fertilizer N improved plant growth. Maximum shoot growth occurred in plots that received

Table 3. Details of experiments conducted during 1985/86, 1986/87 and 1987/88 seasons

Soil	Date of sowing	Treatments	Plot size (m)	Irri. (I) Non-irri. (NI)	No. of pod flushes harvested
		1985/86 season			
Alfisol	19/20 Jun	1) No nitrogen added	4 × 8	I	3
		2) 20 kg ha^{-1} N at sowing			
		3) 20 kg ha^{-1} N at sowing less *Rhizobium* inoculation			
		[a]4) 20 kg ha^{-1} N at sowing less irrigation			
		5) 100 kg ha^{-1} N at sowing			
		6) 20 kg ha^{-1} N at sowing and 50 kg ha^{-1} N at 1 month			
		7) 20 kg ha^{-1} N at sowing and 75 kg ha^{-1} N at 50 % flowering			
		8) 20 kg ha^{-1} N at sowing and 80 kg ha^{-1} N at podfilling			
		9) 20 kg ha^{-1} N at sowing and 80 kg ha^{-1} N after first harvest			
		10) 20 kg ha^{-1} N at sowing and 50 kg ha^{-1} N at 1 month, 75 kg ha^{-1} N at 50 % flowering, 80 kg ha^{-1} N at podfilling and 80 kg ha^{-1} N after first harvest			
Vertisol	21 Jun	Same as above	4 × 8	I	3
		1986/87 season			
Alfisol	17 Jun	1) No nitrogen added	4 × 6	I	3
		2) No nitrogen and without *Rhizobium* inoculation			
		3) 50 kg ha^{-1} N at sowing			
		4) 75 kg ha^{-1} N at about 5 weeks after sowing			
		5) 75 kg ha^{-1} N at about 50 % flowering			
		6) 75 kg ha^{-1} N at podfilling			
		7) N at each growth stage as in 3, 4, 5 and 6			
		8) 75 kg ha^{-1} N after first harvest of pods			
Vertisol	18 Jun	Same as above	4 × 6	NI	3
Inceptisol	14 Jul	Same as above except T8	4 × 6	I	1
Entisol	10 Jul	Same as above except T8	4 × 6	I	1
		1987/88 season			
Vertisol	23 Jun	Same as 1986/87 season	4 × 6	I	3
Inceptisol	10 Jul	Same as 1986/87 season	4 × 6	I	1
Entisol	16 Jul	Same as 1986/87 season	4 × 6	I	1

[a] This treatment was derandomized and grown in an unirrigated strip adjacent to the other plots of each block

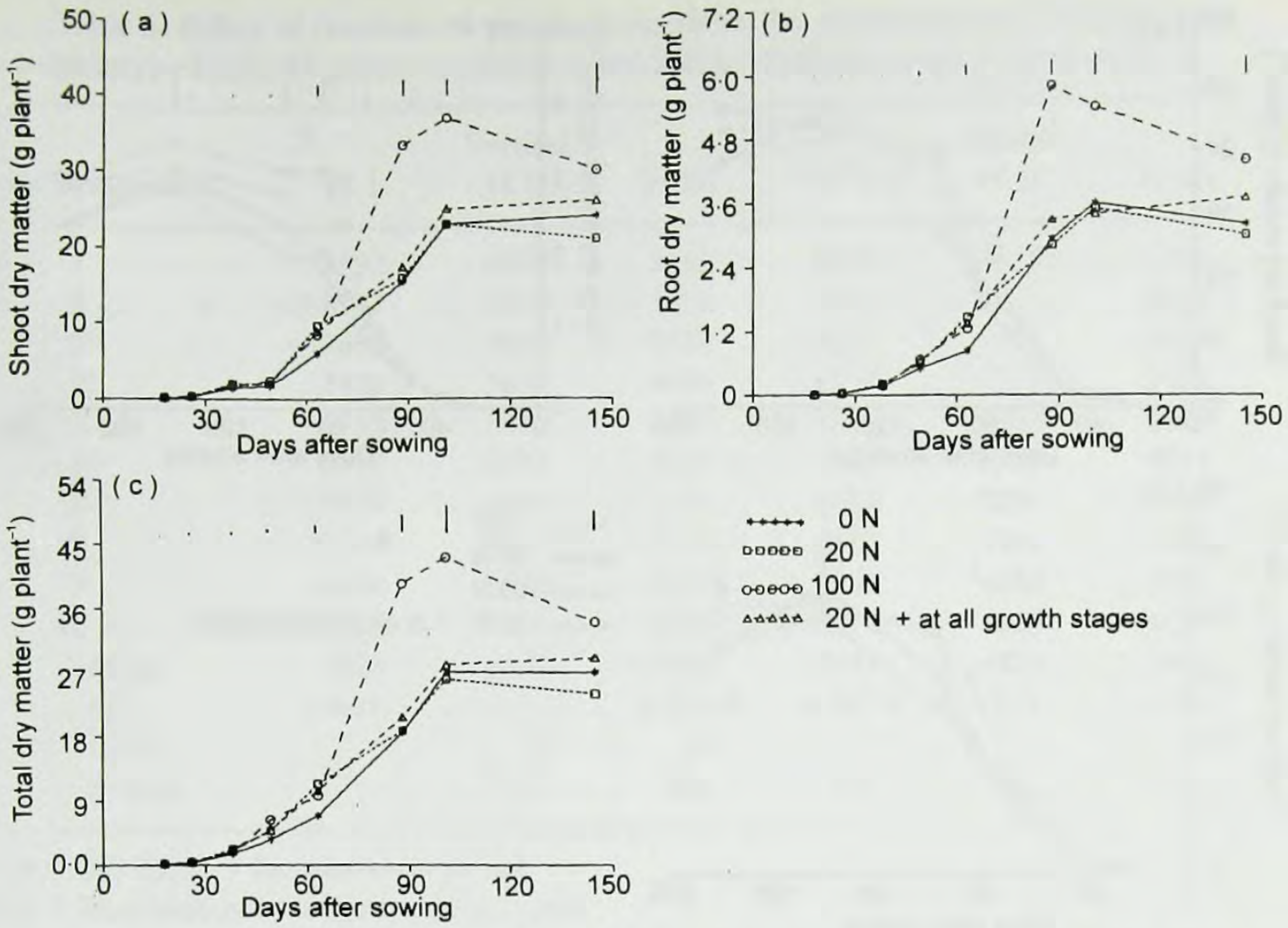

Fig. 1. Effect of fertilizer N on shoot (a), root (b) and total dry matter (c) of pigeonpea genotype, ICPL87 grown on Vertisol, 1985/86. Bars indicate standard errors of means

100 kg ha^{-1} N at sowing (Fig. 1). This effect was exaggerated on a per plant basis due to compensation for the lesser plant stand caused by N toxicity.

In Alfisol, maximum shoot dry matter was recorded at about 120 days after sowing. A significant growth response to fertilizer N was only obtained at 84 DAS, with best growth occurring in treatments 5 (100 kg ha^{-1} N at sowing) and 6 (20 kg ha^{-1} N at sowing and 50 kg ha^{-1} N at 1 month after sowing) (Fig. 2). However, no such response to fertilizer N was seen during the 1986/87 season. In Inceptisol and Entisol also maximum shoot dry matter was observed around 100 days after sowing. There was no clear response of shoot dry matter to fertilizer N in either Inceptisol or Entisol fields (data not presented).

Pigeonpea cv. ICPL 87 grown on Vertisol gave more grain yield in the first harvest than that on Alfisol (Table 4). However the grain yield in the subsequent two harvests was greater on Alfisol than Vertisol. At each harvest the shoot dry matter was greater in Vertisol than Alfisol (Table 5). The total grain yield (total of three harvests) was significantly increased by fertilizer N applied at flowering, pod-filling and at all growth stages in Vertisol but not in Alfisol. During 1986/87 the shoot dry matter and grain yield of ICPL 87 grown on Vertisol were very low due to waterlogging (in early growth stages) and drought (during podding) compared to those obtained on Alfisol, Inceptisol and Entisol (Table 6). The grain yield on Alfisol was similar to the yield obtained during 1985/86. The crop in Entisol recorded 1890 kg grain and 13290 kg shoot dry matter per hectare while the crop in Inceptisol recorded relatively low yields. Fertilizer N did not have any effect on grain and shoot dry matter yields at any of these locations. During 1987/88, the trial on Vertisol experienced waterlogging resulting in relatively low yields, however, the crop showed response trends to fertilizer N similar to that of 1985/86, while no response to fertilizer N was seen in Inceptisol and Entisol (Table 7). The pooled analysis over 2 years (1986/87 and 1987/88) with common treatments over two different soil types (Inceptisol and Entisol) indicate that none of the main effects and the interaction effects were found significant.

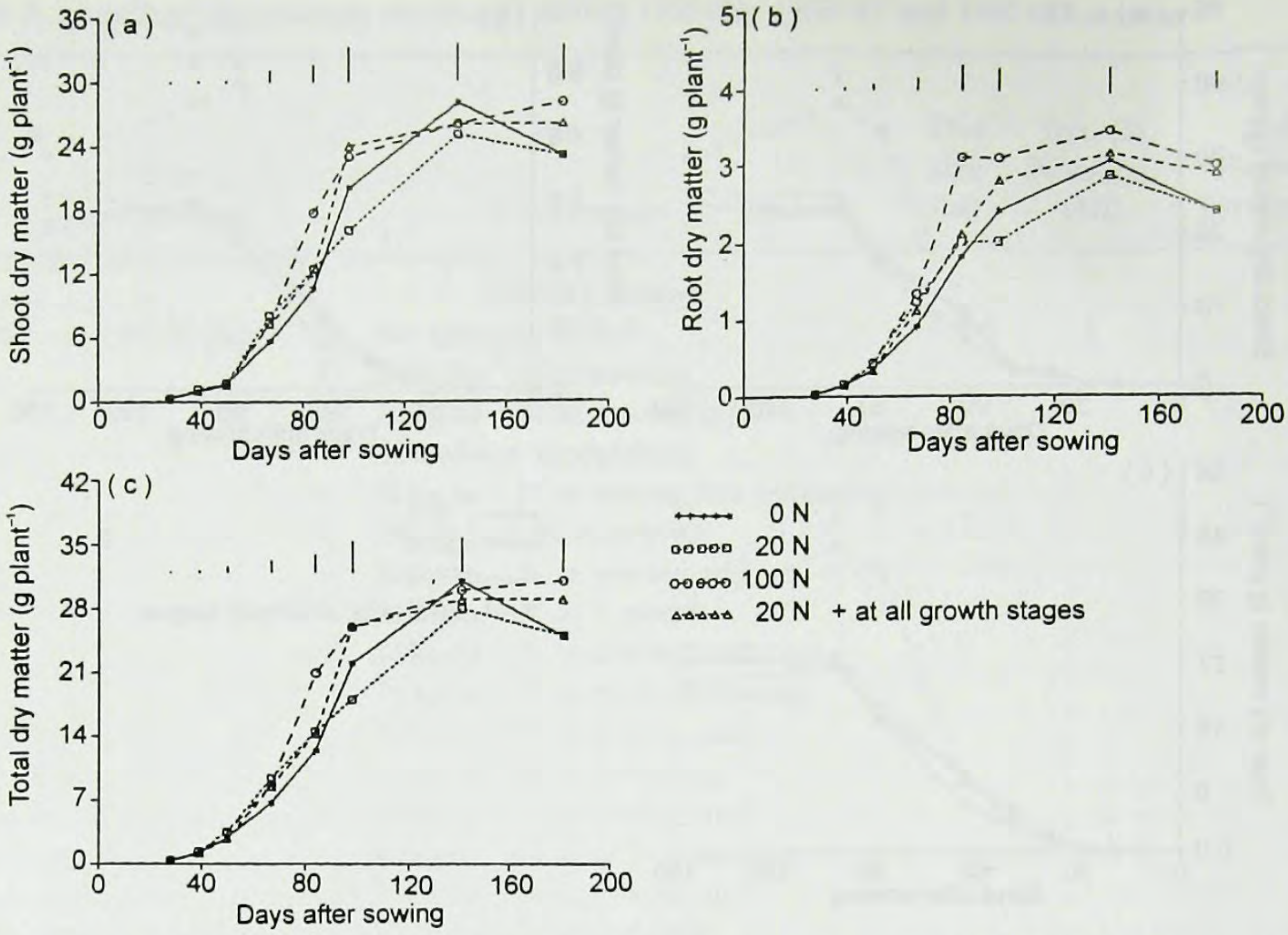

Fig. 2. Effect of fertilizer N on shoot (a), root (b) and total dry matter (c) of pigeonpea genotype, ICPL87 grown on Alfisol, 1985/86. Bars indicate standard errors of means

Table 4. Effect of fertilizer N and time of application on grain yield (kg ha^{-1}) of pigeonpea genotype ICPL 87 grown in Vertisol and Alfisol during 1985/86

	Vertisol				Alfisol			
Treatments[1]	1st harvest	2nd harvest	3rd harvest	Total of 3 harvests	1st harvest	2nd harvest	3rd harvest	Total of 3 harvests
1	1896	563	167	2626	1307	1417	489	3212
2	1904	693	228	2825	1336	1136	509	2981
3	1922	676	190	2787	1470	1362	617	3449
4[a]	1831	719	118	2668	816	990	235	2042
5	1881	533	197	2610	1095	868	404	2367
6	1943	527	226	2696	1529	1079	412	3020
7	2189	682	237	3110	1492	1108	522	3122
8	1873	803	246	2920	1173	1093	452	2718
9	1880	617	303	2800	1273	1119	499	2891
10	2102	679	323	3104	1463	1098	544	3105
Mean	1954	642	235	2831	1349	1142	494	2985
SE	±55.9	±44.5	±23.2	±70.9	±94.3	±151.2	±60.2	±249.4
CV%	6	14	20	5	14	26	24	17
F-Test	**	**	**	**	*	NS	NS	NS

* significant at 5 % probability
** significant at 1 % probability
NS not significant
[1] See Table 3 for treatment details
[a] Not included for statistical analysis

Table 5. Effect of fertilizer N treatment on shoot dry matter (kg ha^{-1}) of pigeonpea genotype ICPL 87 grown on Vertisol and Alfisol 1985/86, at each harvest (H)

	Vertisol			Alfisol		
Treatments[1]	H I	H II	H III	H I	H II	H III
1	5892	6257	5446	8270	4615	3765
2	8547	6849	5806	7726	4673	4041
3	7690	5940	5382	8071	5314	4454
4[a]	7400	5647	4836	6037	3379	3478
5	6935	6583	5791	5894	3958	2585
6	8517	6743	5284	7807	5733	4111
7	9075	6854	5754	6788	5224	4168
8	7994	6417	5952	5567	4491	4106
9	6636	6825	5677	7248	4832	3911
10	7321	7204	5869	6498	4608	4029
Mean	7623	6630	5662	7097	4828	3908
SE	±683.3	±441.7	±334.5	±947.0	±519.0	±456.2
CV%	18	13	12	27	21	23
F-Test	*	NS	NS	NS	NS	NS

[1] See Table 3 for treatment details
[a] Not included for statistical analysis

Table 6. Effect of fertilizer N treatment on shoot dry matter (A) and grain yield (B) (kg ha^{-1}) of pigeonpea cv. ICPL 87 grown on Vertisol, Alfisol at Patancheru, Inceptisol at Gwalior and Entisol at Hisar during 1986/87 season

	Vertisol[a]		Alfisol[a]		Inceptisol		Entisol	
Treatments[1]	A[b]	B	A[b]	B	A	B	A	B
1	3400	1270	2670	3290	5890	1360	13910	2210
2	2600	1070	3330	3170	5990	1820	13990	1610
3	3000	1110	3130	3230	5690	1800	9740	1870
4	2670	1200	3400	3190	4510	1460	17280	1800
5	2800	1180	3070	3210	5330	1660	15470	2060
6	2270	1160	3530	3420	4490	1430	15110	1770
7	2530	1220	2800	2850	6100	1470	7560	1890
8	2930	1100	3000	3100	—[c]	—	—	—
Mean	2800	1160	3130	3180	5430	1570	13290	1890
SE	±353.3	±79.8	±241.3	±204.7	±625.3	±304.9	±1798.8	±184.8
CV%	25.5	13.7	15.5	13	23	39	27	20
F-Test	NS	NS	NS	NS	NS	NS		NS

[a] Total of three flushes of pods
[b] At the time of harvesting first flush of pods, extrapolated from 5 plants sample to kg ha^{-1}
[c] Treatment not used
[1] See Table 3 for treatment details

In mini plot trials there was no effect of fertilizer and *Rhizobium* treatment in the Alfisol, while on the Vertisols, biomass and grain yield were generally superior in treatment 3 (+N) (Table 8).

During 1985/86 on Alfisol, the grain yield

Table 7. Effect of fertilizer N treatment on shoot dry matter (A) and grain yield of pigeonpea (B) ($kg\ ha^{-1}$) of pigeonpea cv. ICPL 87 grown on Vertisol at Patancheru, Inceptisol at Gwalior and Entisol at Hisar during 1987/88 season

Treatments[1]	Vertisol A[a]	Vertisol B[b]	Inceptisol A[c]	Inceptisol B	Entisol A	Entisol B
1	1900	1790	10750	1580	9640	1460
2	4010	1560	11610	1410	9330	1670
3	1980	1450	12250	1680	12650	1470
4	3180	1380	12700	1580	10540	1650
5	2160	2180	11560	1270	9100	1210
6	2990	1850	11930	1460	9460	1380
7	2810	1920	11154	1530	8880	1270
8	1690	1330	—[d]	—	—	—
Mean	2590	1680	11710	1503	9940	1440
SE	±962.9	±260.7	±751	±145	±1205.2	±186.1
CV (%)	64	27	13	19	24	26
F-Test	NS	NS	NS	NS	NS	NS

[a] Shoot dry weight recorded at harvesting third and final flush of pods
[b] Total of three flushes of pods
[c] Shoot fresh weight
[d] Treatment not used
[1] See Table 3 for treatment details

was low in non-irrigated plots compared to irrigated while on Vertisol there was no response to irrigation (Table 4).

Nodulation and nitrogenase activity

In Vertisol, the nodule number and weight of ICPL 87 was very low up to about 40 DAS and reached a maximum at 100 DAS (Fig. 3). The nitrogenase activity of the nodulated roots as measured by acetylene reduction activity (ARA) followed a pattern similar to that of nodulation only up to 90 days, after which it declined markedly (Fig. 3). The ARA per plant and specific ARA both declined at around 60 DAS, coinciding with the flowering stage. Nitrogen fertilizer adversely affected not only nodulation but also nodule activity. The effect of 100 $kg\ ha^{-1}$ N applied at sowing did not last beyond 50 DAS. However, nitrogen applied at all the growth stages adversely affected nodulation and ARA.

In Alfisol, the nodulation and ARA of ICPL 87 were greater than in Vertisol (Fig. 4). Although nodulation increased with plant growth up to 85 DAS, the ARA per plant reached its peak at 40 DAS and then declined. Specific ARA decreased with plant growth up to 50 DAS and maintained this level up to 70 DAS before declining further.

In Inceptisol and Entisol the nodulation of ICPL 87 was very low—the nodule number and mass ($mg\ plant^{-1}$) reached a maximum of 5 and 4 per plant respectively at about 50 days after sowing (data not presented).

Nutrient uptake

Total N content of above-ground plant parts of pigeonpea grown in Vertisol and Alfisol during 1985/86 at the first flush harvest are presented in Table 9. The genotype ICPL 87 grown on Alfisol had more N content (47 $kg\ ha^{-1}$) in aerial biomass than the crop on Vertisol. Tip N concentrations were not very sensitive in being able to detect different fertilizer application levels (Table 9).

Discussion

Fertilizer N had a beneficial effect on plant growth and yield of short duration pigeonpea only sometimes in Vertisol but not in Alfisol,

Table 8. Effect of Mini-NP treatments on grain yield and aerial biomass at first flush harvest of ICPL 87 grown in Vertisols during rainy season 1986, ICRISAT Center, Patancheru

Treatments	Vertisol field designation BL4A	BP11B	BP11C	BP2B
	Grain yield ($t\ ha^{-1}$)			
1 14 kg P ha^{-1} (− *Rhizobium*)	0.64	1.44	0.61	1.55
2 14 kg P ha^{-1} + *Rhizobium*	0.74	1.52	0.87	1.45
3 14 kg P ha^{-1} + *Rhizobium* + N (50 kg ha^{-1} at sowing + 75 kg ha^{-1} before flowering)	0.93	1.75	1.14	1.67
4 *Rhizobium* only	0.74	1.36	0.88	1.49
Mean	0.76	1.52	0.88	1.54
SE	±0.107	±0.117	±0.099*	±0.118
CV (%)	28.0	13.4	22.6	15.4
	Aerial biomass ($t\ ha^{-1}$)			
1 14 kg P ha^{-1} (− *Rhizobium*	2.51	5.42	3.24	5.33
2 14 kg P ha^{-1} + *Rhizobium*	2.62	5.84	3.68	5.52
3 14 kg P ha^{-1} + *Rhizobium* + N (50 kg ha^{-1} at sowing + 75 kg ha^{-1} before flowering)	3.03	6.11	4.81	6.75
4 *Rhizobium* only	2.65	4.68	4.07	5.84
Mean	2.70	5.51	3.95	5.86
SE	±0.200	±0.477	±0.247**	±0.438
CV (%)	14.8	15.0	12.5	15.0

Inceptisol or Entisol. A starter dose of 20 kg N ha^{-1} did not have any beneficial effect on final grain yields, although it increased shoot dry matter at first flush harvest of pods only in Vertisol. This is contrary to the report of KULKARNI and PANWAR (1981) that a starter dose of 20—25 kg N ha^{-1} was beneficial to pigeonpea in most cases. More studies are needed to define the situations where pigeonpea responds to a starter dose of nitrogen. At 50 or 100 kg N ha^{-1} as a starter dose the plants looked greener than others, but this was not reflected in increased yields compared to plots without N. It is not clear why this initial advantage in terms of N content of plant tissue was not reflected in final yields. Similarly N applied at 1 month after sowing did not have any beneficial effect. However, fertilizer N applied at 50 % flowering increased grain yield significantly only in Vertisol but not in Alfisol, Inceptisol and Entisol. Similarly, N applied at pod filling was beneficial only in Vertisol. The fact that there was little difference in yields between treatments 7 (N at sowing and at 50 % flowering) and 10 (N at all stages) during 1985/86 suggests that yield response to N was mainly due to N applied at flowering. This suggests that N becomes limiting at flowering in Vertisols. The increased grain yield due to fertilizer N applied at 50 % flowering was apparently due to increased pod number per plant and relatively more seed weight (data not presented).

The response of pigeonpea cv. ICPL 87 to fertilizer N only in Vertisol but not in the other three soil types suggests that symbiotic nitrogen fixation by pigeonpea was not adequate to meet nitrogen requirements of the crop in the Vertisol only. This was evident in that the nodulation and nitrogenase activity of ICPL 87 were relatively low in Vertisol. One of the reasons for low nodule mass and ARA of pigeonpea in Vertisol was probably the nodule damage (a mean of 45 %) caused by *Rivellia* sp. The nodule damage was relatively less in Alfisol (a mean of 17 % at 50 DAS and 37 % at 84 DAS). These observations are in agreement with those of KUMAR RAO and SITHANANTHAM (1989) who reported that *Rivellia* sp. infestation caused significant reductions in shoot dry weight

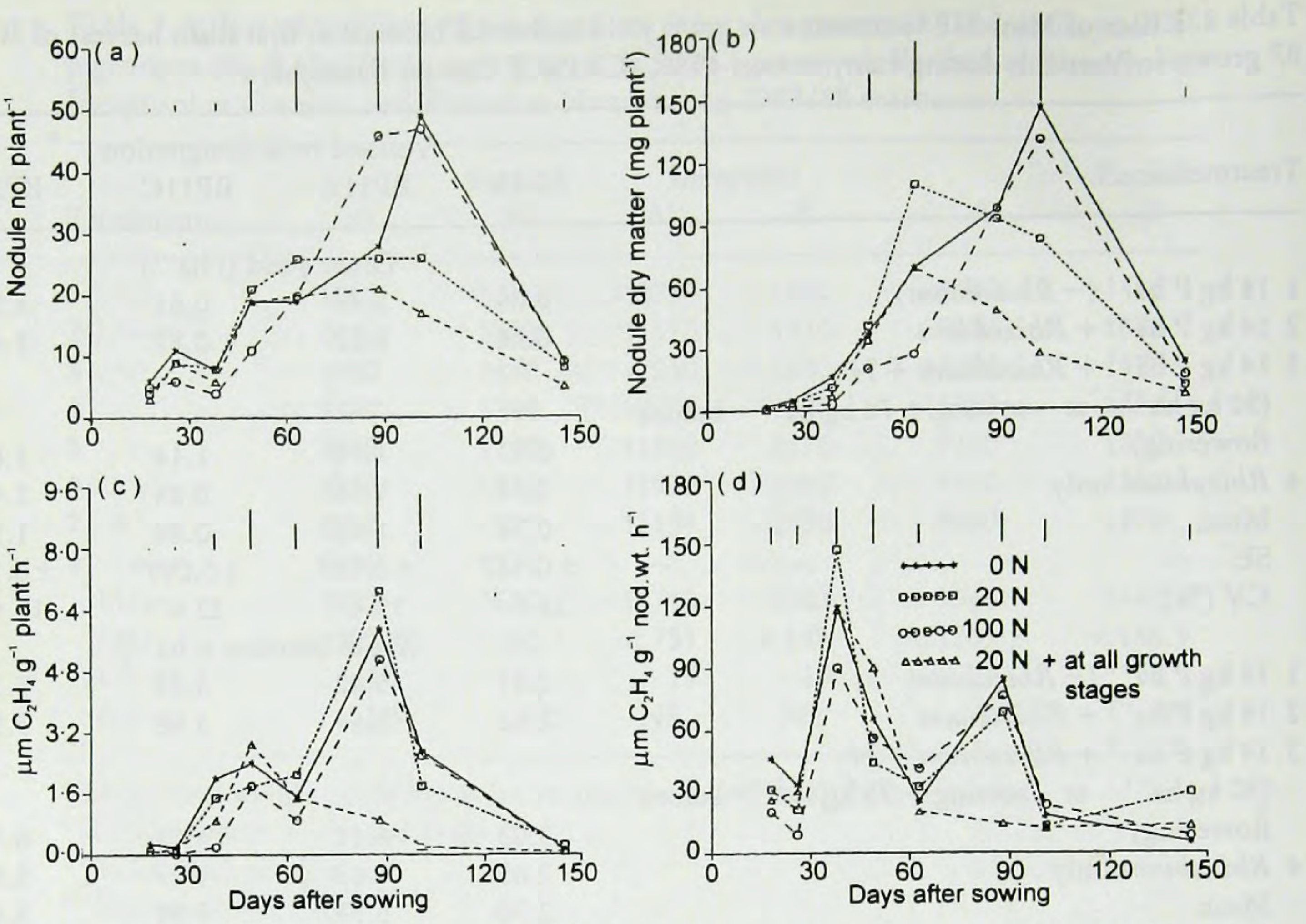

Fig. 3. Effect of fertilizer N on nodulation (a, b) and acetylene reducing activity (c, d) of pigeonpea genotype, ICPL87 grown on Vertisol, 1985/86. Bars indicate standard errors of means

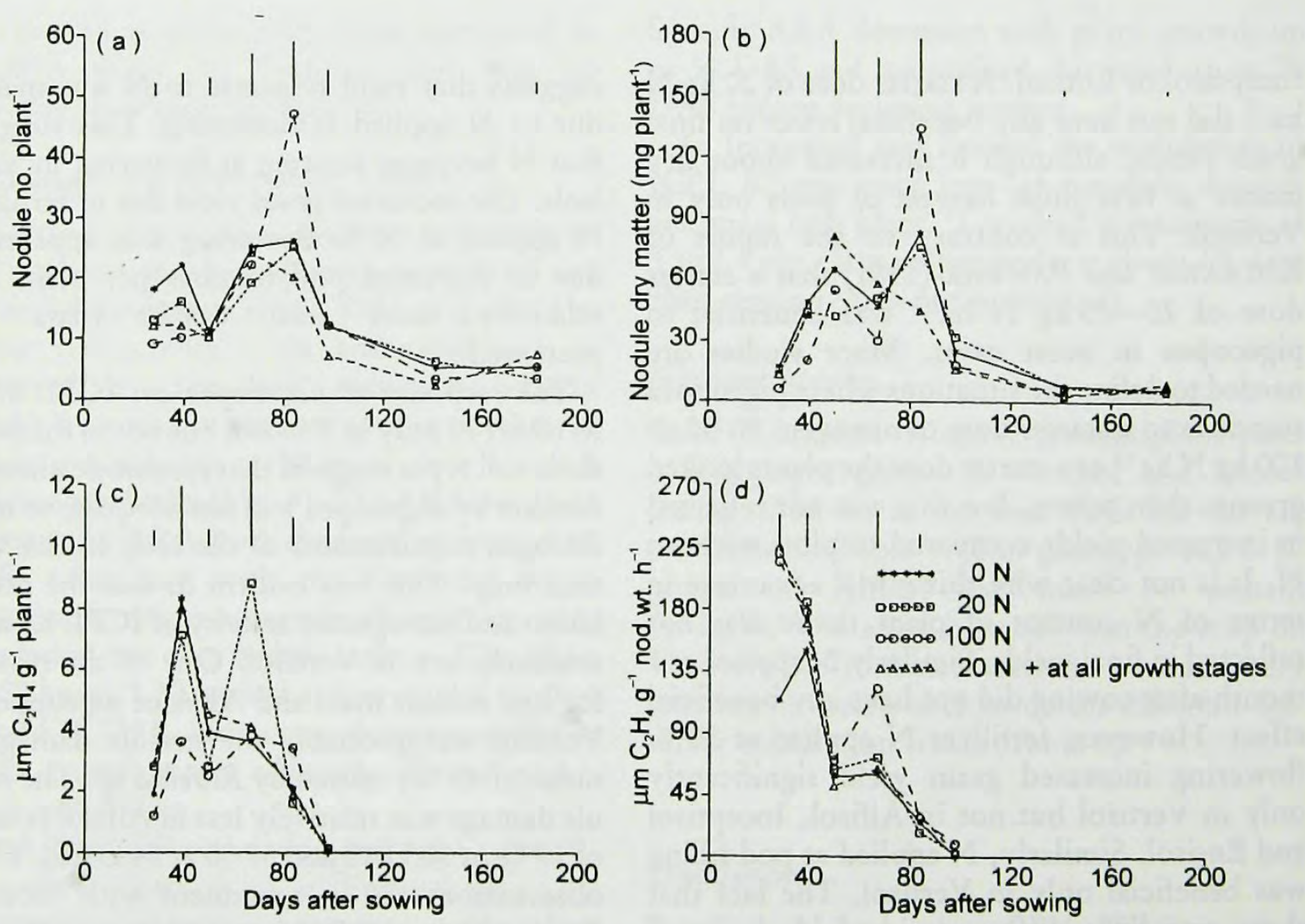

Fig. 4. Effect of fertilizer N on nodulation (a, b) and acetylene reducing activity (c, d) of pigeonpea genotype, ICPL 87 grown on Alfisol, 1985/86. Bars indicate standard errors of means

Table 9. Nitrogen concentration in shoot tip, and nitrogen content of pigeonpea ICPL 87 grown on Vertisol (V) and Alfisol (A) and sampled at the first flush harvest as affected by fertilizer N applied at different growth stages, 1985/86, ICRISAT Center

Treatments[1]	N. concentration in shoot tips (%)		Nitrogen content (kg ha^{-1})							
			Shoot		Podwall		Seed		Total N yield	
	V[a]	A[b]	V	A	V	A	V	A	V	A
1	4.31	4.19	73 (8.5)c	127	5.2	5.4	51.0	44.3	129	176
2	4.39	4.13	80 (8.9)	115	5.7	5.8	51.5	47.6	137	169
3	ND	ND	91 (9.4)	146	5.5	5.8	52.5	48.6	149	200
4	4.47	4.23	84 (9.1)	93	5.9	4.2	51.3	26.0	141	123
5	4.56	4.30	66 (8.1)	105	4.9	4.9	51.9	37.5	122	148
6	4.38	4.64	123 (10.7)	142	6.0	5.8	54.1	51.3	183	199
7	4.11	4.10	107 (10.3)	122	6.5	6.0	61.7	50.6	175	175
8	ND	ND	88 (9.4)	109	5.2	5.0	51.4	39.3	145	153
9	ND	ND	69 (8.3)	125	6.0	5.4	51.2	42.4	126	172
10	4.37	4.30	86 (9.2)	126	6.6	6.6	61.2	50.7	154	183
Mean	4.37	4.27	87 (9.2)	121	5.7	5.5	53.8	43.8	146	170
SE	±0.245	±0.082	±15.8 (0.745)	±18.3	±0.31	±0.47	±1.76	±3.41	±16.3	±19.9
CV%	11	4	36 (16)	30	11	17	7	16	22	23
F-Test	NS	**	NS	NS	*	NS	**	***	NS	NS

[a] Samples collected 63 DAS

[b] Samples collected 67 DAS

[c] Values in parentheses are those after square-root transformation

[1] See Table 3 for treatment details

(22 %), root and nodule dry weights (27 %), seed dry weight (14 %) and total N (29 %) and P uptake (19 %) of a short-duration pigeonpea grown in a Vertisol. Another reason for lesser N_2 fixation in heavy textured soils such as Vertisols is the susceptibility of pigeonpea to oxygen deficits under well watered conditions in these soils (OKADA et al. 1991). Such conditions reduce N_2 fixation capacity. Similarly, under such conditions denitrification might be increased resulting in reduced N supply from soil.

Although we did not measure ARA in Inceptisol and Entisol we found that the pigeonpea nodulation was very low (highest nodule number and mass $plant^{-1}$ were 5 and 4 mg respectively at 40 DAS, compared with 50 and 150 mg in Vertisol). However, the shoot dry matter produced by pigeonpea was highest in Entisol in northern India followed by Inceptisol in central India, much more than that produced in Vertisol and Alfisol in peninsular India (Table 4). Further, there was no indication of any response to N fertilizer in these soils. This could perhaps be due to high N mineralization potential of Inceptisol and Entisol soils compared to Alfisols and Vertisols, i.e. the Inceptisol and Entisol soils were able to mineralize and supply adequate N for pigeonpea, while Alfisols and Vertisols were not able to do so (Table 2). However, it would be interesting to know the extent of nitrogen availability, i.e. from soil or atmosphere (N_2 fixation), to pigeonpea grown in these Inceptisols and Entisols.

The N uptake by pigeonpea at first flush harvest was also significantly influenced by the soil type—129 kg ha^{-1} in Vertisol versus 176 kg ha^{-1} in Alfisol during 1985/86. This again suggests that pigeonpea had less N available, be it from soil or symbiotic N_2 fixation, in Vertisol. The N_2 fixed in the early growth stages in Alfisol was probably enough to sustain growth in later stages in this soil type. By contrast, in Vertisol the poor nodulation and low ARA activity in the early growth stages resulted in N responses at later growth stages. Although ARA tended to increase up to 90 DAS, except for a decline at 60 DAS, in Vertisol the crop had already passed through a critical growth stage requiring more nitrogen (viz. 50 % flowering) and thus it responded to fertilizer N. This may further explain why the crop did not respond to fertilizer N applied after the first flush of pods in Vertisol. These studies failed to detect any significant responses to fertilizer applied at several growth stages on lighter textured soils such as Alfisols, Entisols and Inceptisols. As plant growth, grain yield and N content of pigeonpea on these soils was generally high, it could be concluded that inadequate N_2 fixation was not a yield limitation on these soils.

On Vertisol, in conditions which permitted good plant growth, symbiotic N_2 fixation could not meet the N needs of the plant, particularly in the early reproductive growth period. Of course, this N deficit could be alleviated by application of N fertilizer, at around flowering time provided the surface soil is moist. However, this is not a desirable recommendation in terms of maximizing N_2 fixation by legumes as a contribution to sustainable cropping systems. It is, therefore, more appropriate to attempt selection and breeding of short-duration pigeonpea genotypes with higher N_2 fixing ability in heavy-textured soils. Such selection could be attempted by either by screening genotypes on N-depleted soil (obtained by repeated growth of a non-legume) or by using ^{15}N-based methods such as ^{15}N natural abundance. To assist in this regard, further studies are also needed on the reasons for relatively poor N_2 fixation in soils such as Vertisols and options for overcoming them. For example, the need for alleviation of insect damage and ability to fix N_2 under poor soil aeration conditions should be considered.

Zusammenfassung

Stickstoffbedürfnisse unterschiedlicher Wachstumsstadien von frühreifen Taubenerbsen (*Cajanus cajan* L. Millsp)

Die Reaktion gegenüber N-Düngung eines frühreifen Taubenerbsengenotyps (ICPL 87) wurde im Feld untersucht, um den Spielraum für eine genetische Verbesserung der symbiotischen N_2 — Fixierung bei Taubenerbsen zu bestimmen. Die Felduntersuchung wurde im Jahre 1985, 1986 und 1987 auf einem Vertisol und einem Alfisol am ICRISAT-Zentrum (südlicher Teil Indiens), auf einem Inceptisol in Gwalior (Zentralindien) und auf einem Entisol in Hisar (nördliches Indien) unter möglichst günstigen Umweltbedingungen durchgeführt. Der Stickstoffdünger wurde dem Boden zu verschiedenen Wachstumsstadien zugefügt, um die am stärksten limitierende Phase für Stickstoff zu bestimmen. Eine signifikante Reaktion des Kornertrages gegenüber Dünger-N fand sich in einer Anwendung zum Zeitpunkt der Blüte auf einem Vertisol aber nicht auf einem Alfisol, Inceptisol oder Entisol. Dies läßt vermuten, daß die biologische N_2 — Fixierung bei frühreifen Taubenerbsen nicht ausreicht, um die N-Bedürfnisse des Bestandes auf einem Vertisol zu befriedigen, während auf den anderen Böden eine ausreichende Fixierungsleistung gegeben ist. Die Ergebnisse werden im Zusammenhang mit der Knöllchenbildung und der Acethylenreduktaseaktivität von Taubenerbsen sowie dem N-Mineralisationspotential auf verschiedenen Böden diskutiert. Es kann angenommen werden, daß keine Notwendigkeit besteht, die N_2-Fixierungsfähigkeit von frühreifen Taubenerbsen, die an schweren Böden wie Vertisole angebaut werden, genetisch zu verbessern.

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