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# Intercropping of sesbania (*Sesbania sesban*) and leucaena (*Leucaena leucocephala*) with five annual grasses under semi-arid conditions as affected by inoculation with specific rhizobia and associative diazotrophs

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**Abstract** – Intercropping of legumes and non-legumes is considered to improve the quality and quantity of field forage crops. Under semi-arid desert conditions, intercropping of leucaena and sesbania with some annual grasses (barley, pearl millet, and Rhodes-, rye- and sudan-grasses) was evaluated in a series of field trials. Inocula of specific rhizobia for legumes and a composite of associative diazotrophs for non-legumes were applied in the presence or absence of N fertilizers. Rhizobia inoculation was indispensable, and supported better growth of legumes which extended to the neighboring non-legumes. Associative diazotrophs improved biomass and N yields of non-legumes, particularly in the presence of moderate N fertilization for winter barley and rye grass and of higher doses of 300 kg N·ha<sup>-1</sup> for summer pearl millet and sudan grass. Intercropping improved productivity of non-legumes, in particular barley mixed with sesbania, and the calculated N-transfer from legumes to non-legumes ranged from 20 to 70 kg N·ha<sup>-1</sup>.

**forage crops / intercropping / nitrogen-fixation / desert / leucaena / sesbania**

**Résumé** – Rôle de l'inoculation de rhizobia spécifiques associés à des diazotrophes sur la culture intercalaire de *Sesbania sesban* et de *Leucaena leucocephala* avec cinq graminées annuelles dans des conditions semi-arides. La culture intercalaire de légumineuses et de non-légumineuses est considérée comme un moyen pour améliorer quantitativement et qualitativement la production de fourrage. Dans des conditions semi-arides dans le désert, la plantation intercalaire de leucaena et sesbania entre les graminées annuelles est évaluée à partir d'une série d'essais au champ. Un inoculum constitué par le rhizobium spécifique pour les légumineuses et d'un complexe de bactéries fixatrices d'azote (diazotrophes) associées aux non-légumineuses a été appliqué en présence et en absence de fertilisation azotée. L'inoculation spécifique par le Rhizobium a été indispensable pour améliorer la croissance des légumineuses qui s'est étendue aux non-légumineuses voisines. Les diazotrophes associées ont amélioré la biomasse et le rendement en azote des non-légumineuses en particulier en présence d'une fertilisation azotée modérée pour l'orge d'hiver et le ray-grass et avec une dose d'azote élevée (300 kg·ha<sup>-1</sup>) pour l'orge d'été et l'herbe du Soudan (*Sorghum sudanense*). La culture intercalaire a amélioré la productivité des non-légumineuses en particulier celle de l'orge associée au sesbania et le transfert d'azote calculé des légumineuses aux non-légumineuses est compris entre 20 et 70 kg·ha<sup>-1</sup>.

**culture fourragère / culture intercalaire / fixation d'azote / désert / leucaena / sesbania**

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## 1. INTRODUCTION

Management of limited soil and water resources requires further attention to attain sustainability and build up of fertility of marginal soils. A unique approach in this respect is the concept of “Integrated Fertilizers Management, IFM” which comprises the proper implementation of both chemical and biological fertilization. This approach includes mainly the use of: (1) integration of symbiotic and associative BNF systems to maximize inputs of biologically fixed nitrogen [1, 21], (2) intercropping systems for growing compatible legume and non-legume crops [2, 3, 6, 21], (3) responsive cultivars in respect of drought resistance, salt tolerance, early maturation and nutrient-uptake efficiency [7].

The present study aimed to investigate the concept of IFM in building up biofertility together with increasing productivity of sandy soils of the Egyptian eastern desert. Nitrogen-fixing trees of native sesbania and introduced leucaena were evaluated as legume forage crops for the first time. A number of annual and perennial non-legume forage crops was investigated for mixed cultivation with either legume tree.

## 2. MATERIALS AND METHODS

### 2.1. Site

The experimental site lies at 33°E and 30°S at an altitude of 200 m above sea level in Ismailia Experimental Station. The climate is characterized by (a) range of rainfall, 0.0–22.2 mm, (b) temperature of 13–23 °C in winter and 19–29 °C in summer and (c) relative humidity of 50–70%.

### 2.2. Soil

The field trials were executed in sandy soils of the following properties: total nitrogen, 0.012%; EC, 0.72 dS·m<sup>-1</sup>; pH, 8.9 and saturation percentage of 20.0.

### 2.3. Seeds

Leucaena (*Leucaena leucocephala*) Lam. Dewit and sesbania (*Sesbania sesban*) seeds were obtained from farms of the Faculty of Agriculture, Cairo University. Seeds were drilled in hills at rates of 62.5 and 25 kg·ha<sup>-1</sup> for leucaena and sesbania respectively. Seeds of associative grasses used were pearl millet (*Pennisetum typhoides*) local landrace and sudan grass (*Sorghum sudanense*) cv. Piper in summer followed by rye grass

(*Lolium multiflorum*) cv. Caramba and barley (*Hordeum vulgare*) cv. Giza 124 in winter; in addition to perennial Rhodes grass (*Chloris gayana*) cv. Katambora. Seeds were drilled at respective rates of 21, 31.5, 50, 150 and 15 kg·ha<sup>-1</sup>. Grass seeds were kindly provided by the Forage Research Department, Agricultural Research Center, Giza, Egypt.

### 2.4. Diazotroph strains and inoculation

Local strains of *Rhizobium* spp. specific for leucaena (L9) and sesbania (S3H) were used. A composite inoculum including five associative N<sub>2</sub>-fixing bacterial strains (*Azospirillum brasilense*, *Azotobacter chroococcum*, *Bacillus polymyxa*, *Klebsiella pneumoniae* and *Pseudomonas putida*) was applied for non-legumes. All strains were obtained from the culture collection of ESRU, Faculty of Agriculture, Cairo University.

Rhizobia were grown separately in yeast extract manitol broth medium [19] and incubated with shaking at 30 °C for 3 days. The cultures were mixed at the rate of 2:1 (v/w) with fine peat previously neutralized with 5% CaCO<sub>3</sub>. For the composite inoculum of associative diazotrophs, each strain was separately grown in combined C-source liquid culture medium [9] and incubated for 3–5 days at 30 °C with continuous shaking. Equal volumes of each liquid culture were mixed and added to neutralized fine peat. The peat based inoculum was adjusted to 60–70% WHC, then packed in plastic bags (100 g·bag<sup>-1</sup>), sealed and stored in the refrigerator. Prior to sowing, legume seeds were soaked in boiled water that was left to cool overnight. Seeds were coated by peat mixed with Arabic gum (10 g / 3 ml / 100 g seeds), mixed uniformly and kept in the shade. For non-legume seeds, composite peat prepared for inoculation was drilled in rows (400 g·plot<sup>-1</sup>) before sowing. An extra dose of the respective liquid cultures was sprayed over the seeds before covering at the rate of 1 l·plot<sup>-1</sup>.

### 2.5. NPK and organic fertilization

Superphosphate (P<sub>2</sub>O<sub>5</sub>, 15%) and potassium sulphate (K<sub>2</sub>O, 50%) were incorporated into the soil at respective rates of 300 and 125 kg·ha<sup>-1</sup>. Ammonium sulphate (N, 20.6%) was added as 75, 150 or 300 kg N·ha<sup>-1</sup> in 4 successive doses at 0, 27, 89 and 141 days after sowing. A slow release organic fertilizer in the form of animal manure (C / N, 4:1) was applied at the rate of 4760 kg·ha<sup>-1</sup>. The water regime was sprinkling irrigation.

## 2.6. Experimental design

The plot size was 4 m<sup>2</sup> (2 m × 2 m) including 5 rows 40 cm apart (3 for legumes alternated with 2 for non-legumes). Each treatment was replicated 4 times in a randomized split plot design.

## 2.7. Growth parameters

Plants were cut, at 10 cm height, at 58, 98 and 142 days after sward establishment for summer forage crops and 128, 178 and 276 days for winter ones. Herbage production for each cut was determined for plots as biomass and nitrogen [4] yields. For legumes, plants were uprooted and roots were washed free of soil to determine the number and dry weight of nodules.

## 2.8. Statistical analysis

The statistical programme of MSTAT version 4.00 / EM was used for computer analysis.

## 3. RESULTS

The response of pure summer non-legume stands to inoculation was limited to < 10% in the presence of a low N-fertilization level of 150 kg·ha<sup>-1</sup>. Raising the N dose to 300 kg·ha<sup>-1</sup> resulted in higher biomass yield and magnified the positive effect of inoculation (Tab. I). As much as 22.9% increase for pearl millet and 43.0% for sudan grass were attributed to inoculation. With rational dose of 75 kg N·ha<sup>-1</sup>, pearl millet when mixed with sesbania did significantly produce a seasonal dry matter yield comparable to that obtained by plants grown in pure stands receiving a full dose of 300 kg N·ha<sup>-1</sup>. In this particular case, inoculation of both partners significantly increased the yield of the three cuts accounting for a general increase of 25.3% in total seasonal yield. Intercropping with leucaena, as well, was very supportive for dry matter production of pearl millet with respective yield increases of 38.5 and 39.3% over uninoculated and inoculated pure swards supplemented with 150 kg N·ha<sup>-1</sup>. Responses to either diazotroph inoculation, N fertilization and intercropping with both legume partners were reported, but with lower magnitude, for sudan grass biomass yield.

In general, variations in N yields of non-legume forage crops between inoculation and N fertilization treatments followed somewhat similar trends to those of dry matter. Positive correlations were recorded for N yield with biomass production of the three successive harvests

**Table I.** Dry matter and N yields of pure and mixed stands of summer annual pearl millet and sudan grass as affected by inoculation, N fertilization and legume partners.

Treatments	Dry matter (kg·plot <sup>-1</sup> )		N yield (g·plot <sup>-1</sup> )	
	Uninoc.	Inoc. <sup>a</sup>	Uninoc.	Inoc. <sup>a</sup>
Pearl millet + 150 kg N·ha <sup>-1</sup>	5.09	4.63	41.50	41.60
Pearl millet + 300 kg N·ha <sup>-1</sup>	5.64	6.93	58.10	65.10
Pearl millet + 75 kg N·ha <sup>-1</sup> when mixed with sesbania	5.30	6.64	49.90	68.30
Pearl millet + 75 kg N·ha <sup>-1</sup> when mixed with leucaena	7.05	6.45	63.60	60.80
Sudan grass + 150 kg N·ha <sup>-1</sup>	0.92	1.00	10.10	9.05
Sudan grass + 300 kg N·ha <sup>-1</sup>	0.86	1.23	9.84	11.80
Sudan grass + 75 kg N·ha <sup>-1</sup> when mixed with sesbania	1.53	1.59	20.60	18.90
Sudan grass + 75 kg N·ha <sup>-1</sup> when mixed with leucaena	1.50	1.44	17.40	17.70

LSDs at 0.05 for dry matter and N yields are 0.47 and 9.13 respectively.

<sup>a</sup> Inoculation for leucaena and sesbania with specific rhizobia, and for non-legume with a composite of associative diazotrophs.

( $r = 0.603, 0.357$  and  $0.606$ ) as well as of the total seasonal yield ( $r = 0.513$ ).

Response of non-legumes to intercropping considerably varied depending upon the adjacent legume partner. In the presence of 75 kg N·ha<sup>-1</sup>, uninoculated sudan grass accumulated higher quantities of N (104.0%) than pearl millet (20.2%) when intercropped with sesbania compared to mono-cropped ones received 150 kg N·ha<sup>-1</sup>. Respective increases of 72.3 and 53.3% were estimated for non-legumes neighbouring leucaena. Inoculation of both companions supported better N-accumulation in non-legumes.

As a winter non-legume crop, barley supplemented with 300 kg N·ha<sup>-1</sup> did not respond to inoculation with the mixed inoculum of associative diazotrophs (Tab. II). Reducing the quantity of N fertilizer to 150 kg N·ha<sup>-1</sup> somewhat lowered the dry matter yield. Under these conditions, an increase of ca. 29% was attributed to inoculation. Exceptional biomass was reported for 75 kg N·ha<sup>-1</sup>-fertilized barley, whether inoculated or not, when intercropped with sesbania; three- to four-fold increases in total seasonal yield were obtained. Leucaena, as well, supported better growth of barley, however increases were not comparable to those recorded in the case of sesbania.

**Table II.** Dry matter and nitrogen yields of pure and mixed swards of winter annual barley and rye grass attributed to inoculation, N fertilization and legume partners.

Treatments	Dry matter (kg·plot <sup>-1</sup> )		N yield (g·plot <sup>-1</sup> )	
	Uninoc.	Inoc. <sup>a</sup>	Uninoc.	Inoc. <sup>a</sup>
Barley + 150 kg N·ha <sup>-1</sup>	0.58	0.75	4.97	4.95
Barley + 300 kg N·ha <sup>-1</sup>	0.75	0.74	7.21	9.34
Barley + 75 kg N·ha <sup>-1</sup> when mixed with sesbania	2.43	2.11	19.01	18.68
Barley + 75 kg N·ha <sup>-1</sup> when mixed with leucaena	1.64	1.76	15.39	16.06
Rye grass + 150 kg N·ha <sup>-1</sup>	1.96	2.02	18.08	20.05
Rye grass + 300 kg N·ha <sup>-1</sup>	2.46	2.22	25.75	27.26
Rye grass + 75 kg N·ha <sup>-1</sup> when mixed with sesbania	2.11	2.76	10.27	15.77
Rye grass + 75 kg N·ha <sup>-1</sup> when mixed with leucaena	1.98	2.17	10.77	10.56

Respective LSDs (0.05) for dry matter and N yields are 0.38 and 13.04. <sup>a</sup> Inoculation for leucaena and sesbania with specific rhizobia, and for non-legume with a composite of associative diazotrophs.

Pure stands of rye grass positively responded to an increased N fertilization regime; up to 26% higher biomass yield was attributed to raising N level from 60 to 300 kg N·ha<sup>-1</sup>. Diazotroph inoculation resulted in a slight increase (< 4%) in the presence of a low N fertilization rate. Mixed cultivation with legumes improved biomass production of rye grass. Increases associated with sesbania were ca. 8 and 37% without and with inoculation, respectively. Corresponding increases connected with leucaena were only 1 and 7%.

As expected, raising the N fertilization dose from 150 to 300 kg N·ha<sup>-1</sup> increased the N yield of uninoculated pure canopies of barley and rye grass by 45.1 and 42.4% respectively (Tab. II). Respective increases for inoculated swards were 88.7 and 36.0%. More than 10–14 g N·plot<sup>-1</sup> were scored for barley intercropped with sesbania or leucaena even with reducing the quantity of N fertilizer to 75 kg N·ha<sup>-1</sup>. Inoculation of mixed stands resulted in slight increases in N yields not exceeding 5%.

Compared to barley, N yield of rye grass increased by 6–54% in response to inoculation. On the other hand, intercropping with legumes did not significantly promote the N accumulation in the non-legume forage crop.

Leucaena, compared to sesbania, did not grow normally under Ismailia sandy soil conditions. Plants were stunted and swards were poor.

**Table III.** Biomass and nitrogen yields of pure and mixed stands of sesbania attributed to inoculation, N fertilization and neighbouring non-legume partners.

Treatments	Dry matter (kg·plot <sup>-1</sup> )		N yield (g·plot <sup>-1</sup> )	
	Uninoc.	Inoc. <sup>a</sup>	Uninoc.	Inoc. <sup>a</sup>
Sesbania (0 N)	2.29	3.21	68.70	97.80
Sesbania when mixed with pearl millet + 75 kg N·ha <sup>-1</sup>	3.48	3.76	101.00	106.90
Sesbania when mixed with sudan grass + 75 kg N·ha <sup>-1</sup>	3.73	4.34	111.10	122.20
Sesbania when mixed with barley + 75 kg N·ha <sup>-1</sup>	2.94	2.98	87.42	66.96
Sesbania when mixed with rye grass + 75 kg N·ha <sup>-1</sup>	2.98	2.87	86.43	80.39
LSD (0.05)	0.47		13.04	

<sup>a</sup> Inoculation for leucaena and sesbania with specific rhizobia, and for non-legume with a composite of associative diazotrophs.

Total seasonal yield of non-fertilized sesbania increased by 40.2% as a result of *Rhizobium* inoculation (Tab. III). When cultivated in mixed canopies with either pearl millet or sudan grass supplemented with 75 kg N·ha<sup>-1</sup>, sesbania in particular produced significantly higher biomass for successive cuts (Fig. 1) and cumulative total yield (Fig. 2). Additional increases of 8.1–16.4% in total dry matter yield were ascribed to inoculation. Increases in the legume N yield attributed to inoculation were higher in the mixed stand with sudan grass (10%) than with pearl millet. Irrespective of inoculation, mixed canopies of sesbania with sudan grass and pearl millet showed 33.40 and 20.70 g·plot<sup>-1</sup> more N yields respectively over those grown as single swards. In the majority of cases, intercropping with winter non-legumes, barley or rye grass, had no effect on N yield of the legume partner.

Biomass and N yields of pure and mixed stands of perennial Rhodes grass, leucaena and sesbania according to N fertilization and inoculation with respective composite inoculum of associative diazotrophs and rhizobia are presented in Table IV. Uninoculated full N-dressed grass produced a two-fold increase in dry matter yield compared to the corresponding treatment supplied with a half dose of N fertilizer. Inoculation with mixed inoculum of associative diazotrophs, particularly in the presence of a half N dose, did satisfy a part of the grass

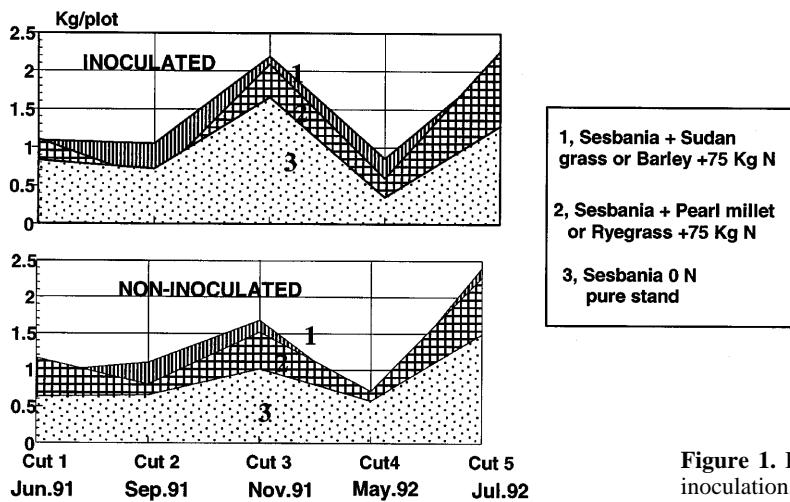


Figure 1. Biomass yield of perennial sesbania as affected by inoculation, N-fertilization and mixed cultivation.

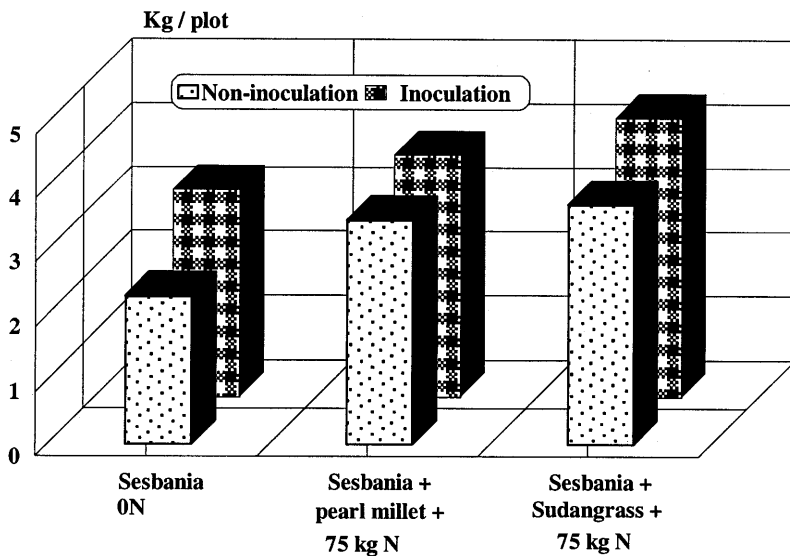


Figure 2. Dry matter yield of sesbania as affected by rhizobia inoculation, N fertilization and mixed cultivation with pearl millet and sudan grass.

N needs and supported 20% yield increase over non-inoculated control. Organic amendment showed no beneficial influence on Rhodes dry matter production. Intercropping of the grass with sesbania dramatically improved its seasonal yield. In the presence of a rational N dose ( $75 \text{ kg N}\cdot\text{ha}^{-1}$ ), biomass yield of mixed sward was significantly higher compared to pure stand fertilized with a full N dose; percentage increases were 65.9 and 29.6 for inoculated and non-inoculated plants respectively. Respective increases of 91.5 and 22.5% were recorded for mixed cultivation with leucaena. Generally, leucaena supported better development of

neighboring Rhodes grass compared to sesbania particularly with inoculation where an increase of  $0.63 \text{ kg}\cdot\text{plot}^{-1}$  was obtained for Rhodes + leucaena system.

Sesbania grown in pure stand significantly responded to inoculation where total seasonal yield increased by 39.6%. Presence of a non-legume partner together with the forage legume generally benefited the growth of the latter. This is demonstrated by the land equivalent ratio (LER). Values of 0.81–1.82 were calculated for the total yield of sesbania in various mixtures (Tab. V). Uninoculated leucaena grew rather poor and did not

**Table IV.** Dry matter and nitrogen yields of perennial forage crops as affected by inoculation, fertilization and mixed cultivation.

Treatments	Dry matter (kg·plot <sup>-1</sup> )		N yield (g·plot <sup>-1</sup> )	
	Uninoc.	Inoc. <sup>a</sup>	Uninoc.	Inoc. <sup>a</sup>
Rhodes grass + 150 kg N·ha <sup>-1</sup>	1.40	1.68	11.62	11.74
Rhodes grass + 300 kg N·ha <sup>-1</sup>	2.84	2.46	25.98	17.92
Rhodes grass + Organic fertilizer*	1.27	1.10	8.45	6.88
Rhodes grass + 75 kg N·ha <sup>-1</sup> when mixed with leucaena	3.48	4.71	26.01	35.06
Rhodes grass + 75 kg N·ha <sup>-1</sup> when mixed with sesbania	3.68	4.08	31.33	28.92
Leucaena (0 N)	nd	1.82	nd	54.69
Leucaena when mixed with Rhodes grass + 75 kg N·ha <sup>-1</sup>	nd	1.71	nd	44.61
Sesbania (0 N)	2.60	3.63	64.33	87.72
Sesbania when mixed with Rhodes grass + 75 kg N·ha <sup>-1</sup>	2.84	3.44	82.34	75.75

LSDs (0.05) for dry matter and N yields are 0.52 and 12.33 respectively.

\* Animal manure (C/N, 4:1).

nd, not determined, dwarf plants (7–8 cm).

<sup>a</sup> Inoculation for leucaena and sesbania with specific rhizobia, and for non-legume with a composite of associative diazotrophs.

support biomass production for successive cuts. Inoculated sward produced a seasonal yield of 1.82 kg·plot<sup>-1</sup> which represent 50% of the biomass produced by sesbania. Mixed cultivation with the non-legume did not seriously affect the development of leucaena.

Rhodes grass supplemented with 300 kg N·ha<sup>-1</sup> contained the highest quantities of N with a 123.6% increase

over the corresponding treatment which received 150 kg N·ha<sup>-1</sup>. Inoculation with associative diazotrophs, in the presence of 300 kg N·ha<sup>-1</sup> in particular, did not increase the non-legume N uptake. Mixed cropping with legumes significantly improved N yield of the grass. Regardless of legume companion, increases of 124–170 and 146–199% without and with inoculation were scored respectively.

Nitrogen yield of sesbania responded to *Rhizobium* when grown alone, where a 36.4% increase was recorded as a result of inoculation. In the mixed stand, the effect of inoculation was somewhat less pronounced. Intercropping of non-inoculated sesbania with Rhodes grass increased the N yield by 18.01 g·plot<sup>-1</sup> compared to the pure stand. For leucaena, mixed cultivation lowered the N content of the plant, but differences were statistically insignificant.

Table VI presents the number and dry weight of sesbania and leucaena root nodules in pure or mixed canopies with pearl millet or sudan grass. Irrespective of the treatment and cropping system, leucaena plants possessed a very low number of nodules with low biomass which slightly increased following *Rhizobium* inoculation. Sesbania plants, in contrast, were well nodulated (11–21 nodules·plant<sup>-1</sup>). Inoculation successfully resulted in increases of 38–118% in numbers and 72–154% in biomass of root nodules.

#### 4. DISCUSSION

The introduction of nitrogen-fixing trees (NFTs) into agroforestry and silvo-pastoral systems can make a major contribution to sustainable agriculture through: (a) potential BNF due to their ability to establish in N-deficient soils and benefits of N<sub>2</sub>-fixed to associated or succeeding crops, (b) building up, restoring and maintaining

**Table V.** LER values for total seasonal biomass yield of sesbania and intercropped non-legumes.

Treatments	Pearl millet	Sudan-grass	Barley	Rye-grass	Rhodes grass
Non-inoculated	1.82 <sup>a</sup>	1.32	1.18	1.13	1.37
	0.82 <sup>b</sup>	3.04	4.65	1.82	2.24
Inoculated <sup>c</sup>	1.53 <sup>a</sup>	0.99	0.81	0.89	1.14
	1.06 <sup>b</sup>	3.19	3.45	1.38	2.17

<sup>a</sup> LER for sesbania; <sup>b</sup> LER for associated non-legumes; <sup>c</sup> inoculation for leucaena and sesbania with specific rhizobia, and for non-legume with a composite of associative diazotrophs.

Where LER =  $\sum_i I_i / M_i$

Where I<sub>i</sub> = intercropped yield ith species

M<sub>i</sub> = monoculture yield of the same species

When LER is significant (more than 1) overyielding has occurred.

**Table VI.** Nodulation of sesbania and leucaena in pure stands or mixed with non-legumes.

Treatments	Number (per plant)		Dry weight (mg·plant <sup>-1</sup> )	
	Uninoc.	Inoc. <sup>a</sup>	Uninoc.	Inoc. <sup>a</sup>
Sesbania	21	29	67	115
Sesbania when mixed with pearl millet + 75 kg N·ha <sup>-1</sup>	11	24	89	194
Sesbania when mixed with sudan grass + 75 kg N·ha <sup>-1</sup>	14	25	35	89
Leucaena	1	6	nd	2
Leucaena when mixed with pearl millet + 75 kg N·ha <sup>-1</sup>	1	1	nd	nd
Leucaena when mixed with sudan grass + 75 kg N·ha <sup>-1</sup>	0	5	0	8

<sup>a</sup> Inoculation for leucaena and sesbania with specific rhizobia, and for non-legume with a composite of associative diazotrophs.

soil fertility, (c) providing food, feed and fuelwood and (d) combating erosion and desertification. The native *Sesbania sesban* (*S. aegyptiaca* as it was previously known) and *Leucaena leucocephala* as perennial fodder crops were investigated in the present study for cultivation in Ismailia sandy soils either in pure stands or intercropped with some annual and perennial forage crops. Compared to other NFTs, leucaena is a promising candidate for marginal soils as it is characterized by a longer tap root and a high rate of annual leaflet drop amounting to 1.2 ton dry matter and 30 kg N·ha<sup>-1</sup>. Leucaena, once established, can survive in areas with ca. 600 mm annual rainfall [8]. This might explain its relatively poor development under the semiarid conditions of Ismailia sandy soils. A maximum seasonal biomass yield of  $\leq 1.82$  kg·plot<sup>-1</sup>, corresponding to 2720 kg·ha<sup>-1</sup>, was obtained only with *Rhizobium* inoculation. Native rhizobia specific for leucaena were absent in the experimental field, and inoculation resulted in limited nodulation ( $< 6$  nodules·plant<sup>-1</sup>); a topic that requires further investigation. It is observed that the tree grew slowly, and by 6–12 months it could not withstand prevailing semi-arid conditions to produce sufficient biomass to justify its use in agroforestry as a fodder crop.

Sesbania is grown for its biomass which is used, in the case of annual types, as fodder and green manure, in particular *S. rostrata*. The perennial types are commonly

used for fodder, soil fertility improvement and fuelwood production [8]. A major advantage of sesbania is their rapid early growth, and that many species are tolerant of a number of stress conditions, e.g. waterlogging, saline, drought and alkaline conditions. *Sesbania sesban*, together with *S. grandiflora*, are the major perennial sesbania that attract attention and were observed to show great promise. They are having a wide range of edaphic and climatic niches, and distributed throughout the tropics with representatives native to all continents including Africa [5]. The most common type in Egypt is most probably *S. sesban* var. *aegyptiaca* (or var. *sesban*) and/or var. *nubica*. They develop wild in all geographical zones of the country and in various soil types.

Under experimental sandy soil conditions of Ismailia deserts, sesbania developed nicely and produced seasonal biomass of more than 5 000–9 000 kg·ha<sup>-1</sup>. A yield that is similar to those reported in the literature, with an average of 9 000–13 600 kg·ha<sup>-1</sup> [15, 16]. The obtained sesbania dry matter production is somewhat comparable to that reported for other perennial legume forage crops such as alfalfa (7 500–6 800 kg·ha<sup>-1</sup>; Rammah, personal communication). Also, results indicated that native rhizobia were effective and further improvement in numbers and biomass of nodules (38–72.7%) are guaranteed by rhizobia inoculation, an effect that was reported for other legumes grown in the same experimental site [10]. In addition, nodule biomass of berseem clover was significantly increased in response to intercropping with either barley or rye grass as well as to introduction of associative diazotrophs to the mixed stand. With respect to non-legume forage crops, pearl millet was more productive (4–7 kg·plot<sup>-1</sup>) compared to other annual and perennial crops. Pure stands positively responded to inoculation with a mixture of associative diazotrophs and increases in seasonal biomass yield ranged from 3 to 43%. While increases due to inoculation were pronounced under moderate N supply for winter barley and rye grass, the higher dose of 300 kg N·ha<sup>-1</sup> supported better responses of summer pearl millet and sudan grass to inoculation. It is probable that the summer environmental conditions of warm temperatures and long days support a faster growth and hence additional nutrient requirement [18]. Corresponding increases attributed to inoculation in N-yield were also reported for pearl millet (12.1%), sudan grass (19.9%), barley (29.5%) and rye grass (10.9%).

Intercropping of legumes and non-legumes under Ismailia sandy soil conditions resulted in obvious increases of non-legume production. The seasonal biomass yield dramatically increased (up to ca. 4–319%). In parallel, increases in N-yield ranged from 20 to 283%. The cropping system recommended is probably

crop-dependent. For non-legumes, pure stands are relatively productive in the case of the fast-growing and high yielding pearl millet. On the other hand, cropping of slow-growing non-legumes is preferred in a mixed pattern with sesbania as the overall yield per unit area is tremendously increased. This can be expressed by LER values which ranged from 1.23 to 4.65. The most productive mixtures with sesbania were of Rhodes grass followed by sudan grass, rye grass and barley. Intercropping also supported better growth for sesbania where higher biomass yield was secured. In accordance with these findings, Hanan et al. (1994) demonstrated that yield of intercropped berseem clover was higher with barley (16–81%) and rye grass (3–34%). This is explained as a plant effect, the deeper and more anchoring roots of barley, in particular, might facilitate close interaction with the root environment of berseem plants. In addition to yield increases, intercropping improved the quality of herbage yield, e.g., protein, crude fiber and ash yield [13]. As to sesbania, results of [17] indicated that addition of *S. aegyptiaca*, with a ratio of 25–50%, to grasses (fodder pearl millet and sorghum) enhanced the crude protein of the mixture to 11–14%, decreased NDF to 52.3% and noticeably changed ADF value and lignin content of the mixture.

Among the factors that support growth of non-legumes mixed with legume [11, 14] is N-transfer from the legume to the non-legume partner. Under Ismailia conditions and with legume-non-legume mixture, N-transfer did take place with values ranging from 50 to 433 kg N·ha<sup>-1</sup>. This depended upon the genotype of each partner, pattern of intercropping, population densities of plants and environmental conditions [3, 10, 12, 20]. Based on N-differences, results obtained during the present study indicated N-transfer to sudan grass (20–27.5 kg N·ha<sup>-1</sup>), barley (36.3 kg N·ha<sup>-1</sup>), Rhodes grass (45–50 kg N·ha<sup>-1</sup>) and pearl millet (20–70 kg N·ha<sup>-1</sup>). It is concluded that intercropping of forage grasses with legumes is of economic and environmental return under semiarid conditions of Egyptian deserts. Sesbania performs better in particular when intercropped with sudan grass.

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