Arab Gulf Journal of Scientific Research, 21 (4), pp 232 - 236 (2003)

ORIGINAL PAPER

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Effect of *Rhizobium* Inoculation on the Yield of Groundnut (*Arachis hypogaea* L.) in the Sandy Soils of the Kordofan Region, Western Sudan

Abstract: Cultivation of groundnut (*Arachis hypogaea* L.) in Western Sudan is still lacking nitrogen fertilizers. Hence, three effective *Rhizobium* strains (IC 7001, IC 7017, and IC 6006) were introduced from ICRISAT (India) and compared to the local strains under the conditions in the Western Kordofan State during the 1999, 2000 and 2001 growing seasons. Under the conditions of higher rainfall in the 1999 and 2001 growing seasons, the introduced strains had relatively higher, but non-significant, pod yields per hectare than the control. However, the naturally inoculated plants of the indigenous strains (i.e., the control) had outyielded those of the introduced *Rhizobium* strains during the lowest rainfall season of 2000. These results indicate that the introduction of rhizobia strains from abroad has no benefits for groundnut production in western Sudan. Hence, the future research on nitrogen fixation by groundnut in this area should be directed to selection and identification of the most effective rhizobia strains from the adapted local populations.

Keywords: Groundnut, *Arachis hypogaea* L., *Rhizobium*, Kordofan State, Sodiri and Barberton cultivars

تأثير التلقيح الريزوبي على إنتاج الفول السوداني تحت بيئة الأراضي الرملية لإقليم كردفان، غرب السودان

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المستخلص: تفتقر زراعة وإنتاج الفول السوداني *Arachis hypogaes* L. في غرب السودان (600 كجم/هكتار) إلى إستخدام الأسمدة النيتروجينية (الآزوتية)، تفادياً لتأثيرها السلبي، مع تذبذب معدلات الأمطار الموسمية، والتي هي وسيلة الري الأوحد. وعليه تنتشر سلاسلات الرايزوبيوم *Rhizobium* المحلية المساهمة في تثبيت وتغذية المحصول بقدر مقدر من عنصر النتروجين الجوي. وفي تجارب حقلية لزيادة الإنتاج، تم إستجلاب ثلاثة سلالات من البكتيريا العقدية *Rhizobium* strains ذات الكفاءة العالية في تثبيت النتروجين الجوي من الهند، خلال الأعوم 1999م-2001م، ومقارنتها تحت ظروف الحقل مع السلالات المحلية السائدة في الإقليم. تشير نتائج التجارب الحقلية إلى فعالية السلالات المستوردة وزيادة الإنتاج، مع إرتفاع معدل الأمطار خلال الموسمين 1999م و2001م، إلا أن الفروقات بينهما لم تكن معنوية. وعلى خلاف ذلك، فقد أوضحت التجارب، خلال الموسم الزراعي 2000م والذي قد سجل أدني معدل للأمطار، تأثيراً واضحاً للسلالات المحلية في زيادة الإنتاج دون وجود فروقات معنوية بين المعاملات المختلفة. وعليه فقد برهنت التجارب عدم جدوي إستجلاب السلالات البكتيرية، لتحسين الإنتاجية في غرب السودان، وقد يعزى ذلك إلى عدم ملائمة السلالات المستوردة للظروف البيئية السائدة. وبهذا نوصى بتوجيه الإهتمامات البحثية إلى الحصول على سلاسلات رايزوبيوم *Rhizobium* strains عالية الكفاءة في تثبيت النتروجين الجوي لمحصول الفول السوداني، من بين السلالات المحلية والمتكيفة مع الظروف البيئية السائدة.

كلمات مدخلية: غرب السودان، إقليم كردفان، فول سوداني، نيتروجين جوي، سماد، سلاسلات بكتيريا، رايزوبيوم، معدل أمطار، بيئة

Introduction

Yield improvement of groundnut (*Arachis hypogaea* L.) is partially dependent on nitrogen (N) nutrition (Ton and Weaver, 1981). In the Sudan, Hadad, *et al.* (1986) reported 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. In Western Sudan, the use of nitrogen fertilizers is not a common practice in groundnut production areas. Hence, the average pod yield is low, about 600 kg/ha (Ishag, *et al.* 1980, Osman and Amin, 2000). Besides the high cost of mineral fertilizers, the direct application of mineral nitrogen is very risky, particularly under the unpredictable rainfall conditions. Therefore, biological nitrogen fixation is one of the ways for solving this problem. Although the soils of western Sudan are densely inhabited with indigenous rhizobia strains (cowpea-miscellany rhizobia) that are capable of nodulating the groundnut roots, the introduction or identification of highly effective strains is being considered as the main strategy for

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attaining this goal. Accordingly, three effective rhizobia strains (IC 7001, IC 7017, and IC 6006) as reported by Rupela *et al.* (1991) were introduced from India and tested with the local strains for this purpose. The main objective of the field experiments described here was to compare the effects of the three introduced rhizobia strains with the indigenous ones on groundnut yield under the prevailing conditions of the Kordofan region.

Material and Methods

An experiment was conducted at El-Behair farm of West Kordofan Research Station, about 25 km Southwest of Lagawa (lat. 11°12´N, long. 29° E) for three seasons (1999, 2000 and 2001). The soil of the site is a sandy loam. The two main groundnut cultivars that are grown in rainfed areas (Barberton and Sodiri) were used for this study. On the other hand, three *Rhizobium* strains (IC 7001, IC 7017, IC 6006) were introduced from ICRISAT (India) and tested with the indigenous rhizobia strains which inhabit the extensive cultivation areas of groundnuts in western Sudan for nitrogen fixation.

The experimental design was a randomized complete block design that consisted of two groundnut cultivars, four rhizobia treatments and five replications. *Rhizobium* strains were introduced as peat-based inoculants. At sowing, a considerable amount of about 5gm from each inoculant was taken and moistened with a solution of gum Arabic, which had been prepared by dissolving 200gm of dry gum into one liter of boiling water. Seeds of each treatment were carefully mixed with the right inoculant paste and dried without heating or exposure to direct sunlight. As a rainfed-based experiment, sowing was made immediately after rainfall every year to avoid the failure of inoculation. Untreated seeds were allocated to indigenous strains treatment, since the soils of this region are very rich in rhizobia strains that are capable of nodulating the groundnut roots.

Seeds were sown in rows at the rate of two seeds per hill with spacing of 60 cm between rows and 20 cm between hills. The plot size was 3 x 5m. The sowing dates were on 9th August 1999, 31st July 2000 and 25th July 2001. The effective rainfall to a depth of 15 cm or more was the main determinant factor for sowing every season. Weed control was done as necessary. During the 1999 and 2000 growing seasons, samples of five randomly selected plants were taken from each plot at 80 days from sowing for root nodule counting. In all seasons, the crop was harvested after 100 days from sowing. At harvest, five random plants were also selected for counting the number of pods per plant. The dry pod yield was adjusted to kilograms per hectare.

Analysis of variance was applied to all treatments using the SPSS package. The treatment means were compared by the least significant difference (LSD).

Results

The experiment was conducted under a rainfed environment. Thus, the rate of rainfall during the season was the main limiting factor for the level of crop production. Rainfall in the 1999 growing season was the highest as compared to the following two seasons. Over the months of July to October, the rainfall values were 584.6, 323 and 474.6 mm for the 1999, 2000 and 2001 growing seasons, respectively (Table 1).

Table 1. Monthly and seasonal rainfall values for 1999, 2000 and 2001 growing seasons.

Month	Rainfall (mm)		
	1999	2000	2001
July	131.9	85.8	106.9
August	189.4	144.4	210.3
September	121.8	85.1	140.3
October	141.5	7.7	17.1
Total	584.6	323.0	474.6

Both separate and combined analyses of variance were applied to all traits under study (Table 2). Data on nodule numbers per plant were taken only for the first two seasons (1999, 2000); this was due to managerial problems and restrictions concerned with releasing a suitable transportation facility to the experimental site at the time selected for nodule counting. However, data on a number of pods per plant and dry pod yield were recorded for all seasons (Table 3). In general, the effects of both cultivars and rhizobia treatments on nodule number, pod number and pod yield per hectare were not significant. On the other hand, the effect of years on these traits was highly significant (Table 2). Irrespective of interaction of *Rhizobium* x Year, no other interaction has significantly affected any of the traits under study.

Table 2. Summary of the separate and combined analysis of variance for traits under study.

Trait	Cultivar			*Rhizobium*			CV x *Rhiz*		
	1999	2000	2001	1999	2000	2001	1999	2000	2001
Nodule number	NS	**	-	*	NS	-	*	**	-
Pod number	NS	**	*	NS	*	NS	NS	**	NS
Pod yield	NS	NS	NS	NS	NS	NS	NS	NS	NS

Combined

Trait	CV	*Rhiz*	Year	CV x *Rhiz*	CV x Year	*Rhiz* x Year	CV x *Rhiz* x year
Nodule number	NS	NS	**	NS	NS	*	NS
Pod number	NS	NS	**	NS	NS	NS	NS
Pod yield	NS	NS	**	NS	NS	NS	NS

* and **: Significant at 0.05 and 0.01, respectively, NS: not significant, CV = Cultivar, *Rhiz* = *Rhizobium*

Table 3. Mean number of nodules per plant, number of pods per plant and pod yield per hectare for two groundnut cultivars as affected by *Rhizobium* inoculation in three successive seasons.

Rhizobium	No. of nodules/plant			No. of pods/plant				Pod yield (kg/ha)			
strain	1999	2000	Ave.	1999	2000	2001	Ave.	1999	2000	2001	Ave.
IC 7017	128.8	24.35	76.57	60.6	19.74	19.8	33.38	3751.1	483.5	989.6	1741.4
IC 6006	147.7	21.75	84.72	72.8	17.98	19.72	36.83	4396.1	474.5	892.3	1921.0
IC 7001	155.9	22.11	89.00	66.2	18.00	19.34	34.51	3759.8	436.4	919.4	1705.2
Control	86.7	24.68	55.69	69.2	22.62	19.92	37.25	4017.2	490.0	889.7	1799.0
LSD (O.O5)	49.13	4.81	25.63	12.01	3.08	5.88	4.53	645.38	136.6	223.7	253.9
CV (%)	41	22	52	19	17	32	24	17	31	26	27
Groundnut cultivar											
Sodiri	133.9	18.80	76.35	68.7	18.02	17.04	34.57	4021	451	849	1774
Barberton	125.7	27.65	76.65	65.8	21.15	22.35	36.42	3941	491	996	1809
LSD (0.05)	34.74	3.41	18.12	8.49	2.18	4.16	3.21	456	96.6	158	179
CV (%)	41	22	52	19	17	32	24	17	31	26	27

The effects of both *Rhizobium* strains and groundnut cultivars on number of nodules per plant, number of pods per plant and dry pod yield per hectare during the three seasons are presented in Table 3. The *Rhizobium* strain had significantly affected the number of nodules per plant in the 1999 growing season. However, it did not affect this parameter during the second season of 2000. The effect of *Rhizobium* on the number of pods per plant was significant for both the 1999 and 2000 growing seasons, whilst it did not affect this trait during the 2001 growing season because of drought spell that affected the crop for about three weeks during the pegging stage (Table 3). The effect of cultivars on nodule numbers per plant was significant only for the 2000 growing season, while they affected the number of pods per plant in both 2000 and 2001 growth seasons (Table 3). In general, the effect of *Rhizobium* strains and groundnut cultivars on dry pod yield per hectare was not significant.

Discussion

The comparison of the three-year results (1999, 2000, 2001) has shown the superiority of the first season (1999) as it outyielded the second season (2000) by 3510 kg/ha and the third season (2001) by 3058 kg/ha. This tremendous variation in yield across the seasons was mainly attributed to differences in seasonal rainfall, which directly affected both numbers of nodules and pods per plant (Table 3). In a study concerned with the effect of water stress on N_2 fixation in cowpea and groundnut crops, Venkateswarlu, *et al.* (1990) found that nodule dry weight, nodule number per plant and nitrogenase activity declined in a water-stress environment. The number of pods per plant was the yield component most affected by watering (Ishag, 1982). On the other hand, Nageswara, *et al.* (1985) reported that the greatest reduction in kernel yield occurred when stress was imposed during the seed-filling phase. These results indicate that water supply is a major environmental factor limiting the yield of groundnut (Ishag, *et al.* 1980).

The effect of *Rhizobium* strain IC 6006 on dry pod yield during the first season was the highest due to high number of pods per plant. On the other hand, the effect of all introduced strains on pod dry yield during the third season was not significantly higher than that of the control. In all instances, non-inoculated plants were well nodulated with no noticeable differences in nodulation patterns of inoculated and non-inoculated plants (Staphorst, *et al.* 1975). In Shambat (Faculty of Agriculture, University of Khartoum, Sudan), Hassan (1997) compared the introduced *Rhizobium* strain IC 7001 with the indigenous ones under the clay soils of the Khartoum area during the 1994 and 1995 growing seasons. He found that the introduced strain was more effective than the local strains especially under drought conditions of the first season when the crop was subjected to water stress for about three weeks during the flowering period because of a River Nile flood that overwhelmed the main watering machine. However, in the sandy soils of the Kordofan region and under the conditions of the lowest rainfall of the 2000 growing season, plants inoculated with indigenous rhizobia strains had higher dry pod yield than those of the introduced strains. This result indicates that the indigenous rhizobia strains are more adapted to the adverse conditions of rainfall scarcity that is always accompanied with higher soil temperatures. Furthermore, it confirms the assumption reported by Hadad *et al.* (1986) that soil conditions in the tropical climate of Sudan might stress added inoculants. In common bean, Hernandez, *et al.* (1989) found that the high soil temperature was the main constraint for N_2 fixation by the beans, where transferring plants from a 26°C to a 38°C environment resulted in elimination of acetylene reduction activity. On the other hand, Kvein and Ham (1985) reported that soil temperature is known to have a varying impact on nodulation and nitrogen fixation by strains of *Rhizobium*. In general, the introduced rhizobia strains have failed to increase groundnut yields under the conditions of the Kordofan region. Similar results were found by Van Der Merwe, *et al.* (1974) who reported that lack of response to seed inoculation was attributed to a relatively high level of effectiveness of the indigenous *Rhizobium* population, which could lead to the fact that seed inoculation with introduced rhizobia strains is unnecessary in areas where groundnuts are produced under extensive cultivation practices. Thus, the results of this study suggest that any future work on nitrogen fixation by groundnut in this region must be directed towards selection and identification of the most effective rhizobia strains from the indigenous populations.

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Ref. 2239
Received 13/11/2002.
In revised form 16/11/2003