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Effect of Iron, Molybdenum and *Rhizobium* on Growth, Yield Attributes and Yield of Summer Groundnut (*Arachis hypogaea* L.) in Loamy Sand Soil

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was carried out to see the effect of different levels of iron, molybdenum and *Rhizobium* inoculation on growth, yield attributes and yield in summer groundnut. The experiment comprised eighteen treatment combinations with three levels of iron (0, 5 and 10 kg Fe ha^{-1}), three levels of molybdenum (0, 1 and 2 kg Mo ha^{-1}) and two levels of *Rhizobium* (without *Rhizobium* and with *Rhizobium* inoculation) were studied with GG-34 variety of groundnut in randomized block

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design as factorial with three replications. Among different treatments, the application of 10 kg Fe ha^{-1}, 1.0 kg Mo ha^{-1} and seed inoculation with *Rhizobium* increased pod yield by 12.7%, 10.4% and 6.1%, respectively.

Keywords: Iron; molybdenum; rhizobium; groundnut.

1. INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop belonging to the family *Fabaceae* (or *Leguminosae*). Groundnut is the king of oilseed crops and vegetable oil economy of country depends very much on it. It is mostly grown for seeds and oil production in the world. It is also known as peanut, monkeynut, earthnut, goober and manillanut. Oil seeds have an important position in Indian economy as it contributes almost 4% to gross national product (GNP). India ranks second in groundnut production in world. In India, during 2020-21 groundnut crop cultivated in about 6 million hectares with the total production of 10.24 mt and productivity of 1703 kg ha^{-1}. India ranks second in groundnut production in world. In India, during 2020-21 groundnut crop cultivated in about 6 million hectares with the total production of 10.24 mt and productivity of 1703 kg ha^{-1} (Anonymous, 2021).

Iron is one of the most deficient nutrients in Indian soils. It is a structural component of cytochrome, hematin and leghaemoglobin. It is also important in the activation of several enzymes including fumaric hydrogenase, catalase, dehydrogenase, oxidase and peroxidase. It helps in the absorption of other plant nutrients. Iron is also associated with chloroplast and protein synthesis.

Molybdenum is an essential plant nutrient found in soil. It is also known as ultra-micronutrient as this is required in very little amount. The molybdenum requirement of legumes is mostly higher than grasses. Molybdenum is more accessible in anion form (MoO_4^{2-}) to plants in alkaline soils as it becomes more soluble at higher pH. While in acidic soils its availability decreases due to anion adsorption. Molybdenum plays an important role in nitrogen metabolism and protein synthesis. It is also required for ascorbic acid synthesis. It acts as a cofactor for nitrogenase enzyme and nitrate reductase enzyme [1].

The atmosphere has 78% nitrogen and a part of this nitrogen is fixed by *Rhizobium* bacteria in association with plant roots. This process is called symbiotic nitrogen fixation. Nitrogen fixation is the direct mechanism involved in plant growth and development. The attachment of *Rhizobium* to the root surface is essential for the establishment of a symbiotic relationship. This complex process involves the formation of nod factors by bacteria and the release of flavonoids and isoflavonoids by plant roots. The inoculation of *Rhizobium* for legumes has been used worldwide. Seed inoculation with an efficient *Rhizobium* strain is the cheapest and most important input in leguminous crop production. Inoculation of legume crops with proper strain of *Rhizobium* can fulfil up to 90% of their nitrogen requirements [2].

2. MATERIALS AND METHODS

2.1 Experimental Details

A field experiment was conducted at Agronomy Farm, BACA, Anand Agricultural University, Anand, Gujarat. Geographically, Anand is situated at 22^0 35’ N latitude, and 72^0 55’ E longitude with an elevation of 45.1 m above the mean sea level. The experiment was performed during the summer seasons of 2021 and 2022 and eighteen treatment combinations involving three factors, each of Fe and Mo at 3 levels and *Rhizobium* at 2 levels were taken. levels of iron include 0, 5 and 10 kg Fe ha^{-1}, levels of molybdenum include 0, 1 and 2 kg Mo ha^{-1} and levels of *Rhizobium* include without *Rhizobium* and with *Rhizobium* inoculation were studied with GG-34 variety of groundnut in randomized block design as factorial with three replications to study effect on growth and yield of groundnut.

2.1.1 Site description

The experimental field was well drained and sandy loam in texture.

2.1.2 Crop management

Recommended dose of fertilizer for summer groundnut was 25:50:0 kg of N, P_2O_5 and K_2O/ha, respectively. The whole dose of fertilizer was applied at the time of sowing.

3. RESULTS AND DISCUSSION

3.1 Growth Attributes

3.1.1 Plant height

The application of iron @ 10 kg ha^{-1} exerted a significant effect on plant height at harvest during both the individual years and in pooled as compared to control but remained at par with 5 kg Fe ha^{-1} in the year 2021. The highest plant height in pooled results 46.29 cm was observed with Fe @ 10 kg ha^{-1} (Table 1). The beneficial effect of iron on plant height might be due to the increase in the availability of this nutrient in deficient soil that resulted in more absorption and translocation of nutrients. Similar kind of results was also reported by Trivedi et al. [3] and Gahlot et al. [4]. Application of molybdenum @ 1 kg ha^{-1} significantly increased plant height at harvest compared to the control. The highest plant height *i.e.,* 46.21, 46.18 and 46.20 cm was obtained with the application of molybdenum @ 1 kg ha^{-1} was found at par with 2 kg Mo ha^{-1} in 2022. The considerable increase in plant height might be due to enhanced photosynthesis and biological nitrogen fixation (BNF) that resulted in better growth of taller plants in these treatments. The results of this study also corroborated the findings of Khan and Prakash [5] and Bhattacharya et al. [6]. Significantly the highest plant height at harvest 45.36 cm was observed by the seed inoculation with *Rhizobium*. The increase in plant height might be due to more biological nitrogen fixation and transformation of nitrogen in plants that resulted in better crop growth. Similar beneficial effects were also reported by Khan and Prakash [5] and Kushwaha [7].

3.1.2 Plant dry biomass

Different levels of application of iron, molybdenum and seed inoculation with *Rhizobium* did not have any significant impact on plant dry biomass at 75 DAS. The higher plant dry biomass at 75 DAS in pooled 6.93 g plant^{-1} was observed with 10 kg Fe ha^{-1}. The highest plant dry biomass *i.e.,* 6.95, 6.97 and 6.96 g plant^{-1} was recorded with the application of molybdenum @ 1 kg ha^{-1} during 2021, 2022 and pooled, respectively.

3.1.3 Number of nodules per plant

The application of iron significantly increased the number of nodules per plant with an increasing rate of Fe application up to 5 kg Fe ha^{-1} but remained at par with 10 kg Fe ha^{-1} during both the individual years. The application of 10 kg Fe ha^{-1} produced the highest number of nodules per plant in pooled was 65.59. The increase in number of nodules with a higher doses of iron application is due to an increment in hemoglobin content in living nodules of plants. Our results were also in agreement with Singh et al. [8]. Application of molybdenum 1 kg Mo ha^{-1} noted the significantly highest number of nodules per plant 65.55 in the pooled analysis, but these results remained at par with 2 kg Mo ha^{-1} application during both the individual years as well as in pool. The beneficial effect of Mo application on nodulation might be because Mo increases activity of nitrogenase enzyme and ultimately nitrogen content in plants that also helps in carbohydrate synthesis. This carbohydrate acts as a source of food for *Rhizobium* and thus increases activity of *Rhizobium*. This *Rhizobium* in turn produces a greater number of root nodules. Similar results were also reported by Singh et al. [9]. Number of nodules per plant increased significantly by seed inoculation with *Rhizobium* during both the years and in pooled. The increase in number of nodules per plant due to seed inoculation with *Rhizobium* was to an extent of 64.11 in pooled. The increase in nodule number might be due to the fact that*Rhizobium* is directly involved in biological nitrogen fixation and seed inoculation with *Rhizobium* lead to increase in microbial population which was less in experimental field. The beneficial effect of *Rhizobium* on nodules number was also observed by Basu [10].

3.1.4 Nodule dry weight

10 kg Fe ha^{-1} application significantly produced the highest dry weight of nodules 89.63 mg per plant in pool. However, these results remain at par with 5 kg Fe ha^{-1} during 2022 and pooled. The increment in nodule weight might be due to increased infection and *Rhizobium* colonization in the rhizosphere because of increased availability of iron. The results of the present investigation were in conformity with Meena et al. [11]. Significantly higher nodule weight per plant 89.91 was recorded in pooled with application of 1 kg Mo ha^{-1}. The beneficial effect of Moon nodule weight might be due to the fact that Mo is an essential component of nitrogenase enzyme that helps in nitrogen fixation by directly transferring electrons to diatomic nitrogen and weakens the triple bond between two nitrogen atoms. This process facilitates nitrogen

reduction. Molybdenum application might have increased nitrogenase enzyme activity and thereby increased the biological nitrogen fixation in root nodules which ultimately increased N content in plant. Improved N content in plant accelerated carbohydrate synthesis that serves as a food for *Rhizobium* which resulted in more infection and a greater number of nodules. Similar findings were reported by Agrawal [12]. The results exhibited in Table 1 explicit that dry weight of nodules in groundnut was found significant with seed inoculation with *Rhizobium* during both the individual years as well as in pooled. It might be due to the fact that the *Rhizobium* population in the experimental field was low and seed inoculation with *Rhizobium* increased the number of *Rhizobium* in the field which is involved in nitrogen fixation. Similar findings were also reported by Tiwari et al. [13].

3.2 Yield Attributes and Yield

3.2.1 Number of pods

It is clear from the data presented in Table 2 that different levels of iron significantly affected number of pods per plant during both the individual years as well as in pooled. Significantly highest number of pods per plant *i.e.*, 24.2, 23.6 and 23.9 were recorded in 2021, 2022 and pooled, respectively with application of Fe @10 kg ha^{-1}. Increase in number of pods per plant due to iron application could be attributed to significant effect of Fe on reproductive organs as stamens and pollens of plants. Increase in number of pods per plant also confirms translocation of photosynthates to sink part of plant. Similar results were also reported by Pidadeh et al. [14] and Singh et al. [15]. Significantly higher number of pods per plant *i.e.*, 23.5, 22.7 and 23.1 was recorded in 2021, 2022 and pooled, respectively with application of 1 kg Mo ha^{-1}. The beneficial effect of molybdenum on number of pods per plant might be attributed to the fact that Mo application increases nitrogenase activity and ultimately more N supply to plants through biological nitrogen fixation. This results in better plant growth and yield. Similar results were also reported by Hirpara et al. [16]. Number of pods per plant increased significantly under the influence of seed inoculation with *Rhizobium* during both the individual years as well as in pooled. The number of pods per plant 23.3 was recorded in pooled. The beneficial effect of seed inoculation with *Rhizobium* on yield attributing characters might be due to more nodulation and availability of nutrients, mainly N in readily usable form that increased number of pods. Similar beneficial effect of seed inoculation with *Rhizobium* was also reported by Sajid et al. [17] and Vahideh and Farhad [18].

3.2.2 Pod yield (kg ha^{-1})

Pod yield of groundnut increased significantly with application of higher dose of iron. Application of 10 kg Fe ha^{-1} reported 2938, 2973 and 2956 kg ha^{-1} pod yield in 2021, 2022 and pooled, respectively. Pod yield increased by 12.7 and 6.8 % compared to control and 5 kg Fe ha^{-1} in pooled analysis. The beneficial effect of iron on pod yield might be attributed to the increment in available Fe content in soil which led to more content and uptake by plant that helped in photosynthetic activity in plant and more development of sink part. These results corroborate with Singh et al. [8]. Significantly highest pod yield was reported under application of 1 kg Mo ha^{-1} compared to other treatments. Pod yield under 1 kg Mo ha^{-1} recorded highest pod yield *i.e.*, 2932, 2960 and 2946 kg ha^{-1} in 2021, 2022 and pooled, respectively. The beneficial effect of Mo on pod yield might be attributed to the fact that Mo content in experimental soil was low and application of Mo improved availability of Mo in soil. Moreover, Mo is component of nitrogenase and nitrate reductase enzyme that helps in biological nitrogen fixation. The overall beneficial effect of Mo on growth and yield attributing characters in groundnut led to more pod yield. Similar beneficial effect of Mo on pod yield was also observed by Shil et al. [19] and Singh et al. [15]. Seed inoculation with *Rhizobium* significantly improved pod yield *i.e.*, 2858, 2873 and 2865 kg ha^{-1} in 2021, 2022 and pooled, respectively which was 6.1% higher as compared to control in pooled. This is mainly due to higher number of *Rhizobium* bacteria in treated plots of groundnut compared to control that fixed atmospheric nitrogen and made available to plants besides supplying growth promoting substances which were also responsible for increasing plant growth and yield. Similar findings were also observed by Biswas et al. [20].

3.2.3 Haulm yield (kg ha^{-1})

Application of 10 kg Fe ha^{-1} increased haulm yield by 12.1 and 5.9 % compared to control and 5 kg Fe ha^{-1} in pooled analysis. Iron application improved yield attributing characteristics of groundnut and that cumulative effect resulted in increased haulm yield. The beneficial effect of

Table 1. Effect of iron, molybdenum and *Rhizobium* on plant height, dry biomass, number of nodules per plant and nodules dry weight

Treatments	Plant height (cm)			Dry biomass at 75 DAS (g plant^{-1})			Number of nodules per plant			Nodules dry weight (mg plant^{-1})		
	2021	**2022**	**Pooled**	**2021**	**2022**	**Pooled**	**2021**	**2022**	**Pooled**	**2021**	**2022**	**Pooled**
Iron (kg ha^{-1}):												
Fe_0	42.50	42.42	42.46	6.75	6.72	6.74	57.28	59.98	58.63	80.04	81.09	80.57
Fe_5	44.16	43.91	44.04	6.92	6.88	6.90	61.49	63.13	62.31	84.69	84.91	84.80
Fe_{10}	46.06	46.53	46.29	6.95	6.91	6.93	65.27	65.92	65.59	89.05	90.21	89.63
SEm ±	0.88	0.83	0.61	0.13	0.13	0.10	1.65	1.33	1.06	2.24	2.05	1.52
CD(P=0.05)	2.54	2.39	1.71	NS	NS	NS	4.75	3.83	3.0	6.45	5.90	4.29
Molybdenum (kg ha^{-1}):												
Mo_0	42.66	43.21	42.94	6.66	6.68	6.67	56.81	58.71	57.76	78.90	78.30	78.60
Mo_1	46.21	46.18	46.20	6.95	6.97	6.96	64.26	66.85	65.55	88.70	91.16	89.93
Mo_2	43.84	43.47	43.65	6.84	6.93	6.89	62.96	63.48	63.22	86.18	86.75	86.47
SEm ±	0.88	0.83	0.61	0.13	0.13	0.10	1.65	1.33	1.06	2.24	2.05	1.52
CD(P=0.05)	2.54	2.39	1.71	NS	NS	NS	4.75	3.83	3.0	6.45	5.90	4.29
***Rhizobium*:**												
R_0	43.03	43.30	43.16	6.79	6.75	6.77	59.24	61.24	60.24	81.24	80.74	80.99
R_1	45.45	45.28	45.36	6.96	6.93	6.95	63.44	64.78	64.11	87.95	90.07	89.01
SEm ±	0.72	0.68	0.50	0.11	0.10	0.08	1.35	1.09	0.87	1.83	1.68	1.24
CD(P=0.05)	2.07	1.95	1.40	NS	NS	NS	3.88	3.12	2.45	5.26	4.82	3.51
CV (%)	8.48	7.95	8.22	8.10	7.97	8.02	11.44	8.96	10.25	11.25	10.20	10.73

Table 2. Effect of iron, molybdenum and *Rhizobium* on number of pods per plant, pod yield, haulm yield and seed index

Treatments	Number of pods per plant			Pod yield (kg ha^{-1})			Haulm yield (kg ha^{-1})			Seed index (g)		
	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
Iron (kg ha^{-1}):												
Fe_0	19.0	19.7	19.3	2632	2615	2624	3452	3529	3491	50.0	50.4	50.2
Fe_5	21.5	21.3	21.4	2773	2763	2768	3668	3719	3694	50.5	50.7	50.6
Fe_{10}	24.2	23.6	23.9	2938	2973	2956	3895	3931	3913	50.9	51.3	51.1
SEm ±	0.5	0.5	0.4	54	55	37	77	72	53	0.4	0.5	0.3
CD(P=0.05)	1.3	1.6	1.0	157	159	106	222	206	149	NS	NS	NS
Molybdenum (kg ha^{-1}):												
Mo_0	19.3	19.9	19.6	2697	2638	2667	3500	3528	3514	50.0	50.3	50.2
Mo_1	23.5	22.7	23.1	2932	2960	2946	3907	3921	3914	51.1	51.2	51.1
Mo_2	21.9	21.9	21.9	2764	2755	2760	3608	3731	3669	50.3	50.9	50.6
SEm ±	0.5	0.5	0.4	54	55	37	77	72	53	0.4	0.5	0.3
CD(P=0.05)	1.3	1.6	1.0	157	159	106	222	206	149	NS	NS	NS
***Rhizobium*:**												
R_0	20.1	19.9	19.9	2704	2695	2700	3574	3626	3600	50.2	50.5	50.4
R_1	23.1	23.5	23.3	2858	2873	2865	3769	3827	3798	50.7	51.1	50.9
SEm ±	0.4	0.4	0.3	44	45	31	63	59	43	0.4	0.4	0.3
CD(P=0.05)	1.1	1.3	0.8	128	130	86	181	168	121	NS	NS	NS
CV (%)	9.23	10.83	10.06	8.31	8.46	8.06	8.91	8.17	8.54	3.70	4.16	3.94

iron nutrition on haulm yield was also reported by Gupta and Sahu [21] and Kumawat et al. [22]. Application of 1 kg Mo ha^{-1} increased haulm yield by 11.4 and 6.7% in pooled compared to control and 2 kg Mo ha^{-1}, respectively. The beneficial effect of Mo on haulm yield was observed. It might be attributed to the fact that Mo content in experimental field was low and application of Mo improved content and uptake of Mo as well as N in plants. Moreover, Mo is an essential component of nitrogenase and nitrate reductase enzyme that helped in more biological nitrogen fixation. The overall beneficial effect of Mo on growth characters in groundnut also led to more haulm yield. Similar beneficial effect of Mo on haulm yield was also observed by Harpara et al. [16]. Seed inoculation with *Rhizobium* increased haulm yield of groundnut by 5.6% in pooled. Increment in haulm yield due to seed inoculation with *Rhizobium* might be attributed to the fact that it provides favorable environment in rhizosphere for nutrient absorption by plants that ultimately led to more photosynthesis efficiency and efficient utilization of photosynthates by the plant. Similar results were also reported by Kushwaha [7] and Vahideh et al. (2015).

3.2.4 Seed index (g)

The data presented in Table 2 revealed that different levels of iron, molybdenum and seed inoculation with *Rhizobium* did not have any significant effect on seed index. The highest seed index *i.e.,* 50.9, 51.3 and 51.1 g was recorded with 10 kg Fe ha^{-1} during 2021, 2022 as well as in pooled, respectively. While the lowest seed index was recorded under control during both the individual years and in pooled. Similar findings of non-significant effect of Fe application on seed index in groundnut was also reported by Meena et al. [11]. Numerically the highest seed index *i.e.,* 51.1, 51.2 and 51.1 g was recorded with 1.0 kg Mo ha^{-1} during 2021, 2022 as well as in pooled, respectively.

4. CONCLUSION

Based on the results of two years of experiments on summer groundnut it can be concluded that for obtaining higher yiel groundnutshould be fertilized with 10 kg Fe ha^{-1} along with 1 kg Mo ha^{-1} and seed inoculation with *Rhizobium.* The inoculation of *Rhizobium* for legumes has been used worldwide. Seed inoculation with an efficient *Rhizobium* strain is the cheapest and most important input in leguminous crop production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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