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"Evaluation of Nitrogen Fixation in Bambara Groundnut Germplasm"

by

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EXECUTIVE SUMMARY

1. Research on nitrogen fixation in bambara groundnut [*Voandzeia subterranea* (L) Thouars] was funded in 1984 and 1985 by AID/W. The work was carried out in Senegal, a dry savanna zone, and Togo a humid zone in West Africa.
2. Several strains of rhizobia from NifTAL and Beltsville were evaluated for effectiveness to nodulate bambara groundnut in growth chamber and greenhouse studies in 1983 and 1984 at the University of Maryland Eastern Shore.
3. The best four strains TAL 169, TAL 651, TAL 642 and TAL 1380 were field tested in Senegal and Togo.
4. All four strains nodulated the two bambara groundnut cultivars and produced higher total dry matter and seed yield than the uninoculated control at both locations.
5. Thirty strains of rhizobia were isolated from nodules collected in fields in Nigeria, Togo, and Sengal in 1984 for evaluation in the laboratory, growth chambers and greenhouse at UMES.
6. TAL 169 and TAL 1380 the best strains from 1984 field trial, TMUN and TBAM, the two best native rhizobial strains from West Africa, MAO 11 and MAO 26 from MIRCEN laboratory at Bambey, Senegal, were evaluated in the field in 1985. The most effective

6. strains were the native rhizobial strains, namely, TMUN and MAO 11 from West Africa.

7. There was better nodulation and seed yield of bambara groundnut in Togo, the humid zone, than in Senegal, the dry zone.

8. Our work indicates the beneficial effect of inoculating bambara groundnut with native rhizobial strains.

9. 150 bambara groundnut germplasm were collected from Togo. Other collections from Senegal, Cameroon and Mali have been added to these in the IBPGR collection at Caccaveli in Togo.

10. 23 of these germplasm collections were evaluated in Togo in 1985 for yield and performance with and without nitrogen application.

11. The trial showed a great variation in response to nitrogen application. The addition of nitrogen suppressed nodulation and nodule dry weight, but enhanced total dry weight and seed yeield.

12. The germplasm collection from Togo had a higher relative efficiency for nitrogen utilization and would be useful sources for collection of rhizobia.

13. Our work should be extended to on-farm-trials in Togo and Senegal, at more locations, to ascertain the applicability of the results and to enable dissemination of information to the local farmers.

14. Linkages were developed with scientists and research institutes and centers in West Africa, notably IITA, Ibadan, Nigeria; Direction Recherche Agronome, Caccaveli, Togo; Institute Scientifique Recherche Agriculture, Dakar, Senegal; Center National Recherche Agriculture, Bambey, Senegal; ORSTOM, Dakar, Senegal; and Direction des Etudes Pedologiques et de L'Ecologie Generale, Lome, Togo.

15. Several Scientists at the research institutes in Togo and Senegal have expressed a willingness to collaborate in subsequent trials - on farm and at research stations.

16. Two papers have been submitted for publication in Tropical Agriculture and a third paper in Field Crops Research.

ACKNOWLEDGEMENTS

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"Evaluation of Nitrogen Fixation Efficiency In Bambara Groundnut Germplasm"

The bambara groundnut [*Voandezeia subterranea* (L.) Thouars] is a very important pulse crop in the semi arid zones of tropical and subtropical Africa. Very little has been done to improve the yield of the crop through breeding, investigations on cultural practices or nitrogen fixation. The small scale African farmer rarely uses fertilizer in growing his pulse crops, but relies on the inherent soil or symbiotically fixed nitrogen. Most soils in Africa are low in nutrients, especially nitrogen. A more efficient N_2 - fixation of the bambara groundnut in those areas where the crop is grown would help to increase the yield of the crop and offer a greater food security to rural Africans. Other benefits of an efficient N_2 - fixation in bambara groundnut would be a reduction in the cost of nitrogen for ensuing crops grown in rotation with the legume, and the production of better quality and high protein food.

We, therefore, initiated a series of studies at the University of Maryland Eastern Shore, Princess Anne, Maryland , USA; Direction Recherche Agronome, Caccaveli/Ativeme, Togo; and the Centre National Recherche Agriculture, Bambey, Senegal with the goal of improving bambara groundnut yields.

OBJECTIVES

The objectives of our work on bambara groundnut were:

(i) Collect and evaluate bambara groundnut land races for high yield and other agronomic characteristics.

(ii) Collect, isolate and evaluate strains of rhizobia from West African soils.

(iii) Establish effective rhizobial strains for specific bambara groundnut genotypes or cultivars.

(iv) Determine nitrogen utilization efficiency of bambara groundnut germplasm.

JUSTIFICATION

The project was conceived with a regional focus in West Africa. Budgetary constraints, however, limited the trials to two countries. These were Senegal and Togo, which represented a dry savanna zone and a humid zone, respectively. The results of our work were expected to be applicable to the important growing areas in West Africa and lead to increases in nitrogen fixation and yield of bambara groundnut.

In spite of the importance of this crop in the farming system in the region and the interest expressed by several national and international crop research centers, notably, the International Institute of Tropical Agriculture (IITA), there is no major research program to improve the yield of the crop. Considering the high cost of nitrogen fertilizer, our work leading to the identification of germplasm with highly efficient nitrogen fixing ability and nitrogen utilization will provide a means of supplying a cheap source and better utilization of nitrogen for increased crop production. We were also encouraged to initiate our work as a result of the interest scientists at IITA, Senegal and Togo expressed in the project.

LITERATURE REVIEW

Very little has been reported in the literature on inoculation with rhizobia, or nodulation and nitrogen fixation in bambara groundnut. Johnson (1966) pointed out that there was no real need for inoculation of bambara groundnut since it nodulates freely. Stanton (1968), however, reported that it is benefical to inoculate a new field with soil from an old field in which bambara groundnut had been previously planted. Doku (1968) reported that there was good nodulation on bambara groundnut in a cross inoculation test using rhizobia from other bambara groundnut, soybean and lima bean. Dennis (1977) found good nodulation of uninoculated bambara groundnut grown in different soils.

Although bambara groundnut is well adapted to soils of low fertility (Stanton, 1968) the addition of nitrogen to savannah ochrosol at planting time or later was recommended by Johnson, (1966). The farmers in Africa rely mainly on the inherent soil or symbiotic nitrogen fixation to grow the crop. In crops, such as cowpeas, it has been found that different varieties show differences in response to nitrogen application (Ahmad *et al.*, 1981). The varieties with high efficiency of nitrogen utilization are those which also show greater efficiency of host-rhizobia association. Knowledge of relative efficiency of nitrogen utilization may be used

to select bambara groundout cultivars with greater nitrogen utilization as well as effective host-rhizobia association.

I. EVALUATION OF NODULATION OF BAMBARA GROUNDNUT BY RHIZOBIAL STRAINS FROM NifTAL AND OTHER SOURCES: LABORATORY AND FIELD TRIALS (1984)

PROCEDURES

Growth Chamber Trial

Inoculation trails with elite rhizobial strains from NifTal (Table 1) and bambara groundnut seeds from West Africa were conducted in Leonard jar assemblies in the growth chamber at the University of Maryland Eastern Shore. The Leonard jar assemblies were prepared by filling the bottle with medium grade vermiculite up to one inch from the top of the inverted bottle. The lower part of the assembly was filled with nutrient solution and the whole wrapped in alumnium foil and sterilized by autoclaving at 15 psi for 45 minutes. Selected bambara groundnut seeds were surface sterilized by soaking in a 3% solution of sodium hypochlorite for 10 minutes and rinsed with 6 changes of sterile distilled water. The seeds were allowed to imbibe sterile water for one hour and then rinsed twice. The seeds were transferred into cooled sterilized enamel germination trays with lint cotton. Five days later three healthy looking pregerminated seeds were planted in the Leonard jar assembly and covered with half inch layer of perlite. Five days after sowing, the seedlings were thinned to one per jar. Inoculation was performed

TABLE 1. Rhizobium strains used in screeing trial

NifTAL	Host of Isolate
TAL 1380	*Crotalaria pavlina*
TAL 651	*Calopogonium muconoides*
TAL 169	*Vigna unguiculata*
TAL 1000	*Arachis hypogaea*
TAL 309	*Macrotyloma africanum*
TAL 437	*Vigna radiata*
TAL 642	*Lablab purpureus*

immediately by pippeting 3ml of turbid culture suspension (10^9 CFU/ml) grown in yeast extract manitol broth (Vincent, 1970). There were two control treatments, namely, one in which plants were not inoculated and a second in which uninoculated plants received 0.05% KNO_3 in the nutrient solution to give an N concentration of 70 ppm. Each inoculation control treatment was replicated three times. The jars were housed in a temperature controlled growth chamber at 30/25°C day/night and daylength of 12 hours. The jars were arranged in the growth chamber in a randomized block design and were replinished with nutrient solution every five days for 14 weeks.

During the growth of the plants, notes were taken on color of leaves. Eight weeks after planting samples were harvested by carefully washing the roots out of the jar and the plant was separated into component parts. Nodules were counted and all plant parts were oven dried at 80°C for 24 hours and weighed when fully dry, and then ground in a Wiley mill for the determination of N content by microKjeldahl method (Yoshida *et al.*, 1976).

Greenhouse Trial

The study was repeated in the greenhouse using the same procedure as in the growth chamber. 3.8 liter size plastic bottles were used in preparation of the modified

Leonard jar assemblies. The lower portion of the plastic bottles was covered with aluminum foil to prevent excessive heating of nutrient solution. Two bambara groundnut varieties, Ada, a small seeded variety from Southern Ghana, and Kara, a large seeded Northern Togo type were used in the greenhouse trial. Greenhouse temperature ranged between 30 to 35°C and daylength was maintained at 12 hours. Similar data, as before, were collected at 35 days after planting.

Field Trials

The four most effective strains were selected for field trials which were located at Ativeme, Togo, on a virgin land of sandy loam soil on the farm of the Direction Recherche Agronome and the second trial was located by Bambey, Senegal, on a free draining sandy soil which had carried sorghum or millet the five previous years at the centre National Recherche Agriculture. A replica of these trails was also located at the Experimental Station, University of Maryland Eastern Shore. Rainfail data in 1984 and 1985 for the two growing seasons are reported in Table 2, and soil analysis at Ativeme is reported in Table 3.

The Ada and Kara varieties of bambara groundnut were used in the field trial. Selected seeds, presoaked for twenty four hours to enhance germination, were

planted on ridges in four row plots which measured 4m long and 0.3 m between ridges with a plant spacing of 0.2m. Before planting, the seeds were placed in plastic pouches followed by sterilized finely ground wood bark and where required, inoculant cultures in yeast extract mannitol broth were placed in the pouch and the contents mixed thoroughly. Two seeds were planted in 5cm deep holes into which was sprinkled a teaspoon of the rhizobial culture in ground wood bark in the rhizobial treated plots. The seedlings were thinned to one 10 days after planting.

Four rhizobial cultures representing four treatments and two control treatments represented by uninoculated bambara seeds and uninoculated seeds which received 50 kg N per hectare were used in a split plot design with varieties as main plots and rhizobia and nitrogen fertilizer as sub-plot treatments. One week after planting all plots received 60kg P/ha and 80kg k/ha. The nitrogen treatment was applied at the time of thinning the seedlings. Plots were maintained by regular hoeing to clear weeds and sprayed against insects.

Plant samples were taken 25 days after planting at flowering by digging up the whole plant and the roots and carefully removing all soil attached to the roots. Nodule counts were made and plant parts dried at 80°C

TABLE 2. RAINFALL DISTRIBUTION AT ATIVEME, TOGO AND BAMBEY, SENEGAL DURING THE GROWING SESSION

PERIOD		RAINFAIL AMOUNT (mm)			
		Ativeme	Bambey	Ativeme	Bambey
June	1-10	42.8	2.8	36.0	0.0
	11-20	48.1	86.0	32.8	0.0
	21-30	13.9	28.2	23.0	30.5
July	1-10	19.9	9.5	141.4	9.6
	11-20	127.6	3.0	30.5	51.7
	21-31	42.0	58.2	6.5	15.5
August	1-10	25.0	73.0	86.3	30.0
	11-20	27.9	49.5	32.3	83.5
	21-31	23.1	7.0	0.0	40.5
September	1-10	38.3	36.0	59.9	45.0
	11-20	54.1	50.3	86.4	50.7
	21-30	49.2	26.2	21.1	2.3
October	1-10	105.1	7.9	24.7	13.5
	11-20	19.7	0.0	88.0	0.0
	21-31	12.5	0.0	33.4	0.0
	TOTAL	**649.2**	**437.6**	**702.3**	**372.8**

TABLE 3. SOIL DATA OF TEST SITES

			Ativeme	Bambey
		Total		
1.	Organic		1.43%	-
	Matter	N	0.80%	
2.	Minerals	Ca	50.89	-
	exchangeable	Mg	21.98	-
	(meg 100g)	K	0.93	-
3.	Minerals	Na	1.72	-
		P_2O_5(%)	2.94	-
4.	pH	Water	6.23	-
		KCL	5.36	-

for 24 hours and weighed. At maturity, plants were harvested to determine total dry matter and seed yield.

RESULTS

Growth Chamber Trial

The nodulating ability of the different rhizobial strains and their effects on bambara groundnut are shown in Table 4. The rhizobial strains significantly increased nodule number, nodule dry weight shoot dry weight, seed per plant and nitrogen content ($P < 0.01$). Strain TAL 1380 and TAL 169 ranked consistently higher than most of the other treatments in their effects on all characters. Inoculated plants had darker green luxuriant folliage while uninoculated control plants had lighter green and small leaves.

Greenhouse Trial

Results of the greenhouse trial were similar to the growth chamber trial (Table 4). The results of this study as shown in Table 5 indicate that all 6 strains from NifTAL nodulated both bambara groundnut cultivars. This finding confirms the suggestion by Dennis (1977) and Burton (1952) that the bambara groundnut is a promiscuous host for rhizobia from various legumes. All treatments produced dark green luxurious foliage except the uninoculated controls and the Kara variety treatment of TAL651, which produced smaller, lighter green leaves.

TABLE 4. MEAN EFFECTS OF RHIZOBIAL STRAINS ON NODULATION AND PERFORMANCE OF BAMBARA GROUNDNUT GROWN IN GROWTH CHAMBERS INOCULATED WITH RHIZOBIAL STRAINS AT UMES

Strain or Treatment	Nodule number/ plant	Pod number/ plant	Nodule dry wt./ plant (g)	Shoot dry wt./ plant (g)	Seed dry wt./ plant (g)	Percent Nitrogen	Total N(mg)
Uninoculated	.00f**	1.93d**	0.00c**	1.33b**	0.52d**	1.30c**	17.29c**
Nitrogen	.00f**	2.24d	0.00c	1.76b	0.60d	1.50c	26.40c
TAL 169	12.59b	4.58b	0.16a	4.42.a	1.61bc	2.63a	116.25a
TAL 1000	14.77a	3.84c	0.16a	3.28a	1.11c	2.61a	85.61ab
TAL 651	12.17b	3.68c	0.01ab	3.73a	2.62a	1.61bc	60.05b
TAL 309	10.87c	3.52	0.12ab	3.62a	2.04b	2.09ab	75.66ab
TAL 642	8.81d	3.98c	0.12ab	3.99a	1.15c	2.57a	102.54a
TAL 437	6.27e	4.29bc	0.08b	3.15a	1.21c	2.13ab	67.10b
TAL 1380	13.91a	5.38a	0.15a	4.34a	2.51c	2.48d	107.63a

**Means within a column with the same letter are not significantly different, according to Duncan's new multiple range test.

$p<0.01$

The TAL651 treatment was more effective with the Ada variety producing significantly more shoot weight and total N than the uninoculated control.

The best measure of effectiveness of nodulation was the measure of the N accumulation in the plants. all treatments except TAL651 significantly increased the N concentration in the Kara variety over the uninoculated control and TAL1380 was as effective (total N of 101.4 mg) as the +N control (total n of 93.0 mg). The Ada variety was very effectively nodulated by TAL169, TAL1380, TAL309 and TAL642 as plants having received these treatments contained significantly more nitrogen than the +N control plants and therefore seemed to be the variety of the two which benefits more from inoculation. No strain invluenced a significantly higher accumulation of N than the +N control for the Kara variety.

With exception of the TAL651 treatment on the Karva cutivar, all NifTAL strains of rhizobia studied elicited significant responses by increasing the shoot weight and/or increasing the total N content over the uninoculated controls (Table 5). As had been found in other legumes (Elkan et al., 1981; Wynn et al., 1980a), the effectiveness of root-nodule bacterial strains is significantly influenced by host cultivar; and there was

TABLE 5. Total nitrogen, shoot dry weight, and nodular weight and number of bambara groundnuts as influenced by inoculation of elite strains of rhizobia.

Treatment	Total N (mg) *	Shoot dry weight (g) *	Nodule number/ plant *	Nodule dry weight (mg plant $^{-1}$)*
Kara Vareity				
TAL1380	101.4 a	3.32 a	88 b	184.4 ab
N control	93.0 a	2.64 bc	0 e	
TAL437	63.6 bc	2.88 ab	85 bc	141.9 bc
TAL169	56.6 bcd	2.30 cd	84 bc	79.0 c
TAL642	55.6 bcd	2.04 de	81 bc	146.8 bc
TAL309	52.8 bcd	2.44 bcd	62 c	69.7 d
TAL651	28.6 de	1.72 ef	22 de	40.0 d
uninoculated control	15.2 ef	1.00 gh	0 e	
Ada variety				
TAL1380	61.0 bc	2.00 def	83 bc	202.9 a
N control	33.0 e	1.40 fg	0 e	
TAL437	32.6 e	1.38 fg	29 d	66.8 d
TAL169	67.6 b	2.02 def	117 a	175.7 ab
TAL642	62.2 bc	2.06 cde	82 bc	197.1 ab
TAL309	58.6 bcd	1.94 def	79 bc	161.5 ab
TAL651	33.6 de	1.40 efg	67 bc	88.0 cd
uninoculated control	8.2 f	0.48 h	0 e	

*Means followed by common letters within a column are not significantly different at the 5% level of probability as determined by Duncan's Multiple Range Test.

a significantly greater response of the Ada variety than by the Kara variety to strains TAL 169, TAL1380, TAL309 and TAL642 whose respective N accumulations surpassed those gained even by the mineral N controls.

Field Trial

Inoculation of bambara groundnut with the elite rhizobia strains in 1984 at Ativeme produced significantly more nodules and nodule dry weight per plant than the uninoculated and nitrogen treated plots as 25 days after planting (Table 6). Rhizobial strains TAL 1380 and TAL 169, and the nitrogen treatment produced similar shoot dry weight per plant, but only the effect of strain TAL 1380 was significantly greater than strains TAL 651 and TAL 642 and the uninoculated treatments. There were no significant differences between the two bambara groundout varieties and no significant variety and rhizobia treatment on nodule numbers, nodule dry weights and shoot dry weight per plant at 25 days after planting at Ativeme.

At flowering, variety and inoculation effects and their interactions on nodule umber, nodule dry weight and shoot dry weight per plant were significant (Table 7). Inoculated bambara groundnut produced significantly higher mean nodule number on Kara variety than strain TAL 651 and the nitrogen and uninoculated treatments

TABLE 6. Mean effects of rhizobia on nodule number, nodule dry weight (g), and shoot dry weight (g) of bambara groundnut 25 days after planting at Ativeme in 1984.

Treatment	Nodule number/ plant	Nodule dry weight (g)/ plant	Shoot dry weight (g)/ plant
Uninoculated	3.33b**	0.09b*	4.50C**
Nitrogen	2.63b	0.07b	5.29abc
TAL 169	13.00a	0.13a	5.87ab
TAL 642	13.90a	0.12a	5.04bc
TAL 651	15.46a	0.12a	4.85bc
TAL 1380	14.90a	0.14a	6.30a

Means within a column with the same letter are not significantly different according to Duncan's new multiple range test.

*P<0.05

**P<0.01

produced. Strain TAL 1380 produced significantly greater nodule numbers on Ada variety than strains TAL 642, TAL 169 and the nitrogen treated and uninoculated plants. However, the application of strains TAL 169 and TAL 642 only caused significantly greater differences in mean nodule numbers between the Kara and Ada varieties. The mean effects of all rhizobial strains on nodule dry weight were significantly different from the nitrogen and uninoculated treatment. (Table 7). Rhizobial strains TAL 169 and TAL 1380 produced similar nodule dry weights, but the effects of the two strains were significantly different from strains TAL 651 and TAL 642. Nodule dry weights produced by the rhizobial strains on Kara variety were similar. These effects were significantly different from the effects caused by the nitrogen and uninoculated treatments. The effects of all treatment on nodule dry weight produced on Ada were similar. Differences in nodule dry weight produced by the rhizobial strains on Kara and Ada varieties were significant. The mean shoot dry weight of bambara groundnut produced by the application of strain TAL 1380 was significantly different from the shoot dry weights of nitrogen treated and uninoculated plants. The rest of the treatments produced similar bambara groundnut shoot dry weight. The application of rhizobial strain TAL 1380 significantly increased more shoot dry weight

of Kara variety than the application of strain TAL 169, nitrogen and uninoculated plants. Shoot dry weight of Ada varieties were similar for all treatments. The differences in shoot dry weight of Kara and Ada varieties for all treatments were significant.

Seed yields of rhizobia and nitrogen treated bambara groundnut were significantly different from the yield of the uninoculated plants (Table 7). Bambara groundnut which received rhizobial strain TAL 1380 produced significantly greater seed yield than the plants which received nitrogen. Inoculation of Kara variety with strains TAL 1380 and TAL 642 produced significantly greater seed yield per hectare than inoculation with strain TAL 651, nitrogen application and uninoculated treatments. Similarly, the effects of strains of TAL 1380 and TAL 651 on seed yield of Ada variety were significantly greater than the nitrogen application and uninoculated plants. The differences between seed yield of Kara and Ada varieties were significant only with the application of strains TAL 642 and TAL 1380.

There was a significant and positive correlation between nodule number and shoot dry weight ($r = 0.96$, $P<0.01$) and total dry matter ($r = 0.98$, $P<0.01$). Both Ada and Kara varieties showed highly significant and positive correlations between nodule number and shoot dry weight and total dry matter.

TABLE 7

Effects of rhizobial strains on nodule number, nodule dry weight (g), shoot dry weight (g) at flowering, and seed yield (kg) at maturity of Kara and Ada varieties of bambara groundnut grown at Ativeme in 1984

Treatment	Nodule number/plant				Nodule dry weight (g)/plant				Shoot dry weight (g)/plant				Seed yield (kg/ha)			
	Kara	Ada	Inoculation Mean	Variety difference	Kara	Ada	Inoculation Mean	Variety difference	Kara	Ada	Inoculation Mean	Variety difference	Kara	Ada	Inoculation Mean	Variety difference
Uninoculated	4.74c	6.05c	5.40b	-1.31NS	0.19b	0.06a	0.13c	+0.13NS	11.00bc	2.25a	6.03b	+8.75*	916c	404c	660c	+512NS
Nitrogen	3.78c	4.84c	4.13b	-0.70NS	0.17b	0.08a	0.13c	+0.09NS	10.37c	2.88a	6.62b	+7.49*	1664b	1188b	1426b	+476NS
TAL 169	31.00a	11.60c	21.30a	+19.40**	0.50a	0.08a	0.29a	+0.42**	10.92bc	3.45a	7.18ab	+7.47*	1980ab	1516ab	1748a	+464NS
TAL 642	22.74ab	12.60bc	17.67a	+10.14**	0.30ab	0.08a	0.19b	+0.22**	13.15ab	2.63a	7.89ab	+10.52*	2363a	1576ab	1969ab	+788*
TAL 651	20.30b	21.27ab	20.79a	+ 0.93NS	0.31ab	0.10a	0.21b	+0.21**	12.20abc	2.74a	7.45ab	+9.46*	1963b	1601a	1782ab	+362NS
TAL 1380	25.00ab	22.22a	23.61a	+ 2.78NS	0.48a	0.09a	0.29a	+0.39**	13.78a	2.97a	8.38a	+10.81*	2693a	1899a	2296a	+794*
LSD				9.44				0.15				7.07				672

Means within a column with the same letter are not significantly different according to Duncan's new multiple range test.

* $P < 0.05$

** $P < 0.01$

Inoculation of bambara groundnut at Bambey in 1984 with rhizobial strain TAL 1380 produced significantly higher nodule number than the uninoculated plants 25 days after planting (Table 8). All rhizobia treated plants produced significantly more shoot dry weight than the nitrogen treated and uninoculated bambara groundnut plants. At flowering the rhizobia treated plants had significantly greater nodule dry weight than the nitrogen treated and uninoculated plants. Rhizobial strain TAL 1380 was significantly more effective in producing more nodule dry weight than strain TAL 651. Seed yield was significantly greater from plants treated with strain TAL 1380 than the uninoculated plants.

TABLE 8. Mean effects of rhizobial strains on nodule number, nodule dry weight (g), shoot dry weight (g), and seed yield (kg) of Kara variety of bambara groundnut at Bambey in 1984.

	25 days after planting		Flowering		Maturity
Treatment	Nodule number/ plant	Shoot dry weight plant (g)	Nodule dry weight/ (g)	Shoot dry weight/ (g)	Seed Yield kg/ha
Uninoculated	1.63b**	0.73b*	0.08c	1.86a	528b*
Nitrogen	2.57b	0.71b	0.02c	2.11a	1221ab
TAL 169	7.23ab	2.31a	0.30ab	3.36a	1605ab
TAL 642	4.44b	2.21a	0.28ab	3.47a	1533ab
TAL 651	7.07ab	2.25a	0.22b	3.46a	1665ab
TAL 1380	10.82a	2.31a	0.38a	3.48a	2187a

Means within a column with the same letter are not significantly different according to Duncan's new multiple range test.

*P<0.05

**P<0.01

II. COLLECTION, ISOLATION AND EVALUATION OF NATIVE RHIZOBIA FROM WEST AFRICA.

The aim of this work was to search for efficient native rhizobial strains from West Africa for the bambara groundnut.

PROCEDURE

Between June 23 and July 20, 1984, field collections of nodules were made from several legume species in Togo, IITA in Nigeria, and Bambey and its vicinity in Senegal. The procedure described by Vincent (1970) for field collection of rhizobia was followed. Hosts of isolation for those studied are listed in Table 9. After washing and surface sterilization, the nodules were squashed and the contents dropped onto agar slants and kept in a cool dry place for the isolate to incubate for about three weeks as we travelled through West Africa. Agar plates of the isolates were made in the laboratory. A total of 30 slow and fast growing isolates were obtained and some have been tested in the laboratory and greenhouse for their ability to nodulate and effectively fix nitrogen in association with bambara groundnut in growth pouches and Leonard jar assemblies.

TABLE 9. Total nitrogen, shoot dry weight and nodular weight and number of bambara groundnuts (Ada) as influenced by inoculation of indigenous strains of rhizobia.

Treatment	Host of Isolation	Total N (mg) *	Shoot dry weight (g) *	Nodule number/ plant	Nodule dry weight (mg plant $^{-1}$) *
TMUN	*Vigna mungo*	59.6 a	2.72 a	170 a	125 a
TBAM	*Voandzeia subterranea*	30.0 ab	1.36 b	117 a	93 ab
+N control		26.0 b	.93 bc	0 b	--
TPEA	*Arachis hypogaea*	18.3 bc	0.87 bc	36 b	40 b
SCOW	*Vigna unguiculata*	17.3 b	0.90 bc	3 b	10b
TCEN	*Centrosema pubescens*	133.0 c	0.75 c	19 b	22 b
TCRO	*Crotalaria juncea*	12.3 c	.81 bc	20 b	38 b
SARA	*Arachis hypogaea*	10.7 c	0.64 c	13 b	63 b
TSOY	*Glycine max*	10.7 c	0.66 c	5 b	9 b
NKAS	*Kerstingiella sp*	10.7 c	0.65 c	9 b	4 b
SSPH	*Sphenostylis stenocarpa*	10.3 c	0.70 c	18 b	24 b
NBAM	*Voandzeia subterranea*	9.7 c	0.55 c	22 b	24 b
TCAJ	*Cajanus cajan*	7.7 c	0.45 c	13 b	16 b
TPEU	*Pueraria phaseoloides*	5.0 c	0.37 c	0 b	--
uninoculated control		5.0 c	0.36 c	0 b	--

The first letter of the code name for each rhizobial strain is the beginning letter of the country of origin, i.e. T-Togo, S-Senegal, and N-Nigeria

*Means followed by common letters within a column are not significantly different at the 5% level of probability as determined by Duncan's Multiple Range Test.

RESULTS OF SYMBIOSES OF WEST AFRICAN WILD STRAINS WITH THE ADA GENOTYPE

Unfortunately the rhizobia isolated from soils in Nigeria and Senegal were totally ineffective with cultivar Ada. Nodulation was poor, and no strain of rhizobia from legumes of these two countries had significantly higher N accumulation in their shoots, nor was the mean plant dry weight significantly heavier than the nodules formed were pale, small and scattered throughout on lateral roots. However, since we did not simulate the environmental conditions of the soil from which these isolates were obtained, our ecological conditions may have been adverse to conditions in which effective nodulation occurs for the respective rhizobia-legume association.

Two isolates from Togo showed good responses (Table 9). TMUN nodulation resulted in the mean total N content and shoot dry weights being significantly greater than those of the +N and uninoculated controls. TBAM nodulated well and the total and shoot dry weights of plants inoculated with this strain were significantly greater than those of the uninoculated control. While wild strains of rhizobia from *Arachis hypogaea, Centrosema pubescens, Cajanus cajan, Glycine max* and *Crotalaria juncea* did nodulate the bambara groundnuts, nodulation was ineffective.

Rhizobia isolated from Pueraria phaseoloides failed to nodulate the bambara groundnut. However, nodulation tests on the original hosts were not run and since this is the only certain method of identifying rhizobia, strains from these hosts can not be ruled out as potential inoculants for V. subterranea. Also since P. phaseoloides satisfactorily nodulates in very acidic soils (Lanarau et al., 1953), the isolates obtained from this plant may effectively nodulate if soil conditions are more acidic.

COMPARATIVE EVALUATION OF EFFECTS ON NODULATION OF BAMBARA GROUNDNUTS BY NifTAL AND INDIGENOUS STRAINS OF RHIZOBIA (1985)

Results of field trials in 1984 and greenhouse trials in that same year influenced the choice of inoculating bambara groundnuts in 1985 with TAL 1380, TAL 169, TMUN and TBAM. Two indigenous cowpea strains, MAO 11 and MAO 26 provided by Dr. Mamadou Gueye were also included in the 1985 study. Experimental procedures used were unchanged from those used in 1984.

In the trial at Ativeme in 1985 using the above inoculants, nodule number and shoot dry weight 25 days after planting were not significantly different. However, these traits and nodule dry weights at flowering, and seed yield at maturity were significantly influenced by the rhizobial strains. Inoculation of

bambara groundnut with West African rhizobia, TMUN, TBAM, MAO 11 and MAO 26 produced significantly more nodules than NifTAL strains TAL 169 and TAL 1380 which in turn produced more nodules than the nitrogen and uninoculated treatments (Table 9a). Nodule dry weights produced by plants inoculated with TMUN and MAO 11 were significantly higher than from the nitrogen and uninoculated control plants. Bambara groundnut inoculated with rhizobial strains produced higher shoot dry weight than the nitrogen treated and uninoculated plants. The effect of strain MAO 11 on shoot dry weight was significantly greater than TAL 1380 and TAL 169. Inoculation of Kara variety produced significantly different shoot dry weight while the Ada variety gave similar response to all treatments (Table 9a). The differences between the two varieties in shoot dry weight from rhizobia and nitrogen treatments were all significant.

Rhizobia treated plants produced significantly higher grain yield and total dry matter per plant than uninoculated plants (Table 10). Strain TMUN produced significantly greater grain yield per plant than all treatments except MAO 11. There was also a significant variety and strain interaction. The effects of inoculation with strain TMUN on total dry matter was similar to MAO 11 and MAO 26, but superior to the other

TABLE 9A. EFFECTS OF RHIZOBIAL STRAINS ON NODULE NUMBER, NODULE DRY WEIGHT (G) AND SHOOT DRY WEIGHT (G) AT FLOWERING OF BAMBARA GROUNDNUT VARIETIES GROWN AT ATIVEME IN 1985

Treatment	Nodule number/ plant	Nodule dry weight/ plant (g)	Shoot dry weight/plant (g)			
			Kara	Ada	Inoculation Mean	Variety Difference
Uninoculated	6.05c	0.01b	1.01b**	0.71a	0.82c**	+ 0.21NS
Nitrogen	6.16c	0.01b	1.33b	0.75a	1.04c	+ 0.58**
TAL 169	13.59b	0.03ab	1.99ab	0.62a	1.31b	+ 1.37**
TAL 1380	13.70b	0.03ab	1.89ab	0.80a	1.35b	+ 1.09**
TMUN	17.91a	0.06a	2.24a	0.72a	1.48b	+ 1.52**
TBAM	16.03a	0.05ab	2.16a	0.71a	1.44ab	+ 1.45**
MAO 11	16.00a	0.05a	2.28a	1.00a	1.64a	+ 1.28**
MAO 26	16.00a	0.05ab	2.28a	0.65a	1.47ab	+ 1.64**
LSD						0.44

Means in a column or variety followed by the same letter are not significantly different according to Duncan's new multiple range test.

**P < 0.01

TABLE 10. EFFECTS OF RHIZOBIAL STRAINS ON TOTAL DRY WEIGHT (G) AND SEED YIELD (KG) AT MATURITY OF BAMBARA GROUNDNUT VARIETIES GROWN AT ATIVEME IN 1985

	Total dry weight/plant (g)				Seed yield kg/ha			
Treatment	Kara	Ada	Inoculation Mean	Variety Difference	Kara	Ada	Inoculation Mean	Variety Difference
Uninoculated	61.83c**	59.77c**	60.80c**	+ 2.06NS	742d**	396d**	569f**	+ 346NS
Nitrogen	73.26a	65.92ac	69.59b	+ 7.34	2003bc	1873a	1938c	+ 130NS
TAL 169	71.45a	68.25bc	69.85b	+ 3.02NS	2167b	1318b	1743d	+ 849**
TAL 1380	75.44a	61.87bc	68.66b	+ 13.57**	2448a	870c	1659d	+ 1578**
TMUN	75.76a	70.69a	73.23a	+ 5.07NS	2665a	1931a	2298a	+ 743**
TBAM	74.21a	65.02bc	69.62b	+ 9.19**	2084bc	1860a	1972bc	+ 224NS
MAO 11	73.16a	66.93ab	70.05ab	+ 6.23NS	2482a	1807a	2145ab	+ 675**
MAO 26	70.88a	70.71a	70.80ab	+ 0.17NS	1888c	892c	1390e	+ 996**
LSD				6.73				660

Means in a column or variety followed by the same letter are not significantly different, according to Duncan's new multiple range test.

** $P < 0.01$

strains and the nitrogen and uninoculated treatments. The differences in dry matter yield between Kara and Ada varieties were significant when rhizobial strains TAL 1380 and TBAM and nitrogen were applied. The application of rhizobial strain TMUN produced significantly greater grain per hectare than the other strains except MAO 11. There was a significant variety and inoculation interaction which caused the application of strains TAL 169, TAL 1380, TMUN, MAO 11 and MAO 26 to produce significantly greater differences in yield of Kara compared to Ada variety.

The Ada variety in 1985 had a poor emergence at Bambey and was excluded from the data presented in Table 11. Inoculation of bambara groundnut with rhizobial strains TBAM, TAL 169 and TAL 1380 produced significantly greater nodule volume than the nitrogen and uninoculated control treatments. Inoculation of bambara groundnuts with the other rhizobial strains, however, produced similar nodule volume to the two control treatments. The effect of rhizobial strain TAL 1380 on shoot dry weight was significantly higher than all other treatments ($P < 0.01$). The other rhizobial strains were similar in their effects on shoot dry weight but only strain TBAM and MAO 11 produced significantly greater bambara groundnut total dry weight than all treatments. The effects of strain MAO 11 on

TABLE 11. EFFECTS ON RHIZOBIAL STRAINS ON NODULE VOLUME (ML), SHOOT DRY WEIGHT (G) AND TOTAL DRY WEIGHT (G) OF BAMBARA GROUNDNUT AT BAMBEY (1985)

Treatment	Nodule volume/ plant (ml)	Shoot dry weight plant (g)	Total dry weight/ plant (g)
Uninoculated	0.02c**	1.32c**	1.35d**
Nitrogen	0.02c	1.32c	1.45d
TAL 169	0.04ab	1.74bc	1.87bd
TAL 1380	0.04ab	2.87a	3.00a
TMUN	0.03bc	1.57bc	1.68bd
TBAM	0.05a	1.98b	2.36ab
MAO 11	0.03bc	2.04b	2.14bc
MAO 26	0.03bc	1.85bc	1.95bd

Means in a column followed by the same letter are not significantly different from each other according to Duncan's new multiple range test.

**$P < 0.01$

total dry weight per plant was significantly different from the two control treatments. The remaining rhizobial strains had similar effects.

In the 1985 field trial at Ativeme nodule number was significantly correlated with shoot dry weight ($r=0.94$, $P < 0.01$), root dry weight ($r=0.76$, $P < 0.05$), dry weight of mature plant ($r=0.77$), $P < 0.05$). Ada variety did not show any significant and positive correlations between nodule number and other characters. However, in Kara variety there were positive correlations between nodule number, and nodule dry weight ($r=0.99$, $P < 0.01$) and shoot dry weight ($r=0.91$, $P < 0.01$).

DISCUSSION

The rhizobial strains used in the growth chamber and green house studies were all effective as indicated by nodule formation, green color of leaves, and significantly higher shoot weight. The effectiveness of selected strains was also found in the field trials in Ativeme, Togo; Bambey, Senegal; and Princess Anne, USA. The strong responses in nodulation and growth of bambara groundnut to the application of rhizobial strains indicate that root nodule symbiosis plays an important role in growth and performance of bambara groundnut.

Since the application of rhizobial strains increased nodule number, shoot dry weight and total dry matter as compared to the uninoculated and nitrogen control treatments it is inferred that the resident rhizobia and both inherent and applied nitrogen did not supply the nitrogen requirement of the bambara groundnut. Similar findings were reported in work with winged bean (Ikram and Broughton, 1980).

Our experiments confirmed other reports that the symbiotic effectiveness of rhizobial strains on legumes are not always identifical (Elkan et al., 1981; May and Bohlool, 1983; Wynne et al., 1980a). The greater effectiveness of the TMUN and MAO 11 strains, both isolates from West Africa, indicates that these two strains were more competitive in their region of origin. The differences in magnitude of response between local and imported strains suggest that the origin of the rhizobia is important and should be considered when searching for an effective nodulation in a given area.

The two bambara groundnut genotypes used in the trails produced significantly different responses to inoculation which means that certain bambara groundnut genotypes and rhizobial strain combination will respond better to the symbiotic association. This interaction of host and strain further emphasizes the importance of

considering the selection of appropriate bambara groundnut and rhizobia for high yield as practiced with other legume crops.

Our experiments, although limited, indicated that the nodulation and performance of the bambara groundnut were superior in the wet humid zone of Togo, compared to the dry Savanna zone of Senegal. Although bambara groundnut is adapted to dry regions (Hepper, 1970), nodulation and performance will be enhanced under higher than normal moisture regimes, as similarly reported for soybean (Sprent 1971).

The data in this part of the report lead us to the conclusion that bambara groundnut nodulation and yield could be enhanced by inoculation with selected rhizobial strains such as TMUN and MAO 11. Also the bambara groundnut genotype and strain interaction should be considered in evaluating and selecting for effectiveness of nodulation and performance.

III. COLLECTION AND EVALUATION OF BAMBARA GROUNDNUT GERMPLASM.

Grain yield of bambara groundnut is generally low. The local African farmer relies on unimproved land races. There are several land races in the sub-Saharan region of West Africa about which not much is known.

TABLE 12. BAMBARA GROUNDNUT CULTIVARS AND THEIR COUNTRIES OF ORIGIN

CULTIVAR NAME	COUNTRY OF ORIGIN
Sarakawa 1	Togo
Sarakawa 2	Togo
Sarakawa 3	Togo
Sarakawa 10	Togo
Thitchao 3	Togo
Awandjelo 1	Togo
Ketao 2	Togo
Ketao 3	Togo
Alheride 1	Togo
Lassa 1	Togo
Lassa 3	Togo
Lassa 4	Togo
Kara	Togo
Ada	Togo/Ghana
78-1	Senegal
79-1	Senegal
83-126	Mali
83-127	Mali
83-129	Mali
83-130	Mali
83-131	Mali
Sudcam	Cameroon

The aim of this part of our study was to collect several of these land races for evaluation and determine their responses to various factors which may enhance yield improvement.

PROCEDURE

An expedition to collect bambara groundnut land races in Togo was organized by the IBPGR representative in Togo and was partly sponsored by funding through this project. Over 150 land races were collected in Togo. The germplasm collection was increased and described after growing on the farm of Direction Recherche Agronome at Ativeme in 1985. Fifteen of these cultivars for Togo, two cultivars from Senegal, five cultivars from Mali and one cultivar from Cameroon (Table 12) were grown in four row plots with nitrogen and without nitrogen as main plot treatments and cultivars as subplots. Each treatment was replicated four times.

Plots measured 3.0m long. Rows were 0.3m apart and ridged to a height of 0.3m. Plant spacing in rows was 0.2m. Each plot received a basal application of 60kg P/ha and 80kg K/ha fertilizer. The +N treated plots received 50kg N/ha fertilizer in furrows 5.0cm deep between plants 7 days after seedling emergence.

Plant samples were taken at flowering for data collection on nodules and dry matter production. At

Table 13 Effect of nitrogen treatment on mean nodule number per plant produced by bamabara groundnut cultivars

Cultivar		Nodule Number/Plant -N*	+N*	Mean of Cultivar*	Difference (+N)-(-N)*
Sarakawa	1	80.3bc	30.9ghij	59.1cd	-42.3**
Sarakawa	2	69.0cdef	44.6efghij	56.8cd	-24.2
Sarakawa	3	100.3a	86.6a	93.4a	-13.6**
Sarakawa	10	87.3ab	85.3a	86.3a	- 2.0NS
Thitchao	3	61.2defg	38.9ghij	56.3cd	- 4.3NS
Awandjelo	1	58.4fgh	54.2acdefg	56.3cd	- 4.3NS
Ketao	2	91.2ab	61.9bcd	76.5ab	-29.3**
Ketao	3	59.8fgh	46.9cdefgh	53.4cde	-12.9**
Ketao	9	45.4ghijk	59.6bc	51.5defg	+14.2**
Alheride	1	54.8fgh	64.7b	59.7cd	+ 9.9**
Lassa	1	77.1bcde	59.9bcde	68.5bc	-17.2**
Lassa	3	78.1bc	36.3hijk	57.5cd	-42.4**
Lassa	4	57.7fgh	46.9cdefgh	52.2cdef	-10.8**
Kara		77.4bcd	58.4bcdef	67.0bc	-14.8**
Ada		43.9ghijk	29.1ijkl	36.5fghi	-19.1**
78-1		30.0kl	16.6l	23.3i	-13.4**
79-1		34.8ijkl	43.5efghi	39.1efgh	+ 8.8NS
83-126		45.9ghij	32.9hijk	39.4efgh	-13.0**
83-127		48.8ghi	62.6bc	55.7cd	+12.9**
83-129		53.1gh	47.8cdefgh	50.5defg	-5.3NS
83-130		26.2 l	21.5kl	24.1hi	-4.7NS
83-131		30.8jkl	25.4jkl	28.1hi	-5.3NS
Sudcam		33.9ijkl	42.8fghi	38.3efghi	+8.9NS
N Mean ℵ		58.5	47.9		
LSD 0.01					9.81

*Means in a column followed by the same letter are not significantly different, according to Duncan's new multiple range test (DMRT).

ℵ N Means with the same bar are not significantly different, according to DMRT.

** = $P < 0.01$; NS = Not significant.

maturity another set of samples were collected and data on dry matter and yield recorded after oven drying and weighing. Yield data were also expressed in terms of R.E. (Relative Efficiency = $\frac{\text{Seed weight of -N}}{\text{Seed weight of +N}}$). Nodule numbers and all dry weights were analyzed statistically and means were compared.

RESULTS

There were symptoms of nitrogen deficiency in most cultivars in the -N treatment during the first two weeks after seedling emergence. The green color was, however, restored in most cultivars from about the third week. Nodule distribution on the bambara groundnuts in both -N and +N treatments varied on the tap and lateral roots indicating a heterogenous distribution of the native rhizobial strains in the soil.

Nitrogen treatment, cultivar and their interaction were all highly significant. The overall number of nodules in the -N treatment was higher than the +N (Table 13). Bambara groundnut cultivars from the Togo collection seemed to produce more nodules than cultivars from other sources.

The nodule dry weight data followed a similar pattern as the nodule number (Table 14). The +N treatment seemed to restrict nodule formation and nodule dry weight increase.

Table14 Effect of nitrogen treatment on mean nodule dry weight per plant produced by bambara groundnut cultivars

Cultivars		Nodule dry weight/plant (g) -N*	+N*	Mean of Cultivars*	Difference (+N)-(-N)*
Sarakawa	1	0.10def	0.09cdef	0.10def	-0.01NS
Sarakawa	2	0.18bcd	0.05cdef	0.13cde	-0.13**
Sarakawa	3	0.22bc	0.22a	0.23a	-0.00NS
Thitchao	3	0.11def	0.10cdef	0.11cdef	-0.01NS
Awandjelo	1	0.10def	0.07cdef	0.08defg	-0.03NS
Ketao	2	0.18bcd	0.09cdef	0.14bcd	-0.09**
Ketao	3	0.13cde	0.08cdef	0.11cdef	-0.05**
Ketao	9	0.32a	0.11cd	0.22a	-0.21**
Alheride	1	0.15bcd	0.20ab	0.17abc	+0.05**
Lassa	1	0.17bcd	0.11cd	0.14bcd	-0.06**
Lassa	3	0.17bcd	0.05cdef	0.11cdef	-0.12**
Lassa	4	0.13cde	0.06cdef	0.09def	-0.07**
Ada		0.20bc	0.09cdef	0.14bcd	-0.11**
Kara		0.07ef	0.03ef	0.05g	-0.04NS
78-1		0.05f	0.02f	0.03g	-0.03NS
79-1		0.04f	0.03ef	0.03g	-0.01NS
83-126		0.06ef	0.03ef	0.05g	-0.03NS
83-127		0.09e	0.08cdef	0.08defg	-0.01NS
83-129		0.08e	0.04ef	0.07efg	-0.04NS
83-130		0.04f	0.05cdef	0.03g	+0.01NS
83-131		0.05f	0.04ef	0.04g	-0.01NS
Sudcam		0.09e	0.05cdef	0.07efg	-0.04NS
N Mean✗		0.12	0.08		
LSD	0.01				0.05

*Means in a column followed by the same letter are not significantly different, according to DMRT.

✗ N Means with the same bar are not significantly different, according to DRMT.

** = $P < 0.01$; NS = Not significant

Table15 Effect of nitrogen treatment on total dry weight (g) per plant at flowering of bambara groundnut cultivars

Total dry weight/plant (g)

Cultivar		-N*	+N*	Mean of Cultivar*	Difference (+N)-(-N)*
Sarakawa	1	20.61abcd	23.65ab	22.13abc	+1.52NS
Sarakawa	2	15.23efg	14.14e	14.70k	-1.09NS
Sarakawa	3	14.68efg	17.40cde	16.04fghijk	+2.72NS
Sarakawa	10	16.80cdefg	13.72e	15.26ghijk	-3.08**
Thitchao	3	17.52cdef	20.38bcd	18.90cdef	+2.85NS
Awandjelo	1	18.97abcde	16.70de	17.84efghij	-2.27NS
Ketao	2	23.36a	23.30ab	23.33a	-0.6NS
Ketao	3	19.05abcde	24.08ab	21.56abcd	+5.03**
Ketao	9	13.58fg	14.04e	13.81k	+0.46NS
Alheride	1	16.80cdefg	19.76bcd	18.28defghij	+2.96NS
Lassa	1	23.61a	26.63a	25.12a	+3.02NS
Lassa	3	17.26cdef	20.19bcd	18.72cdefg	+2.91NS
Lassa	4	22.85ab	26.54a	24.69a	+3.69**
Kara		21.66abc	24.44ab	23.05ab	+2.78NS
Ada		12.56fg	16.58de	14.57jk	+4.02**
78-1		23.26a	24.72ab	23.99a	+1.46NS
79-1		16.35defg	16.33de	16.34fghijk	-0.02NS
83-126		17.53cdef	19.50bcd	18.52cdefgh	+1.97NS
83-127		11.79g	15.92de	12.85k	+4.13**
83-129		13.41fg	16.57de	14.99ijk	+3.16**
83-130		15.99defg	17.88cde	16.93efghij	+1.89NS
83-131		13.29fg	20.07bcd	16.68efghij	+6.78**
Sudcam		17.63cdef	22.56abc	20.09bc	+4.93**
N Mean&		17.56	19.78		
LSD 0.01					3.06

* Means in a column followed by the same letter are not significantly different according to DMRT

& N means with the same bar are not different according to DMRT.

** = $P < 0.01$; NS = Not significant

Table 16 Effect of nitrogen treatment on total dry weight (g) per plant at maturity of bambara groundnut cultivars

Cultivar		Total dry weight/plant (g) -N*	+N*	Mean of Cultivar*	Difference (+N)-(-N)*
Sarakawa	1	81.34abc	109.62bcd	95.44cd	+28.28**
Sarakawa	2	79.06abc	83.08fgh	94.57d	+ 4.02NS
Sarakawa	3	82.82ab	117.63bc	100.22bcd	+34.81**
Sarakawa	10	64.86cde	90.04efg	77.45ef	+25.18**
Thitchao	3	56.49efg	71.55hij	64.42ghij	+15.06**
Awandjelo	1	58.50def	93.59def	76.19f	+34.79**
Ketao	2	90.86ab	125.13ab	107.99abc	+34.27**
Ketao	3	84.78ab	113.51ijklm	99.15cd	+28.73**
Ketao	9	42.97fghij	64.38ijklm	53.67hij	+21.41**
Alheride	1	88.26ab	114.94bc	101.60bcd	+26.68**
Bassa	1	75.42abcd	112.32bc	93.87d	+36.90**
Bassa	3	86.93ab	104.00cde	111.44ab	+17.07**
Bassa	4	95.33a	136.90a	116.12a	+14.57**
Bara		47.17fghi	70.00hijk	58.58gh	+22.83**
Bda		29.99j	33.56o	31.77l	+ 3.57NS
8-1		40.06ghij	46.38no	43.22jk	+ 6.32NS
9-1		41.98fghij	53.48klmn	47.73hij	+11.50**
3-126		39.08hij	48.08mno	43.58jk	+ 9.00NS
3-127		33.60ij	45.32no	39.46kl	+11.72**
3-129		39.57ghij	48.49mno	44.03ijk	+ 8.92NS
3-130		46.40fghij	58.37klmn	52.38hij	+11.97**
3-131		45.60fghij	66.32hijkl	55.96ghi	+20.72**
Bdcam		55.00efgh	78.00gh	66.50fg	+23.00**
Mean		61.15	84.51		
SD	0.01				10.47

Mean in a column followed by the same letter are not significantly different according to DMRT.

N means with the same bar are not significantly different according to DMRT.

= $P < 0.01$; NS = Not Significant

At flowering the nitrogen and cultivar treatments and their interaction on total dry weight were also significant. However, the +N treatment promoted a higher dry weight production than the -N treatment (Table 15). The difference in total dry weight under +N and -N treatment were significant in Sarakawa 10, Ketao 3, Lassa 4, Ada, 83-127, 83-127, 83-127, 83-129, 83-131 and Sudcam. The Togo cultivars again produced higher total dry weight than the others.

The responses to the treatments on total dry weight at maturity were also significant and similar to the effect on total dry weight at flowering (Table 16).

Pod dry weight was significantly affected by nitrogen and cultivar treatments and their interaction. +N treatment caused significantly greater between +N and -N treatment (Table 17). The differences from Togo, except Lassa 1, and also for only 83-131 from Mali and Sudcam from Cameroon.

Seed yield was also significantly increased by the +N and cultivar treatments (Table 18). Again the cultivars from Togo outyielded those from Mali, Senegal and Cameroon. Alheride 1, 78-1 and 83-126, and 83-127 did not produce significant difference in the +N and -N treatments.

There was a range of REs from 0.34 to 1.01. Sarakawa 2, Sarakawa 3, Alheride 1, Lassa 1, Lassa 3 and 83-130 had excellent RE values.

Table 17 Effect of nitrogen treatment on pod dry weight (g) per plant at maturity of bambara groundnut cultivars

Pod dry weight/plant (g)

Cultivar		-N*	+N*	Mean of Cultivar	Difference Between +N and -N*
Sarakawa	1	23.66de	33.25def	28.46cd	+ 9.59**
Sarakawa	2	39.51a	47.52a	43.51a	+ 8.01**
Sarakawa	3	38.90a	46.64ab	42.77a	+ 7.74**
Sarakawa	10	18.58defg	32.16def	25.37d	+13.58**
Thitchao	3	21.47def	37.35bcde	29.40cd	+15.88**
Awandjelo	1	16.61efgh	24.35fgh	20.48ef	+ 7.74**
Ketao	2	28.36bcd	46.10ab	33.33bc	+17.74**
Ketao	3	21.53def	28.35efg	24.88de	+ 6.82**
Ketao	9	33.78abc	43.84abc	38.81ab	+10.06**
Alheride	1	23.46de	34.53cde	28.99cd	+11.07**
Lassa	1	24.26cde	28.82efg	26.52cd	+ 4.56NS
Lassa	3	37.50ab	46.26ab	41.88a	+ 8.76**
Lassa	4	38.15ab	49.82a	43.98a	+11.67**
Kara		34.35abc	40.74abcd	37.54ab	+ 6.39**
Ada		4.25i	8.63kl	6.44h	+ 4.38NS
78-1		4.22i	6.02kl	5.12h	+ 1.80NS
79-1		9.43ghi	13.63ijkl	11.53gh	+ 4.20NS
83-126		8.55hi	10.73jkl	9.64gh	+ 2.18NS
83-127		3.39i	5.11 l	4.25h	+ 1.72NS
83-129		3.14i	8.64kl	5.89h	+ 5.50NS
83-130		11.87fghi	14.86hijk	13.36g	+ 2.99NS
83-131		12.07fghi	20.62ghi	16.34fg	+ 8.55**
Sudcam		9.47fghi	18.57hij	14.02fg	+ 9.10**
N Means ø		20.28	27.76		
LSD 0.01					5.90

* Means in a column followed by the same letter are not significantly different, according to DMRT.

ø N means with the same line are not significantly different, according to DMRT.

** = $P < 0.01$; NS = Not Significant.

Table 18 Effect of nitrogen treatment on seed yield (kg) per hectare of bambara groundnut

Cultivar		Seed yield (kg/ha) -N*	+N*	Mean of Cultivar*	Difference between +N and -N*	R.F
Sarakawa	1	1583jk	2506def	2044def	+ 923**	0.6
Sarakawa	2	2991a	3581ab	3286a	+ 590**	0.8
Sarakawa	3	2931ab	3507ab	3219a	+ 576**	0.8
Sarakawa	10	1399k	2424ef	1912efg	+1025**	0.5
Thitchao	3	1616jk	2822d	2219d	+1206**	0.5
Awandjelo	1	1251kl	1836gh	1543h	+ 585**	0.7
Ketao	2	2137ghi	2877cd	2512c	+ 750**	0.7
Ketao	3	1581jk	2127fg	1854g	+ 546**	0.7
Ketao	9	2545bcde	3236bc	2904b	+ 691**	0.7
Alheride	1	2601abcd	2741de	2571c	+ 140NS	0.7
Lassa	1	1825hij	2172fg	1991defg	+ 347**	0.9
Lassa	3	2815abc	2794de	2804b	- 21NS	0.8
Lassa	4	2874ab	3703a	3289a	+ 829**	1.01
Kara		2382defg	3266b	2824b	+ 884**	0.78
Ada		320no	597mno	458 l	+ 277**	0.75
78-1		336no	476no	406 l	+ 140NS	0.53
79-1		708m	924klm	811jk	+ 216**	0.71
83-126		623mn	815nlmn	719k	+ 192NS	0.77
83-127		233o	378 o	305 l	+ 145NS	0.76
83-129		236o	695mno	465 l	+ 459**	0.61
83-130		895ln	1110jkl	1002ij	+ 215**	0.34
83-131		910ln	1552hi	1231i	+ 642**	0.82
Sudcam		714m	1412ij	1063ij	+ 698**	0.56
N mean ℵ		1544	2068			0.50

LSD 0.01 211

* Means in a column followed by the same letter are not significantly different, according to MDRT

ℵ N Means with the same bar are not significantly different according to DMRT

** = P < 0.01; NS = Not Significant

DISCUSSION

The symptoms of nitrogen deficiency shown in the -N treatment at the initial stages of growth while the plants of the +N treatment were green and robust indicates a beneficial effect of starter nitrogen to bambara groundnut as was reported in other legumes (Hartfield *et al*., 1974., Summerfield *et al*., 1977; Wynne *et al*., 1980). However, the +N treatment depressed nodule numbers and nodule dry weight significantly suggesting that the amount of nitrogen applied was probably too high for nodulation. Other reports in the literature also indicated similar decreases in nodulation and nodule dry weight after nitrogen was applied (Allos and Bartholomew, 1955, Dadson and Acquaah, 1984, Hard6 *et al*. 1968; Dala and Quilt, 1977, Donawa and Quilt, 1981 and Ahmad *et al*. 1981).

Since the higher nodule numbers and nodule dry weight in the -N treatment did not cause higher total dry weight it is inferred that the indigenous rhizobia population were ineffective, and, hence, failed to supply the needs of the crop. This could be due to low rhizobia numbers (Weaver and Frederick, 1974) ineffective or imperfect indigenous strain and host association (Minchin *et al.* 1981), or deliterious effects of abundant N on nodulated plants (Ahmad *et al*.

.pn50

1981, Day et al; 1978; Zarough and Munns, 1979).

The differences in cultivar response to nitrogen in this study confirm findings on crops such as cowpea in which cultivars treated with nitrogen produced different responses in growth and yield (Ahmad et al., 1981).

There was selective infectivity by the indigenous rhizobial strains as shown by cultivar differences in response in the -N treatment. Similar reports were made from work with groundnuts (Wynne et al; 1980a, 1980b), and cowpea (Minchin et al.; 1978, 1981). The differences in response by cultivars within the +N treatment indicate that certain cultivars are able to utilize nitrogen better than others. This agrees with findings on cowpeas (Ahmad et al. 1981). Thus, optimum yields in presence of applied nitrogen requires an appropriate and responsive cultivar as has been suggested for cowpea (Ahmad et al, 1981) and soybean (Awai, 1981).

The greater response by the cultivars from the Togo collection suggests a better adaptation of the Togo germplasm to local conditions such as higher moisture soil and environmental conditions including native rhizobia, soil temperature, acidity and minerals.

The R.E. ratings were used as a criterion for

nodule selection in cowpea (Ahmad et al., 1981). In our study the most probable candidates to yield effective and efficient rhizobial strains are Sarakawa 2, Sarakawa 3, Alheride 1, Lassa 1, Lassa 3 and 83-130.

Since the nitrogen applied seemed to depress nodulation, it is suggested that trials with different N application should be undertaken to establish the optimum starter nitrogen.

OUR STUDY HAS SHOWN:

1. Nitrogen application is important to increase the yield of bambara groundnuts.
2. Bambara groundnut cultivars vary greatly in their responses to inoculants and N applications.
3. That based on R.E. probable bambara cultivars that will yield effective and efficient strains of rhizobia are Sarakawa 2, Sarakawa 3, Alheride 1, Lassa 1, Lassa 3 and 83-130.

LINKAGES DEVELOPED

During the initiation and implementation of this project linkages were developed between UMES and Research institutes in West Africa. These were Direction Recherche Agronome, Caccaveli, Togo, Center National Recherche Agriculture, Bambey, Senegal; Institute Scientific Recherche Agriculture, Dakar,

Senegal; International Institute of Tropical Agriculture, Ibadan Nigeria; ORSTOM, Dakar Senegal; and the Ministry of Agriculture and Rural Development, Togo.

Before project was approved by USAID letters of commitment permitting the project to be implementd in Togo and Senegal were received from the Ministry of Agricultural and Rural Development, Togo and ISRA, Senegal, respectively.

Scientists in West Africa who participated in the project were Mr. Guy Mergeie, IBPGR Geneticist based in Togo, and Dr. Mamadou Gueye, Soil Microbiologist of MIRCEN located at Bambey, Senegal. Other Scientists who assisted in Senegal were Dr. P. I. Thiongane, Director General, ISRA, Mr. Mamdou Sonko, Directeur Scientifique de ISRA, Dr. Moktar Toure, Director General for Scientific Research Senegal, Dr. EL-Hadji Gueye, Director of CNRA, Bambey Station, Mr. Ndoye, Legume Physiologist, CNRA Bambey, Dr. Mbaye Ndoye, Director of Crop Population, CNRA Bambey, and Mr. Ndiaga Cessay, legume breeder, CNRA, Bambey.

In Togo we were assisted by Mr. Anain Gasson, Minister of Agriculture and Rural Development Lome, Dr. Aithnar, Director of DRA, Caccaveli, Mr. Tetevi, Deputy Director, DRA Caccaveli, Mr. Ngu Yen Vu, Consultant, DRA, Caccaveli, Mr. Geanet, Agronomist, Mr. Diambianni, Agronomist and Dr. Komla Denanyoh, Direction des Etudes

Pedologiques e de L'Ecologie Generale. In both Togo and Senegal we were permitted to use their laboratories, equipment and land. We reimbursed the stations for labor and materials we used on the project.

At IITA, Ibadan, we met Dr. Okigbo, Deputy-Director General and discussed the research on bambara groundnut with him. We also met and discussed the N_2 - fixation work with Dr. Mulongoy, Soil Microbiologist, Dr. Ng, Geneticist, Dr. Otoo, Agronomist and Dr. Jakai, Entomologist. We obtained bambara groundnut seeds from Dr. Ng, and visited his legume plots where we collected fresh nodules for rhizobia isolation.

In both Senegal and Togo we reported to USAID Offices whenever we were in the country and had considerable assistance from the missions in various ways. USAID Officials we met in Senegal were Mr. McMann, AO and Mr. Larry Harms, Assistant ADO and Mr. John Baylis, ADO. In Togo we met Mr. Golden, Director of Mission. Ms. Barbara Howard, Deputy Director of Mission, Mr. Bliss, AO and Mr. Richard Caldwell, Program Officer. We informed the AID officials of all our activities and made exit reports before our final departure to the US.

We obtained rhizobia strains from NifTAL, from Dr. Padma Somasegaran, and Beltsville, from Dr. Harry Kaiser. Dr. Mamadou Gueye also supplied some rhizobia strains for our trails in 1985.

ACCOMPLISHMENTS

The following are the major accomplishments of the project.

1. Linkages with scientists at the Direction Recherche Agronome, Togo; Center National Recherche Agriculture; and Institute Scientifique Recherche Agriculture were established.
2. 30 rhizobia strains were isolated from legumes growing in West Africa. Rhizobial strains from NifTAL, Hawaii, MIRCEN, Senegal; and native strains isolated from West African soils capable of nodulating bambara groundnut were identified.
3. Over 150 bambara groundnut germplasm were collected from Togo. Seeds of these have been multiplied and have been stored at the DRA, Caccaveli, Togo.
4. High yielding cultivars of bambara groundnut were identified.

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