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an yields were uniformly low, and unaffected by cultivar, at the altepeque site. Fertilization did not enhance yield though a significant ›nse to inoculation was achieved with both the Nitragin and CIAT ılants (see Table 3).

these experiments fixation parameters varied markedly between sites, in their relation to yield. Thus at Ahuachapan nodule weight was not ted by cultivar or treatment, while nodule number was negatively :lated with yield (r = -0.41); at Turin, nodule number was unaffected by ' and nodule weight was negatively correlated with yield (r = -0.20); ıezaltepeque, positive correlations between nodule number (r=0.28) nodule weight (r = 0.40) and yield were observed. This, together with the ıble response to the two sources of inoculant used, and extensive ılation of the uninoculated controls at each location (see Table 4) lights the need for additional experimentation on the use of inoculant nologies under small-farmer production systems.

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RESPONSE OF GROUNDNUT (*ARACHIS HYPOGAEA*) TO INOCULATION

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Summary

Though groundnut is nodulated by a number of rhizobia belonging to the cowpea miscellany, the nodulation and nitrogen (N_2) fixation achieved under farmers' conditions is often inadequate. Studies at ICRISAT have attempted to overcome this by examining a large number of inoculant strains and various methods of inoculation.

Large variability between groundnut rhizobia in ability to fix N_2 exists, but poor correlations between nodule mass and plant dry weight gains can occur. Inoculum size is important with nodule number and distribution and N_2 fixation enhanced by heavier inoculation rates. Liquid inoculants have provided greater increases in yield than either granular or seed slurry inoculation, the latter method reducing germination and stand establishment. Several field trials at ICRISAT, both in the rainy and irrigated, post-rainy seasons, have given significant responses to inoculation, even though the soil already contains 10^4 rhizobia/g. The cultivar Robut 33-1 with strain NC 92 has given most consistent results.

INTRODUCTION

Though groundnut (*Arachis hypogaea* L.) is nodulated by rhizobia of the cowpea miscellany (Fred, Baldwin & McCoy, 1932), and can, under optimum conditions, fix most of the nitrogen (N_2) needed by the plant (Pettit *et al.*, 1975; Burton, 1976), nodulation in farmers' fields in southern India is generally poor. In one survey, 52 of 95 fields examined showed inadequate nodulation, with rates of N_2 (C_2H_2) fixation less than one-tenth that which can be obtained under reasonable field conditions. Poor nodulation and N_2

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fixation are undoubtedly one reason for low groundnut yields in India, currently averaging about 800 kg/ha.

ICRISAT maintains a collection of *Rhizobium* for groundnut and has experimented extensively with strain evaluation and inoculation method. This paper reports some of these studies.

MATERIALS AND METHODS

``ot trials using the methods detailed by Nambiar & Dart (1980) were :rtaken to determine the nodulation and dry matter production achieved following inoculation with 14 selected strains for groundnut. N-free plants and plants supplied nitrate were used as controls in this study.

Similar methods were used to evaluate the number of rhizobia required to achieve profuse nodulation and active N_2 fixation in the groundnut cultivars TMV-2 (bunch), Kadiri 71-1 (runner) and Robut 33-1 (semispreading). Strain NC 92 was applied as a broth culture inoculant to the base of eight-day-old plants at inoculation rates ranging from 2.2 x 10^2 to 3.2 x 10^9 cells/seedling. Plants were supplied sterile, N-free nutrient medium during growth and were harvested 57 days after planting, when nodule number, total N/plant and shoot dry weight were determined. Plants supplied nitrate were again used as controls.

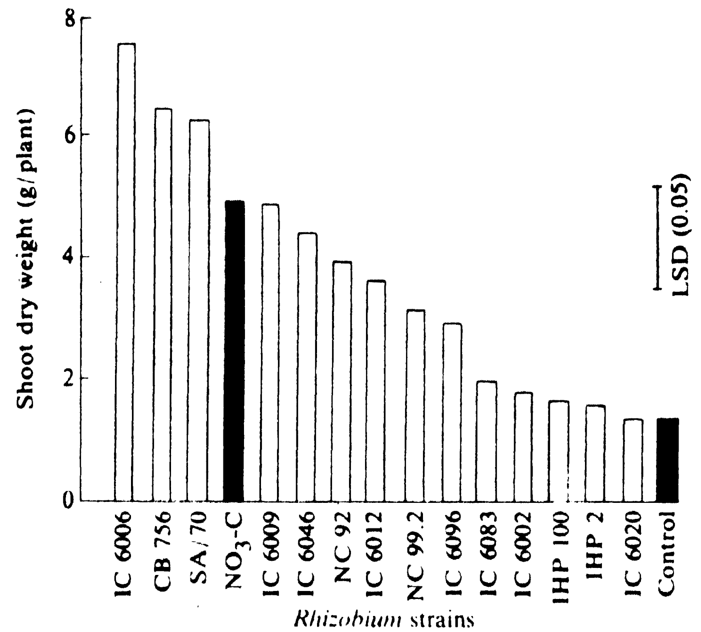
Inoculation trials with groundnut have been undertaken at ICRISAT since 1977. These have included a range of cultivars (TMV 2, Kadiri 71-1, Robut 33-1, Argentine, AH 8189, and MH2) and strains (5a/70, IC6006, ICG 60, NC92, NC 43.3 and NC 7.2) and have used both granular and liquid inoculation. Fertilization in these trials has been at recommended local levels.

Finally, inoculation method has been studied using granular and liquid soil-applied inoculation in comparison with conventional slurry inoculation. :eeds in this trial were treated with thiram before planting.

RESULTS AND DISCUSSION

Response of groundnut to inoculation with selected strains of *Rhizobium* is shown in Figures 1a and 1b. Strains varied markedly in nodule development, and in ability to promote plant growth. While a good correlation between nodule development and plant growth was observed under the -N conditions of the experiment, the strains IC6083, IHP 100 and IHP 2 developed appreciable nodule mass without obvious benefit to the plant.

Tables 1 and 2 show the response of groundnut cultivars to inoculant level. From these results it is apparent that groundnut requires a heavy inoculation rate (10^7 rhizobia/seed) for adequate nodulation and N_2 fixation. Nodulation and fixation were reduced when only 10^4 rhizobia/seed were applied, while no primary root nodules and only a few secondary root nodules developed when only 10^2 rhizobia/plant were applied. The changing pattern of nodulation as



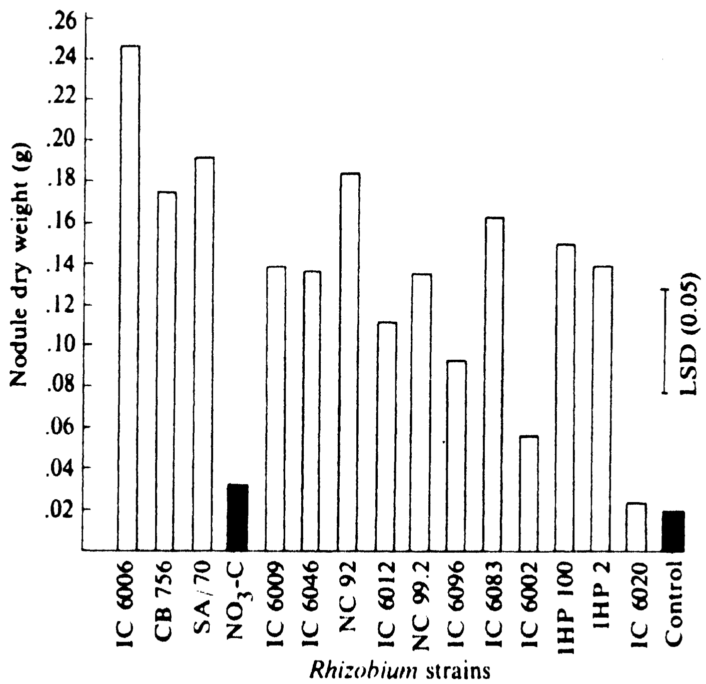


Figure 1: Shoot production and nodule formation by groundnut inoculated with different *Rhizobium* strains. Three plants per 20 cm x 20 cm pot.

the inoculation rate was reduced resembled the response to delayed inoculation reported by Dart & Pate (1959). Similar responses to inoculation rate are reported by Weaver & Frederick (1972) in soybean.

Table 3 summarizes the results of field inoculation trials conducted at ICRISAT from 1977-1980. Although response to inoculation was not always obtained, 'Robut 33-1', which is in the final stages of national release in India, gave substantial increase in pod yield in four of the eight experiments. Tables 4 and 5 show the excellent response of 'Robut 33-1' to inoculation with strain

TABLE 1: Influence of *Rhizobium* inoculum level on nodulation and N_2 fixation by groundnut cv. Kadiri 71-1.

Level of *Rhizobium* applied as broth (no./seed)	Shoot dry wt (g/plant)	Nodule dry wt (g/plant)	Total N (mg/plant)
3.2 x 10^9	3.38	0.13	73.2
5.5 x 10^7	2.38	0.12	50.3
x 10^4	1.08	0.03	18.6
[illegible] x 10^2	0.97	0.02	14.3
Nitrate control	4.34	0	89.8
SEM ±	0.39	0.011	2.1
LSD (5%)	1.13	0.031	21.7

TABLE 2: Effect of *Rhizobium* inoculum population on nodule dry weight production and N_2 fixation by groundnut.[1]

Rhizobium inoculum (cells/seed)	Nodule weight (mg/plant)		N_2 fixation (mg N/plant)	
	Robut 33-1	TMV-2	Robut 33-1	TMV-2
2.7 x 10^2	18	18	25	17
2.7 x 10^4	36	79	23	31
x 10^6	125	101	48	39
x 10^8	119	120	-	48
LSD[2] (5 %)	90		4.1	

[1]Harvested at 61 days after planting.
[2]For comparison within a particular cultivar.

NC92. One significant feature of those responses to inoculation is that they were obtained in fields containing more than 10^4 cowpea group rhizobia per gram of soil and uninoculated plants were well nodulated and yield levels were high.

Inoculation with a liquid culture applied to the soil below the seed proved superior to either granular or conventional slurry inoculation. Not only did the liquid inoculant cause fewer problems in the germination of seedlings (see Table 6), its use resulted in significantly enhanced grain yield (see Table 7).

TABLE 3: Summary of inoculation trials conducted at ICRISAT.

Year/season	Soil type	Cultivars	Strain	Pod yield response
Rainy season 1977	HF,[1] Alfisol	TMV-2 Kadiri 71-1	5a/70	Nil
Rainy season 1977	LF, Alfisol	Kadiri 71-1 Robut 33-1, TMV-2	5a/70	TMV-2, 25 %, Robut 33-1, 32 %
Rainy season 1977	HF, Vertisol	Kadiri 71-1 TMV-2	5a/70 IC 6006	Nil
Rainy season 1978	HF, Alfisol	Robut 33-1 Argentine AH-8189	5a/70 ICG-60 IC 6006 Mixture	Nil
Rainy season 1978	LF, Alfisol	MH-2 Argentine Robut 33-1	5a/70 ICG-60 6S Mixture	Robut 33-1, 26 % (NS)
Post-rainy season 1979	HF, Alfisol	MH-2 Robut 33-1 AH-8189	NC 92 IC 6009 Mixture	Robut 33-1, 28.5 %
Rainy season 1979	HF, Alfisol	Kadiri 71-1 Robut 33-1 AH-8189	5a/70 IC 6006 NC 43.3 NC 7.2 NC 92	Robut 33-1, 25.7 %
Post-rainy season 1980	HF, Alfisol	Robut 33-1	NC 92	Nil

[1]HF = High Fertility LF = Low Fertility.

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.ƃLE 4: Response of groundnut yield (kg/ha) to *Rhizobium* inoculation in the 1978-79 post-rainy season, ICRISAT.

Cultivars	Inoculum strain			
	Uninoculated	IC-6009[1]	NC 92[2]	Mixture (IC 6009 + NC 92)[1]
MH-2	2220	1890	1940	2030
Robut 33-1	3510	3330	4520[3]	2810[4]
39	2830	2860	2680	2810

[1]Inoculum applied as granule.
[2]Inoculum applied as liquid.
[3]Significant at the 1 % level.
[4]Significant at the 5 % level.

Coefficient of variation, 15 % ; LSD, 291 kg/ha.

TABLE 5: Effect of *Rhizobium* inoculation on groundnut yield (kg pods/ha) in the 1979 rainy season, ICRISAT.

Rhizobium strain	Cultivar		
	Kadiri 71-1	Robut 33-1	Ah 8189
5a/70	360	800	420
IC 6006	480	790	290
NC 43.3	460	960	480
NC 7.2	450	950	420
NC 92	570	1160[1]	480
Control	500	870	470

SEM ± 24 CV = 20%

[1]Significant at 5 % level.

TABLE 6: Effect of method of inoculation on percentage germination of groundnut.

Method of inoculation	Germination	
	ICRISAT Center	Solipur (outside ICRISAT station)
Control, uninoculated	83	77
Seed slurry inoculated	46	71
Liquid inoculant in furrow	98	79
Granular inoculant	73	57
L S D (5 %)	9.6	9.1
Coeficient of variation %	8	13

TABLE 7: Effect of different methods of inoculation on groundnut yield (kg/ha), 1980 rainy season, ICRISAT.

Rhizobium strain	Method of inoculation		
	Granular	Liquid	Seed
5a/70	1290	1770	240
NC 92	1020	1640	1020
6006	1000	1630	930
Mixture (5a/70 + NC 92 + 6006)	1050	1520	1000
SEM ±		134	
Uninoculated control		1345 ± 77.4	
Coefficient of variation		15%	

CONCLUSION

The data presented above indicate that it is possible to obtain increase in pod yield of groundnut by inoculating with *Rhizobium* even in fields where a substantial native population already exists. It may be possible to achieve inoculation responses in many farmers' fields where nodulation is found to be poor, provided other major constraints which limit yields are overcome. Methods of applying inoculum in liquid or granular form below the seed need to be developed for the small farmer.

REFERENCES

Burton, J.C. (1976) Pragmatic aspects of the *Rhizobium*: leguminous plant association. *In*: Proc. First Internat. Symp. Nitrogen Fixation, Vol. 2. W.E. Newton & C.J. Nyman, (Eds.). Pullman, Washington State Univ. Press, Pullman, WA, USA. Pp. 429-446.

Dart, P.J. & Pate, J.S. (1959) *Aust. J. Biol. Sci.* 12, 427-444.

Fred, E.B., Baldwin, I.L. & McCoy, E. (1932) Root nodule bacteria and leguminous plants. Univ. of Wisconsin Studies, No. 52.

Nambiar, P.T.C. & Dart, P.J. (1980) Studies on nitrogen fixation by groundnut at ICRISAT. *In*: Proc. Internat. Symp. Groundnut, R.W. Gibbons (Ed.). ICRISAT, Patancheru, AP, India. Pp. 110-124.

Pettit, R.E., Weaver, R.W., Taber, R.A., & Stichler, C.R. (1975) Beneficial soil microorganisms. *In*: Peanut production in Texas, J.E. Miller, (Ed.). Texas Agricultural Experimental Station, Texas A&M Univ. College Stn., TX, USA. Pp. 26-33.

Weaver, R.W. & Frederick, L.R. (1972) *Agron. J.* 64, 597-599.