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Full Length Research Paper

Effect of rhizobial strains and sulphur nutrition on mungbean (*Vigna radiata* (l.) wilczek) cultivars under dryland agro-ecosystem of Indo-Gangetic plain

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A field experiment was conducted to find out the effect of rhizobial strains (Uninoculated, Tal 442 and MO 5), and sulphur (S) levels (15, 30 and 45 kg ha^{-1}) on mungbean cultivars (SML-668, Pusa Vishal, and HUM-1). Rhizobium strains, at par among themselves, and significantly superior over uninoculated. Cultivar HUM-1 and application of 45 kg S ha^{-1} recorded higher plant height, primary branches, green trifoliates, leaf area index, dry matter accumulation, nodule numbers and nodule dry weight, increased days to maturity, number of pod and higher grain and straw yield as compared to cultivars Pusa Vishal and SML-668, and S application at 15 and 30 kg ha^{-1}, respectively. Nodule number was highest in HUM-1 × MO 5 and application of 45 kg S ha^{-1} in Pusa Vishal and HUM-1. Maximum dry matter recorded with HUM-1 × 45 kg S ha^{-1}. Strain MO 5 showed maximum grain protein irrespective of cultivars and sulphur levels.

Key words: Agronomic evaluation, organic farming, protein content, sulphur removal.

INTRODUCTION

Mungbean (*Vigna radiata* L.) is an important legume of Asian origin, and is widely cultivated in the countries of Asia, Australia and Africa continents (Yang et al., 2008). It is an important summer pulse crop of many South Asian countries including India, Pakistan and Bangladesh, Thailand and Korea (Hussain et al., 2006). Because of its ecological versatility, mungbean is widely cultivated in various climate and geographical regions of India, playing an important role in local economy and sustainable agriculture.

It is an established practice to use mungbean rhizobia as inoculants, which enrich soil nitrogen leading to increased crop yield. One of the impediments to higher nitrogen fixation efficiency is the inability of rhizobia used as inoculants to form the majority of nodules under field conditions. Competition from indigenous strains usually limits the performance of the inoculant strains (Keyser and Cregan, 1987). Along with that inadequacy of compatibility between the field rhizobia and the legume is often considered as being the major cause of suboptimal yields (Amarger, 2001). It is therefore important to identify the strain responsible for nodulation.

India is the world's largest producer of pulses and occupies about 23 million ha area covering different soil types (Srinivasarao et al., 2004). Sulphur (S) deficiency in these soils is widespread and extended up to 60% of total pulse area (Ganeshamurthy and Saha, 1999). Deficiency of S is progressively increasing due to intensive cropping systems and use of S free fertilizers usage. An insufficient supply of S can affect yield and quality of the crop adversely (Scherer et al., 2006); because S is required for protein and enzyme synthesis as well it is a constituent of the amino acids methionine and cysteine (Scherer, 2001). Application of 30 kg S ha^{-1} in mungbean was found optimum and this dose can increase plant height, primary branches, functional leaves, dry matter, nodule number and nodule weight per plant seed yield (Singh and Yadav 1997).

There is also variation among cultivars in their response to Rhizobial strains or sulphur application. Therefore, mungbean cultivars need to be evaluated for

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their genetic potential to produce nodules with particular rhizobial strains and for the nitrogen fixation potential of the nodule produced (Pohelman, 1991).

The effect of rhizobial strains, sulphur nutrition and mungbean cultivars only has been investigated in isolation; therefore, information on the integrated application of these factors is lacking. The present investigation was conducted to study the interactive effects of rhizobial strains and sulphur nutrition on mungbean cultivars under dryland agroecosystem Indo-Gangetic plain of India.

MATERIALS AND METHODS

Site and soil information

A field trial was carried out at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during rainy seasons of 2003 and 2004. The experimental site was located at 25°18'N, 83°30'E and at an elevation of 128.93 m above mean sea level and represents the Indo-Gangetic alluvial plains of India. The predominant soil in the experimental field was sandy clay loam classified as Inceptisol (Typic Ustochrept) with a pH of 7.42, and 0.43% organic matter. Available N (197.02 to 200.18 kg ha^{-1}) and S (18.25 to 18.34 kg ha^{-1}) contents were low whereas, available P (23.41 to 25.64 kg P_2O_5 ha^{-1}) and K (210.2 to 211.0 kg K_2O ha^{-1}) were medium. Approximately 85% of the total annual rainfall is received from June to September. During the study, the total annual rainfall in 2003 and 2004 was 984.1 and 928.46 mm, respectively. The average maximum temperature during the study ranged between 31.1 to 34.4°C in 2003 and 24.2 to 38.6°C in 2004 whereas the average minimum temperature were 24.8 to 28.8°C during 2003 and 25.2 to 27.4°C during 2004.

Trial establishment

The experiment was laid out in a split-split plot design with three replications in a plot size of 5 × 3.6 m. Main-plot treatment comprised of three cultivars of mungbean *viz.* SML-668, Pusa Vishal, HUM-1 (Malviya Jyoti). Three level of sulphur 15, 30 and 45 kg ha^{-1} were applied in sub-plot whereas in sub-sub plots three rhizobium inoculations (uninoculated control, Inoculated with Tal 442 and MO 5) were allocated randomly.

Cultivar SML-668 was developed by Punjab Agricultural University, Ludhiana, India, whereas Pusa Vishal and HUM-1 (Malviya Jyoti) were developed by Indian Agricultural Institute, New Delhi, India and Banaras Hindu University, Varanasi, India, respectively. Strain Tal 442 was obtained from NifTAL, Hawai, USA whereas; MO 5 is a local strain of mungbean (*V. radiata*) rhizobia obtained from Department of Genetics and Plant Breeding, Banaras Hindu University, Varanasi. MO 5 was released in All India Coordinated Pulse Improvement Project after rigorous test in rhizobium-plant interaction trial for five year at various agro-climatic zones of India.

In the thoroughly prepared seed bed, a uniform dose of 16 kg N, 46 kg P and 48 kg K was supplied through 100 kg DAP and 80 kg MOP prior to sowing. Sowing was done in rows spaced at 30 cm apart on 18th July, 2003 and 16th July, 2004 having a recommended seed rate of 20 kg ha^{-1}.

The Rhizobium cultures used were Mo 5 and Tall 442 which was carrier based cultures. The required quantity of the cultures, that is, @ 200 g culture per 10 kg seed was mixed to 10% sugar solution to form slurry. The slurry was sprinkled on seeds and mixed with hand to make a uniform coating over the seeds and then the seeds were spread on a polythene sheet in shade to avoid direct sunlight. Seeds were sown immediately.

Sulphur was applied 21 days before sowing to the +S plots in the form of elemental agricultural S. Weeds, diseases and insects were regularly controlled with a range of commercial chemicals based on standard procedures. Harvest began on 13 September and ends on 23 September, on both the year.

Biometrical observation

Growth parameters like plant height (cm), number of primary branches ($plant^{-1}$), number of green trifoliates ($plant^{-1}$), leaf area index (LAI), dry matter (DM) accumulation (g $plant^{-1}$) were recorded periodically but it was presented only at 60 DAS in this paper. Leaf area index (LAI) was calculated using formula as mentioned below. Leaf area is:

$$\boldsymbol{Leaf\ Area\ Index}\ (LAI) = Leaf\ area/Ground\ area$$

Leaf area of plant was measured using leaf area meter "Systronics Leaf Area meter- 211" The dry matter accumulation by above-ground biomass and nodules were recorded after drying at 60°C for 3 days.

The mature pods of crop were picked manually twice during the growth after 60 days of sowing. Nodule number ($plant^{-1}$) and nodule dry weight (mg $plant^{-1}$) was presented at 45 DAS. Crop growth rate (CGR) was computed as per procedure described by Radford (1967). Yield and yield attributes were recorded at harvest, whereas, protein-content and sulphur removal were estimated after harvest. Protein content in grain was computed by multiplying the nitrogen content in grain with the factor 6.25, as suggested by AOAC (AOAC 1970). Sulphur removal that is, sulphur uptake by above ground biomass, was worked out by turbidimetric method as suggested by (Quin and Wood 1976).

Data analysis

Data were analyzed separately for both years. Bartlett's test was used to test for homogeneity of variance among treatments. After testing for homogeneity, all data were subjected to analysis of variance as described by Gomez and Gomez (1984) and mean separation accomplished by least significant difference (LSD) at the 5% level of probability. Only significant interaction effects among different factors are presented. Three-way interactions were not significant and thus are not presented.

RESULTS AND DISCUSSION

Effect of mungbean cultivars

Cultivar HUM-1showed higher plant height, number of primary branches, number of green trifoliates, LAI, shoot dry matter, nodule-dry weight (Table 1) and nodule-number (Table 3) and had taken more time to maturity (Table 1) as compared to cultivars Pusa Vishal and SML-668. Pod to shoot ratio was found non-significant between cultivars. Cultivar HUM-1 showed significantly higher CGR from 15 to 30 to 45 to 60 days stage of crop growth over Pusa Vishal and SML-668. Pusa Vishal and SML-668 recorded almost equal CGR.

Table 1. Effect of rhizobial strains, sulphur levels and Cultivars on plant height, primary branches, green trifoliate and leaf area index (LAI), nodule dry weight, days to maturity, shoot dry weight and pod: shoot ratio in Mung bean.

Treatments	Plant height (cm)		Number of primary branches (plant^{-1})		Number of green trifoliate (plant^{-1})		Leaf area index		Nodule dry weight (mg plant^{-1})		Days to maturity		Shoot dry matter (g)		Pod : Shoot ratio	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Cultivars																
SML-668	56.23	57.92	7.63	8.53	13.11	14.44	1.714	1.804	78.34	97.85	61.65	62.16	9.06	10.54	0.504	0.507
Pusa Vishal	58.29	58.27	8.29	9.07	15.14	16.58	1.858	1.840	81.90	101.07	62.06	62.41	9.94	11.21	0.523	0.526
HUM-1	64.31	65.24	9.06	9.96	16.98	18.38	1.981	1.994	85.63	105.66	67.13	67.52	11.86	13.24	0.483	0.487
LSD (0.05)	4.97	5.13	0.78	0.81	1.79	1.98	0.186	0.178	6.56	7.76	2.89	2.51	0.66	0.85	NS	NS
Sulphur levels (kgha^{-1})																
15	57.27	58.49	7.61	8.51	13.52	14.81	1.641	1.751	80.61	99.54	62.73	63.02	9.87	11.20	0.513	0.514
30	59.90	61.26	8.33	9.23	15.14	16.54	1.942	1.919	82.23	101.55	63.79	64.18	10.22	11.50	0.519	0.523
45	60.63	61.97	9.04	9.94	16.57	18.05	1.967	1.969	83.40	102.99	64.68	64.89	10.77	12.29	0.516	0.519
LSD (0.05)	2.53	2.26	0.27	0.30	1.45	1.35	0.134	0.121	2.33	2.57	1.92	1.83	0.48	0.44	NS	NS
Rhizobial strains																
Uninoculated control	58.11	58.63	7.88	8.78	14.37	15.69	1.662	1.6333	80.16	98.40	62.93	63.55	9.90	11.09	0.511	0.513
Tal 442	59.69	61.23	8.41	9.31	15.11	16.51	1.923	1.9833	82.22	102.79	63.73	64.21	10.43	11.89	0.505	0.506
MO 5	60.03	61.57	8.68	9.58	15.74	17.21	1.968	2.0213	83.00	103.39	64.36	64.74	10.54	12.02	0.509	0.508
LSD (0.05)	1.66	2.05	0.14	0.16	0.69	0.77	0.083	0.057	1.69	2.15	0.66	0.64	0.29	0.39	NS	NS

* *$P < 0.05$*, NS- not significant.

At harvest, HUM-1 produced maximum number of pod while lower pod length, number of seed per pod, 1000-seed weight. Whereas, Pusa Vishal recorded vice-versa response as compare to HUM-1 that is, minimum number of pod but maximum pod length, seeds per pod, 1000-seed weight (Table 2). Pusa Vishal and SML-668 showed similar number of pod and 1000-seed weight. HUM-1 yielded significantly more grain and straw than Pusa Vishal and SML-668. SML-668 recorded minimum yield, both grain and straw, though it was statistically at par with the Pusa Vishal for grain yield. Cultivar SML-668 recorded maximum protein content in grain (Table 5) and straw (Table 6), though it was at par to Pusa Vishal. HUM-1 though recorded minimum protein content. Similar varietal response also obtained for sulphur content in grain and straw (data not shown). Tested cultivars exhibited similar sulphur removal by biomass (Table 3).

Increase in crop growth and yield by HUM-1 was due to one or a combination of reasons: (1) this cultivar produces higher number of green trifoliates and LAI. The amount of photosynthesis is a function of the total leaf area and the solar radiation intercepted (Poehlman, 1991). Therefore, higher number of green trifoliates and LAI is directly proportional to photosynthate production. This might be reason for increased shoot dry weight by HUM-1. Higher shoot dry weight clearly implies that it act as big source that can support larger sink that is, number of pod per plant, thereby resulted in higher grain yield; (2)

Table 2. Response of rhizobial strains, sulphur levels and cultivars on yield attributes, yield and total sulphur removal by mung bean.

Treatments	Yield attributes								Yield				Total sulphur removal (kg ha^{-1})	
	Number of Pod (plant^{-1})		Pod length (cm)		Number of seed (pod^{-1})		1000 seed weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})			
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Cultivars														
SML-668	13.35	15.72	7.04	7.26	8.72	8.94	46.41	46.57	1036	1284	2225	2787	11.40	14.99
Pusa Vishal	12.49	14.75	7.60	7.83	9.85	10.06	47.51	47.68	1116	1435	2598	3390	11.99	16.50
HUM-1	21.54	25.31	6.32	6.51	8.69	8.89	35.43	35.71	1334	1680	2994	3800	12.34	16.69
LSD (0.05)	1.07	1.38	0.37	0.38	1.12	1.21	2.40	2.58	127	165	284	344	NS	NS
Sulphur levels (kgha^{-1})														
15	14.76	17.42	6.83	7.03	8.69	8.89	42.16	42.30	1048	1333	2354	3037	10.19	13.82
30	15.89	18.70	6.99	7.21	9.10	9.30	43.15	43.30	1164	1467	2552	3280	12.01	16.06
45	16.72	19.66	7.14	7.36	9.29	9.49	44.04	44.36	1275	1599	2911	3660	13.86	18.16
LSD (0.05)	0.47	0.54	0.17	0.17	0.47	0.56	0.58	0.61	78	97	109	154	1.09	1.51
Rhizobial strains														
Uninoculated control	15.37	18.13	6.92	7.14	9.02	9.22	42.75	42.90	1110	1380	2472	3099	11.00	14.51
Tal 442	15.83	18.66	7.00	7.21	9.11	9.31	43.19	43.36	1171	1495	2631	3397	12.51	16.94
MO 5	16.17	18.99	7.03	7.25	9.16	9.36	43.40	43.69	1204	1525	2715	3482	13.05	17.54
LSD (0.05)	0.29	0.35	NS	NS	NS	NS	0.38	0.35	41	55	76	102	0.50	0.63

*$P < 0.05$, NS- Not significant.

Table 3. Interaction effect of cultivars with rhizobial strains and sulphur levels on nodule density of mung bean.

Cultivars	Nodule number (plant^{-1})[a]															
	Rhizobial strains								Sulphur levels (kg ha^{-1})							
	2003				2004				2003				2004			
	Un-inoculated	Tal 442	MO 5	Mean	Un-inoculated	Tal 442	MO 5	Mean	15	30	45	Mean	15	30	45	Mean
SML-668	26.02	28.11	28.86	27.66	28.59	30.89	31.72	30.40	24.61	28.47	29.91	27.66	27.04	31.29	32.87	30.40
Pusa Vishal	27.06	30.69	31.43	29.73	29.74	33.72	34.53	32.66	24.46	29.77	34.94	29.72	26.88	32.72	38.39	32.66
HUM-1	27.57	32.89	34.17	31.54	30.29	36.14	37.55	34.66	28.06	31.07	35.5	31.54	30.83	34.14	39.01	34.66
Mean	26.88	30.56	31.49		29.54	33.58	34.60	29.54	25.71	29.77	33.45		28.25	32.72	36.76	
LSD (0.05)																
Cutivars (C)			2.40			2.64					2.40			2.64		
Levels of sulphur (S)											1.30			1.43		

Table 3. Contd.

Rhizobial strain (R)	0.99	1.09		
R at same/different C	1.72	1.89		
C at same/ different R	3.32	3.65		
S at same/different C			2.26	2.48
C at same/ different S			3.01	3.31

*$P < 0.05$.[a]Observed at 45 days after sowing.

Table 4. Interaction effect of cultivars and sulphur levels on dry matter accumulation in mung bean.

Cultivars	Shoot dry matter accumulation (g plant^{-1})[a] Sulphur levels (kg ha^{-1})			
	15	30	45	Mean
SML-668	10.14	10.12	11.35	10.54
Pusa Vishal	10.97	11.53	11.13	11.21
HUM-1	12.48	12.85	14.39	13.24
Mean	11.20	11.50	12.29	
LSD(0.05)				
Sulphur at same/different level of cultivars			0.762	
Cultivars at same/ different level of sulphur			1.043	

* $P < 0.05$.[a] Observed at 60 days after sowing.

HUM-1 recorded higher nodule growth, it is hypothesized that these nodules are effective and helps in better nitrogen fixation thereby resulted in higher grain yield; (3) HUM-1 recorded increase days to maturity, it clearly means more duration provided for photosynthate production and accumulation; (4) HUM-1 recorded higher CGR, it is hypothesized that this cultivar had nutrient-efficient genotype (NEG). NEG may have an increased capacity (i) to exploit the soil (large root surface area), (ii) to convert non available nutrient forms into plant-available forms, and/or (iii) to take up nutrients across the plasma membrane (Rengel, 2001). (5) Low protein content in HUM-1 hypothesized to be due to, this cultivar being relatively longer in duration, higher CGR and that too support larger sink thus more amount of than protein is utilized in developmental process rather accumulated in the grain and straw.

Effect of levels of sulphur

Plant height, number of primary branches, number of green trifoliates, LAI, shoot dry matter accumulation (Table 1), nodule-number (Table 3), nodule-dry weight, and days to maturity (Table 1) increased with application of 45 S kg ha^{-1} in comparison to 15 and 30 kg S ha^{-1}. Significant variation on CGR observed with application of 45 kg S ha^{-1} during 45 to 60 days stage during first year, and 15 to 30 days and onward stages during second year (Figure 1a and b).

Application of 45 S kg ha^{-1} recorded significantly highest yield (grain and straw) and yield attributing characters *viz.* number of pod, pod length, seed per pod, and 1000-seed weight (Table 2). Similarly, increase in protein-content (Table 5) and sulphur-removal (Table 2) were recorded with application of 45 kg S ha^{-1}. Minimum protein content and sulphur removal was associated with 15 kg S ha^{-1}.

Table 5. Interaction effect of rhizobium inoculation with cultivars and sulphur levels on protein content in grain and straw mung bean .

Rhizobial strains	Grain protein content (%)															
	Cultivars								Sulphur levels (kg ha^{-1})							
	Grain				Straw				Grain				Straw			
	SML-668	Pusa Vishal	HUM-1	Mean	SML-668	Pusa Vishal	HUM-1	Mean	15	30	45	Mean	15	30	45	Mean
Uninoculated control	24.03	22.82	22.04	22.96	6.72	6.79	5.95	6.49	21.91	23.28	23.70	22.96	6.14	6.59	6.72	6.48
Tal 442	24.45	23.59	22.98	23.67	6.83	7.02	6.20	6.68	22.56	23.74	24.72	23.67	6.32	6.73	7.01	6.69
MO 5	24.65	23.96	23.34	23.98	6.89	7.13	6.30	6.77	22.78	24.02	25.16	23.99	6.38	6.81	7.13	6.77
Mean	24.38	23.46	22.79		6.81	6.98	6.15		22.42	23.68	24.53		6.28	6.71	6.95	
LSD (0.05)																
Cutivars (C)			1.33			0.37										
Levels of sulphur (S)										0.51				0.15		
Rhizobial strain (R)			0.17			0.05				0.17				0.05		
R at same/different C			0.293			0.09										
C at same/ different R			0.980			0.278										
S at same/different R										1.347				0.372		
R at same/ different S										0.293				0.09		

* *$P < 0.05$.*

Table 6. Interaction effect of cultivars and sulphur levels on straw protein content in mung bean.

Cultivars	Straw protein content (%)							
	2003				2004			
	Sulphur levels (kg ha^{-1})				Sulphur levels (kg ha^{-1})			
	15	30	45	Mean	15	30	45	Mean
SML-668	6.75	6.75	6.93	6.81	7.00	7.58	7.21	7.26
Pusa Vishal	6.10	7.29	7.55	6.98	6.24	6.59	7.25	6.69
HUM-1	5.82	6.09	6.55	6.15	5.96	6.17	6.77	6.30
Mean	6.22	6.71	7.01		6.40	6.78	7.08	
LSD (0.05)								
Cultivars (C)			0.37			0.60		
Levels of sulphur (S)			0.15			0.22		
S at same/different level of C			0.25			0.374		
C at same/ different level of S			0.418			0.670		

* *$P < 0.05$.*

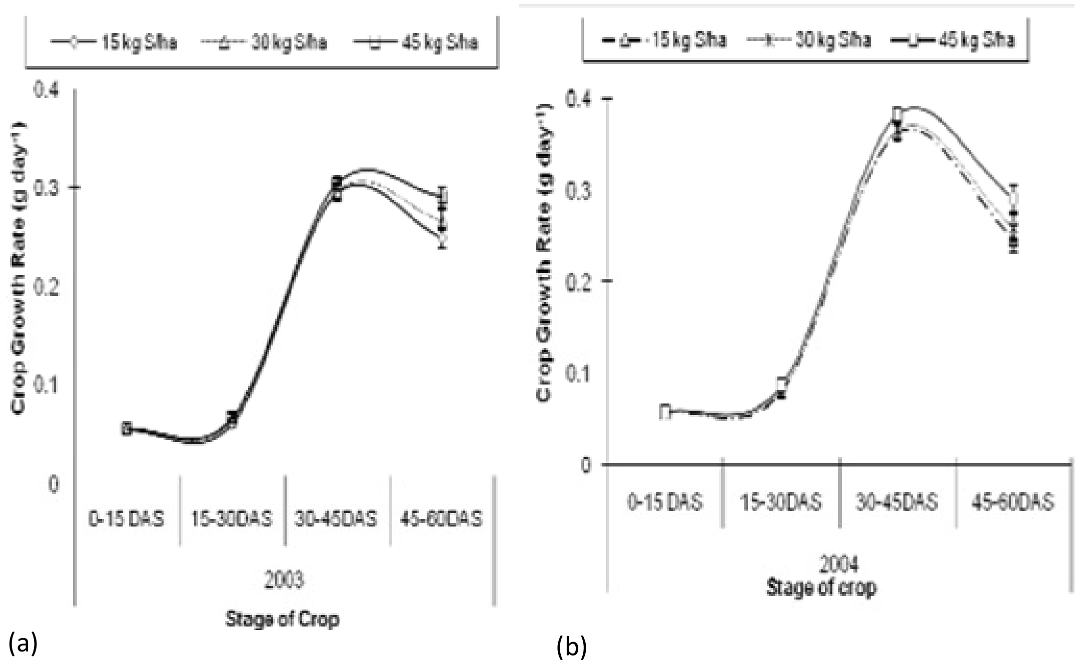

Figure 1a and b. Effect of sulphur levels on crop growth rate at different stage of mung bean.

Due to progressive increase of S deficiency in north-Indian soils (Srinivasarao et al., 2004); all the growth parameters were increased with successively higher level of S (Table 1). Lower S levels resulted in a significant yield reduction of shoots, roots and nodules (Pacyna et al., 2006). Deficiency of S affects number of molecular mechanisms of plants by reduced chlorophyll content (Sexton et al., 1997), reduced amount of glucose and sucrose in shoots and nodules (Scherer et al. 2006) and therefore in a lower photosynthesic rate (Sexton et al., 1997). Since amounts of available photosynthate could become limiting to energy production and as carbon skeletons for ammonia assimilation, and therefore cause a lower N_2 fixation and a reduced yield formation (Scherer et al., 2006). Lange (1998) also suggested that biological N_2 fixation, nodulation, PEP carboxylase and the protein concentration of legumes were reduced with severe S deficiency, while moderate S deficiency diminished the nodule formation and nitrogenase activity. With S deficiency, amino acids and other N forms, accumulating due to lack of being synthesized into proteins, may have some sort of feed-back repression on nitrogen fixation (Janssen and Vitosh, 1974). Whereas, S application might exert flower initiation and increase the seeds per pod by increasing the rate of photosynthesis and transport of sucrose to sink (Marschner, 1988).

Effect of rhizobium inoculation

Both the strains of rhizobium while remaining at par, recorded significantly higher plant growth than the uninoculated control (Table 1). CGR at 30 to 45 days stage also recorded significantly higher with rhizobium inoculation as compared to uninoculated seed.

Rhizobial strains inoculation recorded significantly higher number of pod, 1000-seed weight, grain yield and straw yield (Table 2) than the uninoculated control. Both the rhizobial strains exhibited similar yield attributes and yield (except number of pod and straw yield in 2003). Inoculation with MO 5 recorded maximum protein content in grain (Table 5) and straw (Table 6) followed by Tal 442 and minimum in uninoculated control. Similar trend observed for sulphur removal (Table 2).

Almost all the crop growth characters showed significant difference due to rhizobial inoculation. This is in agreement with those reported by Erman et al. (2009). Variation among isolates may be due to differential adaptation to varied ecological conditions (Amarger, 2001). Increased test weight and grain yield with rhizobial inoculation may be due to better translocation of photosynthates to sink (seed) on assured nitrogen supply and indirect role of nitrogen to help accommodate osmotic imbalances present during final stages of seed filling.

Interaction effect of cultivar, sulphur levels and rhizobium inoculation

Interaction between cultivar x rhizobium and cultivar x sulphur has significantly affect on number of nodules at 45 DAS. In addition, shoot dry matter accumulation significantly interacted with cultivar × sulphur level at 60 DAS during 2004.

At the same level of cultivars, MO 5 strain recorded significantly higher number of nodules among rhizobium treatments (Table 3). SML-668 was least responsive to inoculation with both strains of rhizobium. HUM-1 recorded higher number of nodule with MO 5 strain of rhizobium possible because of highly effective combination of host plant and rhizobia (van Kessel and Hartley, 2000). Rodríguez-Navarro et al. (1999) observed similar interaction effects. In presence of suitable rhizobia strain there is secretion of phenolic compounds, flavonoids, and isoflavonoids by host plant (Peter and Verma, 1990) that resulted in rhizobia-inducing effect, called Ini (increased *nod* gene-inducing activity) in the rhizosphere (Zhang and Smith, 2002) which may result in higher nodule numbers (van Kessel et al., 2000).

Number of nodule and dry matter accumulation significantly increased with application of 45 kg S ha^{-1} in HUM-1, as compared to both the lower dose of S. (Table 4). In S-deficient treatments, mungean nodulation was markedly decreased, which can be attributed to a decline in the requirement for N with reduced S (Lindström et al., 2010). However, according to Scherer and Lange (1996) an increase in the number of nodules by S fertilization of legumes is not the result of increased nodulation per unit length of roots but of a better root growth. HUM-1 had traits of higher growth (table 1) when it was adequately supplied with S it produces more photosynthate, higher carbon metabolism and fixes more N_2 ultimately result in higher dry matter accumulation.

Grain protein content interacted significantly with cultivar x rhizobium, sulphur level × rhizobium in 2003 (Table 5) whereas, straw protein content interacted significantly with cultivar × sulphur level during both year (Table 6). All the three tested cultivars and sulphur levels recorded maximum grain protein content when inoculated with MO 5 rhizobium strain (Table 6). This might be due to MO 5 being ecologically adapted to the locality when supplied with optimum dose of S there is increased biological N_2 fixation, nodulation and PEP carboxylase (Lange, 1998).

In cultivar × sulphur levels interaction, all the three tested cultivars recorded maximum straw protein content when supplied with 45 kg S ha^{-1}. Pusa Vishal and HUM-1 are responsive for S application. Lange (1998) also observed reduced protein concentration with severe S deficiency.

Conclusion

The overall findings indicate that performance of cultivar HUM-1 was better in comparison SML-668 and Pusa Vishal. Application of 45 kg S ha^{-1} showed higher response regarding yield and yield determining parameters. Inoculation with rhizobium strain significantly increased growth, yield and yield attributes compared to uninoculated control. Rhizobium inoculations significantly increase number of nodules in HUM-1 and Pusa Vishal. Application of 45 kg S ha^{-1} recorded maximum dry matter accumulation in HUM-1. Inoculation with MO5 strain recorded maximum protein content in both grain and straw by all the tested cultivars.

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