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Effect of a High Nodulating Selection of Chickpea Cultivar ICC 4948 on Yield and Soil Properties of a Chickpea- Sorghum Cropping System*

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Abstract

Plants of widely different nodulation capacities occurring in a chickpea variety ICC 4948 (=G 130) and later developed into separate lines were compared in a chickpea-sorghum field. experiment. The high nodulating (HN) chickpea selection produced only marginally higher grain yield (3.3-6.9%, mean of the two N levels) than that of the unselected normal variety and the low nodulating (LN) selection. But the HN selection fixed significantly more atmospheric nitrogen at low soil N (as measured by acetylene reduction activity), and also supported increased microbial activity in the rhizosphere. Also, at low soil mineral N level, the microbial flush C:N ratio in the plots of the HN selection was narrower (16.0) than that in plots of the LN (24.4) and nonnodulating (20.4) selections. Increased microbial activity, along with a narrower flush C:N ratio in the case of HN selections compared with the LN selection, lead to an increased availability of N for the following sorghum crop. This resulted in an extra uptake of 20 kg N ha^{-1} by chickpea and sorghum together. These studies indicated the benefits of HN selections of chickpea under low soil N and irrigated conditions for increased N yield and increased microbial activity in a chickpea-sorghum cropping system. These results are for 1 year only and suggest the need to study the cumulative effect of the high BNF lines on crop productivity over time in a cropping systems perspective.

Introduction

Crop production systems in low external input agriculture can be constrained by low availability of nutrients, particularly nitrogen (N) and phosphorus (P). This can consequently threaten farm productivity. Legumes can be integrated into cropping systems to sustain and, in some cases, enhance soil fertility. This requires informed decisions on selection of an appropriate legume, its cultivar, and establishing its biological nitrogen fixation (BNF) through rhizobial inoculation and appropriate management practices (overall, legume technology) to harness legume benefits (Peoples and Craswell, 1992). The overall goal of legume technology should be to select and integrate legumes into various production systems and to enhance their productivity. The inherent ability of legumes to fix atmospheric nitrogen (N_2) and use it as a plant nutrient for their own growth and also to provide N to subsequent crops (Peoples and Craswell, 1992) is one of the major considerations of including legumes in different cropping systems.

High and low nodulating selections from each of two chickpea cultivars ICC 4948 (=G130) and ICC 5003 (=K850) have been developed at ICRISAT

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Asia Center (Rupela, 1994). High nodulating (= high N_2-fixing, as established in subsequent unpublished studies) selections are expected to increase productivity of the cropping system and enhance soil fertility and soil biological properties. This paper reports an experiment examining this possibility in a chickpea-sorghum cropping system involving a high nodulating chickpea selection of cultivar ICC 4948.

Materials and Methods

The experiment was conducted at ICRISAT Asia Center (IAC) on a Vertisol field which remained fallow for 1 year after growing a cover crop of sorghum to deplete soil N. Soil at 15 cm depth at the experimental site at sowing had high population (>10^4 g^{-1} soil) of native chickpea rhizobia, pH 8.3 (1:2, soil:water), OC % 0.50, 561 mg kg^{-1} total soil N, 3.4 mg kg^{-1} soil mineral N, 3.8 mg kg^{-1} soil available P (Page *et al.*, 1982). The experiment was conducted in a split plot design with three replications. Two soil N levels, 0 (N1) and 100 kg N ha^{-1} (N2), were in main plots and four chickpea lines in sub-plots.

The two nitrogen levels were developed well before sowing chickpea. In our experience in India, most research station fields generally had a significantly higher N level than most farmers' fields. The experiment reported here was conducted on a Vertisol field depleted for nitrogen by growing cereal cover crops for at least 3 years, to a level close to that generally found on farmers' fields. To achieve a nitrogen level close to that generally found on research stations, we applied 100 kg N ha^{-1}. Fertilizer N was applied to the N2 plots as urea and followed by two sprinkler irrigations of 42 and 53 mm water at 18 and 22 days before sowing chickpea on 1 Nov 1992, to ensure distribution of the applied N into the soil profile.

Phosphorus as single superphosphate was band-placed at 20 kg P ha^{-1} at the time of sowing of chickpea, followed by a light sprinkler irrigation. Two more irrigations were applied at 53 and 73 days after sowing (DAS).

The four chickpea lines were high (HN) and low nodulating (LN) variants of a chickpea cultivar ICC 4948 (=G130), normal cultivar or variety (V) ICC 4948 and a nonnodulating selection of cultivar ICC 4993 (=Rabat) (Rupela 1992). All these lines were of long duration and adapted to 25-30 °N latitudes (Summerfield et al. 1980). However, with irrigation, these were previously grown successfully at IAC.

Observations on plants dug from a 0.9 m^2 area were made at 46 DAS for nodule number, nodule mass and acetylene reduction activity (ARA, Dart et al., 1972). Chickpea was harvested at 116-120 DAS.

Soil was sampled from each subplot at 2 days before sowing chickpea, at 46 DAS (flowering) and at 118 DAS (harvesting). Four samples using 40 mm diameter cores were collected from the top 30 cm soil profile of each subplot of 12.6 m^2 and were pooled. The pooled samples were analyzed for mineral N, net N mineralization, soil respiration, microbial biomass carbon (C) and nitrogen (N).

Mineral N was extracted from the sieved (2 mm sieve) soil samples suspended in 2 M KCl (20 g soil to 100 mL solution) for 1 h, and filtered through Whatman no. 42. The extracts were stored frozen before analysis for concentration of NO_3^--N and NH_4^+-N at a later date by distilling the aliquot in a microkjeldahl apparatus using MgO and Devarda's alloy (Jackson, 1973). Net N mineralization was calculated as mineral N (NH_4^++NO_3^-) in soil incubated at 25°C for 10 days minus mineral N in soil before incubation. Soil respiration was measured with a 20 g moist sieved soil sample adjusted to 40% water holding capacity (WHC) and incubated in 1 L airtight jars along with 20 mL 1 N NaOH in a bottle for 10 days at 25°C. At the end of the incubation period, carbonate was precipitated by adding $BaCl_2$ solution and excess NaOH was back titrated with 0.5 N HCl using 1% phenolphthalein indicator (Jackson, 1973). Microbial biomass carbon (C) was measured by the chloroform-fumigation and incubation method (Jenkinson and Powlson, 1976) using sieved (2 mm) soil from the field, adjusted to 40% WHC. Microbial biomass C was calculated as flush C divided by Kc (proportion of the biomass C mineralized to CO_2 during incubation). The flush C is the C mineralized from fumigated soil incubated at 25°C for 10 days minus C mineralized from non-fumigated control soil incubated for 10 days, and Kc was taken to be 0.411 as per Anderson and Domsch (1978).

Microbial biomass nitrogen (N) was calculated as flush N divided by Kn (proportion of the biomass N mineralized during incubation). The flush N is the mineral N (NH_4^++NO_3^-) in fumigated soil incubated for 10 days minus mineral N in non-fumigated soil incubated for 10 days, and Kn was taken to be 0.57 as per Jenkinson (1988).

Chickpea was harvested by 2 Mar 1993 and the trial plots remained fallow until 24 Jun 1993, when they were sown to rainfed sorghum CSH 6, without any fertilizer. Sorghum was harvested on 16 Oct 1993 (at 114 DAS) and the grain, stover and N yield assessed.

Results and Discussion

Nodulation and yield of chickpea

The high nodulating (HN) selection of chickpea cultivar ICC 4948 formed about 2 times greater nodule mass than the LN selection at low soil N_1 level (Table 1). The nodule mass of the normal variety (V) at N1 was similar to that of the LN selection. Total dry matter yield of all the chickpea lines except that of the nonnodulating (NN) (reference line) selection was similar at the high soil N level (N2). At N1, yield of the HN selection was greatest and the yield of NN was lowest. The HN selection produced 9-10% greater dry matter and grain yield than the LN selection at N1 (Table 1). Yields of the HN selection, LN selection and the variety were similar, which suggested availability of enough soil N at both the N levels for producing about 2 t ha^{-1} yield of chickpea (with irrigation) and similar yield of rainfed sorghum after chickpea (Table 2). It seems that in some soils and environments, two lines with widely different nodulation and BNF capacities can yield similarly and the benefits of high BNF of the HN selection are apparent only in the N uptake (through high grain protein, and thus an improvement in grain quality only) of chickpea and of the sorghum following it (Table 2).

Table 1. Nodulation, acetylene reduction and yield of different nodulation types of cultivar ICC 4948.

Chickpea lines1	Nodule number plant^{-1}			Nodule dry mass (mg plant^{-1})			Acetylene reduction activity (µM $h^{-1}m^{-2}$)			Total dry matter (t ha^{-1})			Grain yield (t ha^{-1})		
	N1	N2	Mean	N1	N2	Mean	N1	N2	Mean	N1	N2	Mean	N1	N2	Mean
ICC 4948 HN	36	16	26	74	21	48	150	25	88	4.72	4.97	4.84	2.26	2.06	2.16
ICC 4848 LN	6	6	6	34	15	25	86	27	56	4.33	4.82	4.58	2.05	1.98	2.02
ICC 4948 V	9	5	7	46	10	28	94	30	62	4.48	5.00	4.74	2.24	1.95	2.09
ICC 4993 NN	0	0	0	0	0	0	0	0	0	0.83	4.53	2.68	0.26	1.64	0.95
(Control)															
SE	±1.3(1.2)[2]		±0.8	±2.9(2.6)[2]		±1.9	±11.1		±7.8	±0.299		±0.139	±0.110		±0.065
							(11.2)[2]			(0.196)[2]			(0.092)[2]		
Mean	10	6		31	9		83		20	3.03	4.67		1.41	1:81	
SE	±0.7			±1.7				±5.6		±0.242			±0.073		

1. HN = high nodulation, LN = Low nodulation, V = variety, NN = nonnodulating
2. SE to compare means within a N-level.

Nodule mass and nitrogen fixation, measured as ARA, of the different chickpea lines was considerably reduced (in some cases by 4 times) at N2 than that at N1 (Table 1). Suppression in BNF traits due to high mineral N is known in several legumes (Streeter, 1988). Although 100 kg N ha^{-1} was added to the N2 plots, the values of mineral N at chickpea sowing (22 days after N application) both in N1 and N2 plots in the top 15 cm depth were low, 3.4 mg kg^{-1} soil at N1 versus 5.3 mg kg^{-1} soil at N2 (Fig. 1). It seems that the plant growth response is a more sensitive indicator of soil N status than the mineral N measurement in soil at sowing.

Table 2

Grain yield of sorghum and N yield of sorghum + chickpea grown after different nodulation types of ICC 4948.

Chickpea lines[1]	Sorghum grain yield ($t\ ha^{-1}$)			Total N yield of chickpea and sorghum ($kg\ ha^{-1}$)		
	N1	N2	Mean	N1	N2	Mean
ICC 4948 HN	2.38	2.65	2.52	173	160	167
ICC 4948 LN	2.29	2.42	2.36	153	193	173
ICC 4948 V	2.40	2.20	2.30	152	127	139
ICC 4993 NN (control)	1.68	1.95	1.81	32	72	52
SE	±0.249(0.238)[2]		±0.168	±12.0(10.5)[2]		±7.4
Mean	2.19	2.31		128	138	
SE		±0.140			±7.9	

1. HN = high nodulation, LN = low nodulation, V = variety, NN = nonnodulating.
2. SE to compare means within a N-level.

Microbial biomass and respiration

Soil respiration, an indicator of soil biological activity, was not influenced by the addition of N or different chickpea lines (data not shown). It varied with the sampling time and was maximum (84.7 µg C g^{-1} soil 10 d^{-1}) at 46 DAS (flowering stage) and then declined to 39.3 µg C g^{-1} soil 10 d^{-1} at harvest.

Mean microbial biomass was significantly (*P* 0.05) more at N1 (225 µg C g^{-1} soil) than at N2 treatment (198 µg C g^{-1} soil). Mean microbial biomass carbon in soil was 270 ig C g^{-1} soil in presowing soil samples, and decreased significantly (*P* 0.05) to 167 ig C g^{-1} soil at flowering and then increased to 198 ig C g^{-1} soil at harvest. Significant (*P* 0.05) interaction between chickpea lines and N levels at the flowering stage was observed for microbial biomass. At N1, microbial biomass was 1.8 times more in case of the HN than the LN selection and it was also more than the microbial biomass in the soil from plots of cultivar ICC 4948 (V) and that of the nonnodulating ICC 4993 (NN). However, no such differences in microbial biomass were observed in these lines when grown at N2. These results indicate that, when grown at low soil N, the high nodulating line of chickpea supported more microbial activity in the soil, perhaps by providing the necessary C through root exudations and through senescing roots and nodules. Such increased microbial biomass would result in increased availability of soil nutrients in plots of high nodulating chickpea lines.

Soil N during crop growth

Mean mineral N (NH_4^++NO_3^-) in soil was 2.5 times greater (significant at *P* 0.01) in N2 plots than in N1 plots for all the chickpea lines. It increased from 4.5 mg N kg^{-1} soil at sowing to 8.1 mg N kg^{-1} soil at 46 DAS (flowering) and then decreased to 2.75 mg N kg^{-1} soil at harvest. The mineral N content was highest (7.1 mg N kg^{-1} soil) in soil from HN selection followed by that of the LN selection and the normal cultivar. It was lowest in the plots of nonnodulating ICC 4993. A significant interaction (*P* 0.5) between chickpea lines and N level for mineral N content in soil was observed. At N1, lowest mineral N (1.7 mg kg^{-1} soil) was measured in plots of ICC 4948 (V). The generally high mineral N content in soil from HN plots indicated that such lines derived relatively more N for plant growth from BNF and less from mineral N in soil than the LN and NN selections. At flowering, mineral N in soil at N1 was similar for all of the selections, but was three times more (18 mg N g^{-1} soil) in soil from HN plots at N2 than in those of NN at N2 (data not shown).

Microbial biomass N averaged across sampling times and chickpea selections was significantly (P 0.01) higher (15.9 ìg N g^{-1} soil) in N2 plots than in the N1 (10.6 ìg N g^{-1} soil) plots. Mean biomass N across the N levels and chickpea selections increased from 7.7 ìg N g^{-1} soil at sowing to 18.2 ìg N g^{-1} soil at 42 DAS and then decreased to 13.8 ìg N g^{-1} soil at harvest. At flowering, N1 plots of ICC 4948 (HN) had the greatest biomass N (19.5 ìg g^{-1} soil, *P* 0.01) of all the selections (Table 3). Increased biomass N at N1 plots of HN along with increased microbial biomass suggest that this soil would provide more N for plant growth (current and following) than the soil with lower biomass N of the LN and NN plots.

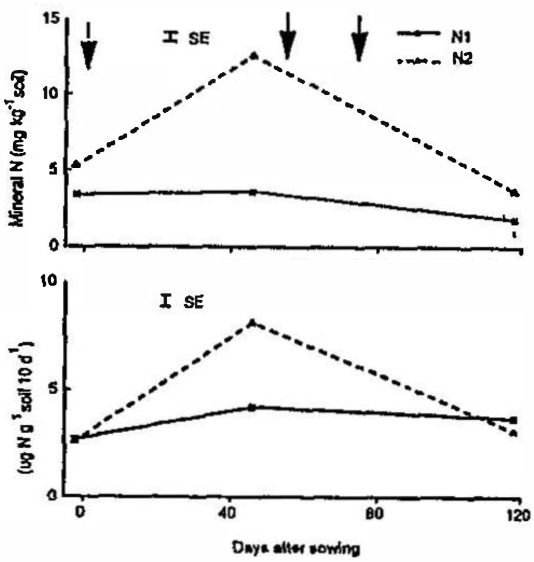

Fig. 1. Mineral N and N mineralization in the top 30 cm soil profiles of two different N levels at different stages of chickpea growth, postrainy season 1992/93. Each data point is a mean of four chickpea lines. Arrows indicate time of irrigation.

The quantity of net N mineralized, when averaged across the chickpea lines and N levels, varied significantly with sampling times. It was maximum at flowering (6.2 ìg N g^{-1} soil 10 d^{-1}) and decreased to 3.3 ìg N g^{-1} soil 10 d^{-1} at harvest (Fig. 1). Chickpea selections did not significantly affect the amount of net N mineralized. However, marginally higher amounts of net N mineralized were observed in the plots of the nodulating selections than in those of the nonnodulating selection. At flowering, consistently higher amounts of net N were mineralized in all the selections grown at N2 level than those at N1 (Fig. 1). No consistent trends for net N mineralization were observed with nodulating selections, as recorded for biomass N and mineral N. This was expected because net N mineralization in soil is much affected by the amount of organic C, mineral N, microbial N in the soil and soil moisture at the sampling.

Table 3

Microbial biomass carbon (C) and nitrogen (N) in soil from low soil N level (N1) plots of different chickpea lines of different nodulation capacities at flowering[1].

Chickpea lines	C (µ g^{-1} soil)	N (µ g^{-1} soil)
ICC 4948 (HN)	316	19.5
ICC 4948 (LN)	172	9.4
ICC 4948 (V)	115	11.9
ICC 4993 (NN)	186	7.3
SE	±37.7	±3.0

1. Data values at N2 level were not significantly different for the different chickpea lines and therefore excluded.
2. HN = high nodulation, LN = low nodulation, V = variety, NN = nonnodulating.

Flush C:N ratio

The flush C:N ratio of the soil, when averaged across the sampling times and nodulating selections, decreased significantly (P 0.05) from 19.9 in N1 to 14.5 in N2 treatment, indicating more N availability for microbial growth at N2. Mean flush C:N ratio in soil varied due to chickpea lines and was minimum (13.8) in HN plots and maximum (18.9) in NN plots. Significant (P 0.05) interaction between nodulating selections and N levels was observed for C:N ratio. In all the selections, narrower C:N ratios were observed at N2 than at N1. The flush C:N ratio in HN plots at N1 was significantly lower by 0.65 times, compared with the C:N ratio of LN plots. Narrow flush C:N ratio suggests an early N mineralization and N availability for the crop. In other words, immobilization of N in soils with narrow flush-C:N ratio will be less than those of wide flush C:N ratio. At sowing, the flush C:N ratio was wider, indicating more immobilization of N to fulfil the N demand of the increased biomass due to wetting after a long dry spell.

Sorghum yield after chickpea

Grain yield of sorghum grown after the HN selection was 4-10% greater than the LN selection (Table 3). Also, the total N uptake of the HN selection at N1 through chickpea and sorghum together was 14% (20 kg N ha^{-1}) greater than that of LN selection. But this was not the case at N2 where maximum N was harvested from LN plots (Table 3) suggesting a significant cultivar x N-level interaction.

Conclusion

The high nodulating (HN) selection was consistent in its nodulation and fixed more nitrogen than the LN selection and the unselected normal variety ICC 4948. Also, the overall N yield in a cropping system perspective was greater in plots growing HN selections than those growing normal cultivar. Soil biological properties, measured as microbial biomass and flush C:N ratio, also improved in plots growing the HN selection. These results are only for one cropping cycle and are being followed up in a long-term experiment.

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References

Andersen, J.P.E. and Domsch, K.H.; 1978. Mineralization of bacteria and fungi in chloroform-fumigated soils. Soil Biol. *Biochem.* 10: 207-213.

Dart, P.J., Day, J.M. and Harris, D., 1972. Assay of nitrogenase activity by acetylene reduction. In: *Use of Isotopes for Study of Fertilizer Utilization by Legume Crops*: Technical Report 149, International Atomic Energy Agency, Vienna, pp. 85-100.

Jackson, M.L., 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi. 488 p.

Jenkinson, D.S., 1988. Determination of microbial biomass carbon and nitrogen in soil. In: *Advances in Nitrogen Cycling in Agricultural Ecosystems*: proceedings of the Symposium on Advances in N-cycling in Agricultural Ecosystems, 11-15 May 1987. Brisbane. Australia (Eds.) Wilson, J.R., CAB International, Wallingford, pp. 368-386.

Jenkinson, D.S. and Powlson, D.S., 1976. The effects of biocidal treatment on metabolism in soil - v. A method for measuring soil biomass. Soil Biol. *Biochem.* 8: 209-213.

Page, A.L., Miller, R.M. and Keeney, D.R., 1982. *Methods of Soil Analysis*, part 2: Chemical and Microbiological Properties. American Society of Agronomy, Inc. Wisconsin, U S A, 1159 p.

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

Rupela, O.P., 1992. Natural occurrence and salient characters of nonnodulating chickpea plants. *Crop Sci.* 32: 349-352.

Rupela, O.P., 1994. Screening for intracultivaral variability of nodulation in chickpea and pigeonpea. In: *Linking Biological Nitrogen Fixation Research in Asia*: report of a meeting of the Asia Working Group on Biological Nitrogen Fixation in Legumes, 6-8 Dec 1993, ICRISAT Asia Center, India (Eds.) Rupela, O.P., Kumar Rao, J.V.D.K., Wani, S.P., and Johansen, C. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Streeter, J., 1988. Inhibition of legume nodule formation and N_2 fixation by nitrate. *Crit. Rev. in Plant Sci.* 7: 1-23.

Summerfield, R.J., Minchin, F.R., Roberts, E.H. and Hadley, P., 1980. The effects of photoperiod and yield of chickpea (*Cicer arietinum* L.). In: *Proceedings* [illegible] *Chickpea Improvement*, 28 Feb-2 Mar 1979, ICRISAT, India (Eds.) van Rheenen, H.A. and Saxena, M.C., Patancheru 502 324, Andhra Pradesh. India International Crops Research Institute for the Semi-Arid Tropics, pp 121-149.

Wani, S.P., Rupela, O.P. and Lee, K.K., 1995. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. *Plant and Soil* (in press).