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INOCULATION OF GROUNDNUT (PEANUT) IN SUDAN[1]

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Field inoculation of groundnut (*Arachis hypogaea* L.) with effective strains of *Rhizobium* is complicated because many tropical soils contain indigenous cowpea rhizobia capable of forming nodules on this host. We evaluated inoculation in an attempt to improve nitrogen fixation in a sub-Sahara soil of Sudan. Greenhouse screening of rhizobia on two Sudanese groundnut cultivars, Barberton (Spanish type) and Ashford (Virginia type), indicated significant differences among the 10 strains tested, mainly in host-plant color ratings and nodule numbers. Two strains, 8A11 (from the Nitragin Co.) and TAL 309 (from NifTAL), were selected for testing in the field. The strains were applied as single or mixed inoculants, formulated (a) in peat and placed with the seed or 5 and 10 cm below the seed, and (b) in oil and applied to the seed. The soil (Entic Pellusterts) at the test site contained 2.1 × 10^4 cowpea rhizobia g^{-1}. When inoculants were added in a peat carrier at seedling depth, the only nitrogen-fixing trait significantly improved ($P < 0.01$), compared with the uninoculated controls, was nodule mass. The TAL 309 strain was serologically distinct from the indigenous cowpea rhizobia, and agglutination reactions indicated that approximately 40% of the main- and lateral-root nodules were occupied by this strain where applied. Unfortunately, this did not result in improved yields. With inoculation in an oil carrier, both nodule mass and pod yield of Barberton were significantly reduced ($P < 0.01$). The Barberton cultivar evidently was sensitive to the presence of oil. As peat inoculant was placed deeper into the soil, both the linear and quadratic terms were significant ($P < 0.05$) for improved top dry weights, whereas other traits were unaffected. The nitrogen control (120 kg N ha^{-1} as ammonium sulfate) significantly depressed nodule numbers and nodule mass and improved top dry weights and tissue nitrogen. The Ashford and Barberton cultivars were significantly different in nodule numbers, top dry weights, pod yields, and nodule mass.

If indigenous rhizobia are less than completely efficient in fixing nitrogen, they must be replaced in nodules by better strains to maximize symbiotic N_2 fixation. Groundnut (*Arachis hypogaea* L.), which is readily nodulated by a diversity of rhizobia in the cowpea miscellany, may be nodulated in many soils of the world by indigenous rhizobia in spite of the introduction of better rhizobial strains in inoculants. This may be especially true in soils that present hostile environments for rhizobial survival, which presumably gives an advantage to the adapted organisms.

Sudan is the fourth largest groundnut-producing country of the world, yet little is know about the groundnut-nodulating rhizobia. Inoculation is not a common cultural practice, and the need for inoculation has not been studied. Initial studies indicated that the soils contain high numbers of cowpea-miscellany rhizobia, yet yields were improved by adding nitrogen fertilizer (Hadad et al. 1982). This suggested that the native rhizobia were not able to supply the complete nitrogen needs of the Sudanese groundnut cultivars, and that inoculation with efficient, competitive rhizobia may be a beneficial practice. Sudan has a wet and dry season that is typical of many tropical countries, and groundnuts are commonly planted in June at the end of the dry season. The soils at time of planting may be particularly hostile for the introduced rhizobia, because the soils are both hot and dry; Musa (1972) has reported surface soil temperatures of 60°C at time of planting. Under normal cultural practices in Sudan, however, desiccation would be only a temporary problem for the introduced rhizobia, because the soils are commonly irrigated shortly after planting.

We assumed that soil conditions in the tropical climate of Sudan might stress added inoculants, so, in addition to inoculation, we also evaluated various methods of adding the rhizo-

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bia. Several methods of improving survival and persistence of inoculant strains have been reported. These include deep placement of inoculants (Schiffman and Alper 1968; Wilson 1975; Marcarian 1982), mixing inoculant strains (Nambiar and Dart 1982), and selection of inoculant carriers (Kremer and Peterson 1982). The deep placement of inoculants may be beneficial in Sudan to reduce exposure to high temperatures that occur in the surface soil. Even though some advocate mixed inoculant strains, others cite the dangers in mixed cultures from (a) differential multiplication rates of the strains, resulting in large differences in the final prepared inoculant; and (b) competition among the strains, resulting in the least effective strain occupying the nodules (Date and Brockwell 1976). Oil carriers have been reported to increase rhizobial survival on the surface of seeds while undergoing moisture and temperature stresses (Kremer and Peterson 1982) and merit evaluation in Sudan as a means of increasing rhizobial survival.

Studies involving competition between inoculant strains and the existing native rhizobia require identification of the competing organisms. Serological differences, identified by using cell agglutination, are commonly used to verify strain recovery (Roughley et al. 1976).

The work reported in this paper was performed in two phases. The greenhouse phase evaluated infectivity and early-growth efficiency of groundnut rhizobia when added to two Sudanese groundnut cultivars. The second phase involved inoculation of field-grown groundnuts at Wad Medani, Sudan, with two strains found to be infective and efficient in the greenhouse. Field inoculation was made as a single strain or a mixture of strains, formulated (a) in peat and placed with the seed or at 5 and 10 cm below the seed, and (b) in oil and applied to the seed.

METHODS AND MATERIALS

Strain selection

Strain selection for the field study was based on greenhouse testing of 10 isolates, 8 of which were regarded by their suppliers to be effective nitrogen fixers on groundnut. The Wad Medani and Sennar strains were field isolates collected from Sudan in the summer of 1980. Strains 26Z6, 8A11, 25B7, and 176A22 were from the Nitragin Company, Milwaukee, Wisconsin; strains USDA 3184, 3187, and 3179 were from the Nitrogen Fixation Laboratory, Beltsville, Maryland; and strain TAL 309 (CB 756) was from North American Plant Breeders, Princeton, Illinois. Two pregerminated seeds each of two popular Sudanese cultivars, 'Ashford' and 'Barberton,' were planted in separate 4-L containers in a sand-perlite mixture (1:1 by volume), inoculated with 1×10^8 cells of a single *Rhizobium* strain, and grown in the greenhouse for 2 mo. Plants were watered with a nutrient solution, and uninoculated and N controls were included (Speidel and Wollum 1980). All treatments were replicated five times. At harvest, top dry weights, nodule numbers, and color ratings were determined. Color was assessed as dark green (5), intermediate colors (4 and 3), and yellow (2).

Site preparation and planting

The field work was conducted in 1981 and 1982 at the end of the dry season and the beginning of the rainy season (mid-June through October) on the heavy clay soils located at Wad Medani. Total rainfall at this location is approximately 200 mm, and supplemental irrigation is required. Wad Medani is located between the Blue and the White Nile Rivers, 120 km southeast of Khartoum. The soils at this location are classified as Entic Pellusterts, fine, smectic, isohyperthermic, and the dominant clay is montmorillonite. The research site (Table 1) was previously planted to cotton. A uniform application of macro- and micronutrients was hand-applied to each plot, and N fertilizer at 120 kg ha^{-1} N (as ammonium sulfate) was applied as an N control (Table 2).

Seeds were hand-planted two per hill on ridges 60 cm apart and with an in-row spacing of 20 cm. The plot size was 2.4 × 12 m, with four ridges per plot. The two cultivars used were Ashford, a late-maturing, spreading variety (Virginia type) and Barberton, an early-maturing, semibunch variety (Spanish type). Planting dates were the 18th and 19th of June in 1981, and the 16th and 17th of June in 1982 for Ashford and Barberton, respectively. Plots were irrigated approximately every 2 wk, depending upon rainfall. All plots were hand-weeded during the growing season to eliminate competition from weeds. Treatments were replicated four times in 1981 and five times in 1982.

TABLE 1

Soil characteristics (0 to 20 cm) of the experimental site at Wad Medani, Sudan[a]

pH	OC, g kg^{-1}	Total N, mg kg^{-1}	CEC, cmol(NH_4^+)kg^{-1}	EC	ESP	Sand	Clay
				ds m^{-1}		%	
8.4 (8.7)	4.7 (3.2)	473 (585)	50	0.52	3.6	21	55

[a] As reported by Glenn et al. (1969). Values in parentheses were determined for samples (0 to 15 cm) collected in 1981.

TABLE 2

Treatments applied to the Sudanese groundnut cultivars Ashford and Barberton during the 1981 and the 1982 growing seasons at Wad Medani, Sudan[a]

Treatment no.	Growing season	
	1981	1982
1	Uninoculated control	Uninoculated control
2	Nitrogen control[b]	Nitrogen control[b]
3	8A11 (peat)	8A11 (peat)
4	TAL 309 (peat)	TAL 309 (peat)
5	Peat mixture (5)[c]	Peat mixture (8A11 & TAL 309)
6	Peat mixture (5)[c]	Oil mixture (8A11 & TAL 309)
7	Peat mixture (10)[c]	8A11 (oil)
8	-	TAL 309 (oil)

[a] All treatments received a uniform application of macro- and micronutrients as shown below

Phosphorus: 40 kg P ha^{-1} (triple superphosphate)
Potassium: 40 kg K ha^{-1} (muriate of potash)
Sulfur: 45 kg S ha^{-1} (elemental sulfur)
Boron: 0.5 kg B ha^{-1} (Borax)
Iron: 0.5 kg Fe ha^{-1} (6% Fe in chelate)
Copper: 2 kg Cu ha^{-1} ($CuSO_4 \cdot 5H_2O$)
Manganese: 15 kg Mn ha^{-1} ($MnSO_4 \cdot H_2O$)
Zinc: 0.6 kg Zn ha^{-1} (14.2% Zn in chelate)

[b] Nitrogen: 120 kg N ha^{-1} (ammonium sulfate).

[c] Mixture of strains 8A11, TAL 309, 25B7, and 26Z6 applied at the sowing depth and at 5 and 10 cm below the seeding depth for treatments 5, 6, and 7, respectively, in 1981.

Methods of inoculation

The peat inoculants (1981 and 1982 seasons) were prepared in granular form at The Nitragin Co., Milwaukee, Wisconsin. The oil-base inoculants (1982 season) consisted of freeze-dried *Rhizobium* cells prepared by Drs. H. Peterson and R. Kremer at Mississippi State University, Starkville, Mississippi. Both inoculants were added at rates to give 10^7 viable *Rhizobium* cells per 2 groundnut seeds. Viable populations were determined in growth pouches (Weaver and Frederick 1972) by the most-probable-number (MPN) technique (Vincent 1970) with siratro (*Macroptilium atropurpureum*) as the test plant. Inoculants for the MPN tests were carried to the field during planting, handled similar to the applied inoculants, and then returned to the laboratory for determination of viable counts. The population of the native cowpea rhizobia, as determined on siratro, was 2.1×10^4 g^{-1} soil.

In all but the deep-placement studies, the peat inoculants were furrow-applied by hand at the sowing depth (5 cm below the soil surface). A scooping device was prepared that allowed the field workers to add a constant volume of the granular inoculant to each pair of groundnut seeds. The oil-base inoculant was seed-applied after the *Rhizobium* cells were suspended in groundnut oil (Kremer and Peterson 1982). Mixtures of the strains to give a total of 10^7 viable *Rhizobium* per two groundnut seeds in peat or oil-base carriers were applied at the seeding depth in the 1982 season. Seeds and applied inoculant were immediately hand-covered with soil after sowing and were irrigated within 24 h. For the deep-placement treatments (1981), a stick was used to open a furrow at 10- and 15-cm depths on top of each ridge where the peat inoculant was placed. The furrows were immediately filled with soil to within 5 cm of the soil surface, and the groundnut seeds were planted. The ridges were then completely reformed by hand to their original contour. In three locations in the plot area, Tempilabels were placed in plastic bags and buried (a) with the seed at a 5-cm depth and (b) 10 cm below the seed at a 15-cm depth. The uninoculated and N controls received neither peat nor oil.

Sampling and harvest

For assessment of the nitrogen-fixing traits, a section of row containing 12 plants, beginning 0.5 m from the end of the outer two rows, was sampled during the early flowering stage. Nodule counts, shoot dry weights, and Kjeldahl ni-

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trogen of the shoots were determined. Fifty representative nodules, 25 main root and 25 lateral root, were randomly selected from each treatment. The nodules were transferred to test tubes containing silica gel for desiccation and transported to the laboratory at Iowa State University for *Rhizobium* isolation and the determination of nodule occupancy.

Plot harvest was preceded by light irrigation to minimize pod losses. The plants in 10 m of the center two rows in each plot were dug for pod yield determinations. The harvests were approximately 90 and 120 d after sowing for Barberton and Ashford, respectively.

Determination of nodule occupancy

Agglutination reactions were used in identifying strains recovered from nodules. Antisera were prepared for strains 8A11, TAL 309, and a native strain from the research site. For antigen preparation, antiserum production, and agglutination reactions, the methods described by Vincent (1970) were followed, and titers of at least 1:1280 were obtained for each after rabbit injection. Results were reported as positive or negative agglutination.

Methods of statistical analysis

In the greenhouse screening, each strain was expected to act independently of other strains, and a multiple range test (Duncan) was used to evaluate data. In field evaluations, the cultivars were established in a split-plot design, with treatments assigned randomly to complete blocks within each cultivar (Table 2). The effects of year, cultivar, and treatment were evaluated by using single degree-of-freedom contrasts (Chew 1976; Nelson and Rawlings 1983). Treatment means were presented in separate tables, and standard errors were given as a measure of data precision. Thus, based on the contrast being evaluated, treatment means may appear in more than one comparison. Regression techniques were used in evaluating the depth of inoculant placement.

RESULTS AND DISCUSSION

The *Rhizobium* strains used as inoculants in the field were selected on the basis of greenhouse testing with the Sudanese cultivars Ashford and Barberton (Table 3). Significant differences were found among strains, mainly in color ratings and nodule numbers (both cultivars). Top dry weights, however, were less variable due to strains, and Ashford top weights were statistically the same among all the strains tested. We found greater differences with Barberton. Ashford is a Virginia-type seed, which is larger than the Spanish-type Barberton, and perhaps the greater seed reserves of Ashford minimized strain differences. Strains 8A11, TAL 309, 25B7, and 26Z6 seemed to be four of the better strains

TABLE 3

Greenhouse screening for nitrogen-fixing traits with the cultivars Ashford and Barberton

Treatment	Ashford			Barberton		
	Color	Top dry weight, g plant^{-1}	Nodule number, no. plant^{-1}	Color	Top dry weight, g plant^{-1}	Nodule number, no. plant^{-1}
Uninoculated control	2.0d[a]	0.60b	0.0e	2.4e	0.42cd	0.0c
Nitrogen control	5.0a	1.15a	0.0e	5.0a	1.24a	0.0c
Wad Medani	3.8abc	0.65ab	23.0cde	2.8e	0.45bcd	10.8c
Sennar	4.0abc	0.79ab	66.8abc	3.6cd	0.49bcd	31.2bc
26Z6	5.0a	0.67ab	43.2bcde	4.4abc	0.61bc	72.6a
8A11	5.0a	0.98ab	83.0ab	4.4abc	0.67bc	63.8a
USDA 3184	3.5bc	0.43b	26.5cde	3.0de	0.37d	17.8c
USDA 3187	3.0cd	0.55b	4.5de	2.6e	0.43cd	1.2c
25B7	5.0a	0.81ab	56.0bcd	4.4abc	0.77b	64.6a
USDA 3179	3.3bc	0.68ab	112.3a	3.8cd	0.44cd	75.0a
176A22	4.5abc	0.69ab	54.3bcd	4.0bc	0.50bcd	29.2bc
TAL 309	5.0a	0.94ab	64.8abc	4.8ab	0.73bc	47.6ab

[a] Values are averages of five replications; means within the same column followed by a common letter are not significantly different at the 0.05 level of probability by Duncan's multiple range tests.

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TABLE 4

Effect of the common treatments in 1981 and 1982 on the nitrogen-fixing traits of the cultivars Ashford and Barberton, Wad Medani, Sudan

Treatment	Nodulation				Yield					
	Number		Mass		Top dry weight		Tissue nitrogen		Pod	
	1981	1982	1981	1982	1981	1982	1981	1982	1981	1982
	no. plant^{-1}		mg plant^{-1}		g plant^{-1}		%		kg ha^{-1}	
Ashford										
Uninoculated control	72.6[a]	95.1	19.0	69.2	3.35	6.28	3.47	2.72	1743	1629
N control[b]	38.4	81.3	26.3	66.4	2.65	10.82	3.49	3.07	1899	1712
8A11	63.0	128.5	40.5	84.0	4.58	6.25	3.26	2.84	1698	1597
TAL 309	67.8	96.8	29.3	81.0	3.55	5.21	3.36	2.59	1632	1878
SE	10.9	7.8	3.8	3.6	0.31	0.69	0.07	0.08	69	87
Barberton										
Uninoculated control	52.0	69.8	17.3	50.0	2.90	4.58	3.82	2.67	1351	580
N control[b]	35.7	63.8	17.0	33.6	3.58	9.48	3.93	2.72	1438	910
8A11	46.7	61.9	18.5	55.6	3.18	5.12	3.63	2.68	1333	681
TAL 309	41.1	60.1	25.8	67.6	2.95	5.07	3.40	2.61	1455	674
SE	3.8	5.1	1.7	4.4	0.17	0.56	0.07	0.07	35	38

[a] Values are averages of four observations in 1981 and five observations in 1982.
[b] Added at sowing as ammonium sulfate $(NH_4)_2SO_4$ at 120 kg ha^{-1} N.

TABLE 5

Mean squares from analysis of variance and levels of significance based on F-tests for common treatments in 1981 and 1982

Source	*df*	Nodulation		Yield		
		Number	Mass	Top dry weight	Tissue nitrogen	Pod
Year (*Y*)	1	15 460**[a]	26 285**	215.4**	10.29**	5 916**
Cultivar (*C*)	1	13 764**	5 253**	10.6*[a]	0.08	25 883**
Treatment (*T*)	3	1 436	1 131**	29.2**	0.29*	333
Uninoculated vs. inoculated	1	31	1 544**	0.6	0.18	62
Nitrogen vs. inoculated	1	3 013*	2 479**	54.5**	0.77*	506
8A11 vs. TAL 309	1	655	14	3.1	0.12	163
$Y \times C$	1	1 736	912*	2.2	0.83*	5 341**
$Y \times T$	3	400	269	28.4**	0.05	72
$C \times T$	3	90	295	1.1	0.01	35
$Y \times C \times T$	3	473	66	1.9	0.11	272

[a] *,**indicate significance at the 0.05 and 0.01 levels, respectively.

on both cultivars, with good color ratings and high nodule numbers, and were selected for field application in 1981. Only two strains, 8A11 and TAL 309, were used in 1982, because the addition of the oil-base carrier dictated a reduction in the total number of strains tested.

Strains and cultivars

The number of nodules and nodule mass, top dry weights, and pod yields (Table 4) differed significantly between cultivars and between years (Table 5). The Ashford cultivar was better nodulated, and pod yields were consistently higher than those of the Barberton cultivar both years. The conditions for growth by early flowering in 1982 evidently were much better than in 1981, as indicated by top dry weights; however, N contents were lower in 1982. The lower N contents may be because of dilution of N by vegetative growth resulting in a lower percent-

age of N. When one considers the average total N in the shoots over both cultivars, the 1981 average (dry weight times percentage) was 122 mg N per plant, and the 1982 average was 181 mg N per plant. Because no visual growth abnormalities were present either year of the study, we cannot explain the better early growth in 1982.

Another apparent abnormality in the data is the low Barberton yields in 1982. We believe that the main factor was difficulty in extracting the nuts from the heavy clay soil. The moisture at time of harvest is critical, because the individual clods must be broken open by hand to expose the nuts. We believe that more nuts of the smaller seeded Barberton were left in the field, for they are more difficult to extract than the larger seeded Ashford. These are very important management problems facing growers of groundnuts in central Sudan. We were able to extract nodules more effectively from the soil than nuts, because we carried individual sections of soil with plants to a canal and carefully washed away the soil. This was not practical when harvesting nuts.

Inoculation resulted in increased nodule mass (Table 5), but did not improve top dry weights, tissue nitrogen, or pod yields. Most of the treatment differences were because of the nitrogen control, and the effects of nitrogen fertilization are well established in the literature (Mukhtar and Yousif 1979).

Inoculant carriers

In 1982, we evaluated peat versus oil-base carriers (Table 6). With Barberton, nodule mass and pod yields were significantly greater ($P < 0.01$) with the peat inoculum than with the oil inoculum (Table 7). With Ashford, both these traits, as well, were significantly greater with the peat inoculum, but significance was only at the 0.10 level (not shown in table 7). Top dry weights and tissue N were little affected by inoculant carrier. In an earlier study, Kremer and Peterson (1982) reported higher rhizobial populations from seeds inoculated with an oil carrier than from seeds inoculated with a peat carrier after exposure to 16 d of temperature-moisture stress. In this study, however, plots were irrigated within 24 h after sowing, which is the common irrigation practice of the region. Shelled groundnuts are very fragile for direct inoculation. The decreased nodule mass and pod yields of Ashford and Barberton with the oil-base inoculant may reflect an interference of the oil with germination or early growth of the plant. Barberton evidently was more sensitive than Ashford to oil application. Consistent differences were not found between single and mixed inoculants in any of the measured traits (Table 7).

Nodule occupancy data (Table 8) indicated that TAL 309 occupied 30 to 44% of the tested nodules and that differences between oil and peat carriers were insignificant. The Wad Medani isolates, obtained from the control plots, were serologically identical to 8A11, and agglutination reactions could not be used to determine 8A11 strain recovery. The peat carrier resulted in equal percentages of main- and lateral-root nodules occupied by TAL 309, but the oil carrier gave a higher percentage with lateral-

TABLE 6

Nodulation and yield parameters of peat and oil-base inoculants with the groundnut cultivars Ashford and Barberton, Wad Medani, Sudan, 1982

Treatment	Nodulation				Yield					
	Number		Mass		Top dry weight		Tissue nitrogen		Pod	
	Ashford	Barberton	Ashford	Barberton	Ashford	Barberton	Ashford	Barberton	Ashford	Barberton
	no. plant^{-1}		mg plant^{-1}		g plant^{-1}		%		kg ha^{-1}	
8A11										
Peat	128.5[a]	61.9	84.0	55.6	6.25	5.12	2.84	2.68	1597	681
Oil	100.4	66.7	72.4	45.2	5.18	4.83	2.65	2.54	1615	385
TAL 309										
Peat	96.8	60.1	81.0	67.6	5.21	5.07	2.59	2.61	1878	674
Oil	99.2	67.7	72.8	52.0	5.05	4.70	2.62	2.57	1299	500
8A11/TAL 309 mixture										
Peat	96.4	78.3	81.0	67.2	5.03	5.07	2.51	2.58	1743	684
Oil	104.2	90.5	75.6	56.0	6.21	5.57	2.27	2.50	1639	500
SE	4.5	3.8	1.9	2.5	0.40	0.34	0.05	0.04	52	31

[a] Values are averages of five observations.

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TABLE 7

Mean squares from analysis of variance and levels of significance based on F-tests for peat and oil-inoculant treatments

Variable	df	Nodulation				Yield					
		Number		Mass		Top dry weight		Tissue nitrogen		Pod	
		Ashford	Barberton	Ashford	Barberton	Ashford	Barberton	Ashford	Barberton	Ashford	Barberton
Treatment	7	876	504	175	626**[a]	18.3**	13.0**	0.15**	0.03	395	364**
Peat vs. oil	1	265	502	411	1153**	0.1	0.1	0.02	0.05	1110	1001**
Check vs. strains	1	360	5	281	226	2.5	0.8	0.02	0.04	1	1
Nitrogen vs. strains	1	2261	438	509**	2401**	120.6**	84.8**	0.79**	0.08	99	1410**
Single vs. mixed	1	236	2739*	4	282	0.6	0.6	0.02	0.02	149	18

[a] *,**indicate significance at the 0.05 and 0.01 levels, respectively.

TABLE 8

Groundnut nodule occupancy in the treatments receiving strain TAL 309, Wad Medani, Sudan, 1982

Inoculant carrier	Occupancy[a]	
	Main-root nodules	Lateral-root nodules
Peat	38.0 ± 4.7	36.0 ± 7.1
Oil	30.0 ± 2.0	44.0 ± 4.3

[a] Means ± SE of 50 nodules identified per treatment.

root nodules. The increase in strain TAL 309 recovery from the oil carrier in the lateral-root nodules may indicate late infection, not reflected in the measured nitrogen-fixing traits (Table 6). The oil carrier might have protected the rhizobia longer than the peat carrier.

Depth of inoculant placement

Deep placement of inoculants may reduce stress on the *Rhizobium* because of desiccation or high temperature. The 43°C spot on the temperature-sensitive labels changed color during burial. The labels were dug just before irrigation, and the 49°C spot had not changed color, indicating that neither the 5- nor the 15-cm depths were above 49°C before water was added. Results showed that, as the depth of inoculant placement increased, only top dry weights significantly improved (Table 9). (Both the linear and quadratic components for top dry weights were significant at $P < 0.05$ on the basis of F-tests, but inasmuch as no other regressions were significant, data are not shown in table format.) The increase in pod yields with depth was not significant, and the number of nodules per plant and the weight of nodules per plant were unaffected by placement depth. This disagreed with the weight-compensation phenomenon suggested by Schiffman and Alper (1968), where deep placement of inoculum resulted in higher nodule weights but decreased nodule numbers. Also, unlike the results in soil with no (Wilson 1975) or few (Marcarian 1982) rhizobia, the distribution of nodules along the root in this soil with a high indigenous population was not related to the depth of inoculant placement. Visual

TABLE 9

Placement depth of a mixed inoculant and nitrogen-fixing traits of groundnuts, Wad Medani, Sudan, 1981

Application depth, cm[a]	Nodulation		Yield		
	Number, no. plant^{-1}	Mass, mg plant^{-1}	Top dry weight, g plant^{-1}	Tissue nitrogen, %	Pod, kg ha^{-1}
0	43.0[b]	27.13	3.13	3.43	1639
5	58.0	22.00	3.31	3.39	1667
10	46.0	26.13	3.98	3.48	1754
SE	4.3	1.84	0.13	0.05	56

[a] Mixture of strains applied at planting with the seed (application depth equals 0, 5, and 10 cm below the seed).

[b] Values represent an average of eight observations; because there was no cultivar by depth interaction ($P < 0.05$), the observations for both cultivars Ashford and Barberton were pooled.

observations of the nodules indicated a rather uniform distribution throughout the rooting system.

CONCLUSIONS

Results of these studies failed to demonstrate decided advantages with inoculation, despite the use of methods reported to improve rhizobial survival. Although the soil contained 2.1×10^4 g^{-1} cowpea rhizobia, strain TAL 309 successfully competed for nodule sites with the indigenous rhizobia. Inasmuch as plant growth characteristics were not consistently improved, this suggests that the indigenous rhizobia were fixing nitrogen equal to the introduced strains or that other, unknown, factors were limiting groundnut production. Adding 120 kg N ha^{-1} resulted in improved growth parameters, indicating that not all the nitrogen requirements were being met by nitrogen fixation. The N-fertilized plots could be spotted with ease both years of the study by their greener and more robust growth at time of flowering.

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