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Effect of sulphur and iron on nodulation, yield attributes and yield of groundnut (*Arachis hypogaea* L.)

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Abstract
An experiment was conducted at Agronomy farm, S.K.N. College of Agriculture, Jobner during kharif season 2017. The treatments comprising four Sulphur levels (control, 20 kg S/ha, 40 kg S/ha and 60 kg S/ha) and four foliar spray of iron (control, foliar spray of 0.5% FeSO4 at flowering, peg formation and flowering + peg formation) assigned to main and subplots of Randomized Block Design, respectively were replicated thrice. Groundnut variety RG-425 (Raj Durga) was used as a test crop. Result showed that increasing in level of S up to 60 kg/ha and foliar spray of 0.5% $FeSO_4$ at flowering + peg formation stages in groundnut resulted significant improvement in nodulation, yield attributes and yield over rest of treatments.

Keywords: Groundnut, iron, nodulation, sulphur, yield attributes

Introduction
Groundnut (*Arachis hypogaea* L.) is a self-pollinated, annual, herbaceous, autotetraploid legume with 2n= 40 chromosomes belonging to the family Leguminosae (Fabaceae). It is also known as the “Wondernut” or “Poor man’s Cashewnut”. It is one of the such plant, the all parts of which contribute to economy of the farmer. It is a world largest source of edible oil, ranks 13th among the food crops as well as 4th most important oilseed crop of the world (Ramanathan, 2001). In world groundnut cover 26.4 m ha area, 37.1 millonmetric ton production and 1400 kg/ha productivity, India rank first in acreage (70 lakh ha), and second in production (85 lakh million tonne), (Anonymous, 2017) [3]. In India, it was cultivated on an area of 6.6 m ha with production of 4.7 MT and productivity of 1486 kg/ha during 2016-2017 (AICRPG, 2016). Currently, six states *viz.*; Gujarat, Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra and Rajasthan account for more than 90 per cent of the total groundnut area and 89.3 per cent of total production. Groundnut is the principal *kharif* oil seed crop of the Rajasthan state. It was grown on 5.90 lakh hectare in the state with total production of 11.40 lakh tones and average productivity of 2051 kg/ha (Anonymous, 2017) [3]. In Rajasthan, the highest yield (2,862 kg/ha) was estimated for Sikar. It is mainly grown in arid and semi-arid districts of Ganganagar, Hanumangarh, Jaipur, Bikaner, Sikar, Churu, Jodhpur, Chittorgarh and Nagaur.

Optimization of mineral nutrition is also a key factor to enhance productivity of groundnut. Sulphur is one of the secondary plant nutrients in which most of the Indian soils are deficient. In Rajasthan, it has been reported to be deficient mainly in the soils of Jaipur, Jodhpur and Udaipur districts (Tandon, 1986) [20]. It imparts important and specific role in the synthesis of sulphur containing amino acids like methionine (20%) and cysteine (27%) and synthesis of proteins, chlorophyll and oil content. Moreover, it is also associated with the synthesis of vitamins (biotin, thiamine), co-enzyme-A metabolism of carbohydrates, proteins and fats. Sulphur is a constituent of protein and play an important role in oil synthesis. Since groundnut is rich in both in oils and protein, requirement of sulphur for this crop is substantial. It improves nodulation and pod yield, reduces the incidences of diseases. Sulphur increases chlorophyll content and decreases chlorosis, (Singh, 2007) [19].

Iron is an essential micronutrient takes active part in the metabolic activities of the plant. It acts as activator of dehydrogenase, proteoses and peptidase enzyme, directly or indirectly involved in the synthesis of carbohydrate and protein in plant. It is a structural component of porphyrin molecule, cytochrome, haems, hematin, ferrochrome, and leghaemoglobin involved in oxidation reduction reaction in respiration or in root reduces. It is an important part of the enzyme nitrogenase which is essential for nitrogen fixation bacteria. The ferredoxins are Fe-S proteins and are the first stable redox compound of the photosynthetic electron transport chain (Havlin *et al*., 1999) [8]. 1% spray of $FeSO_4$ to groundnut increased pod and haulm yield two folds by increasing chlorophyll and active iron. It also plays an important role in legumes for nodulation and nitrogen fixation. Application of iron also found to improve the protein content in groundnut kernels. Application of Fe successfully prevented occurrence of chlorosis and increased chlorophyll content, pod yield and micronutrient uptake (Rabari *et al*., 2018) [14].

Material and Methods

The present study was conducted at Agronomy Farm field no. 3e of Department of Agronomy and the plant and soil samples were analysed in Department of Soil Science and Agricultural Chemistry, S.K.N. College of Agriculture, Jobner (Rajasthan) during the *kharif* season, 2017. Geographically, Jobner is located at 75.28^0 East longitude and 26.06^0 North latitude at an altitude of 427 metres above mean sea level. This region comes under Agro Climatic Zone III-A (Semi-arid eastern plain) of Rajasthan. The climate of the region is typically semi-arid characterized by the aridity of atmosphere and salinity of rhizosphere with extremes of the temperature both during summer and winter. The average rainfall of this region is about 400 to 500 mm (90% of received during monsoon season). The mean daily maximum and minimum temperatures during the growing season of groundnut fluctuated between 31.5 to 36.6 and 13.8 to 26.6 respectively. Similarly, mean daily relative humidity ranged between 37 to 81%. The soil of research site (before kharif 2017) was loamy sand in texture with pH 8.2, organic carbon by Walkley-Black method (1.62 g/kg), EC_e (1.10 ds/m), $KMnO_4$ oxidizable N (131.10 kg/ha), 0.5 M $NaHCO_3$ extractable P (14.9 kg/ha), 1N NH_4OAC extractable K (132.80 kg/ha), available sulphur (8.6 mg/kg) and available iron (2.80 mg/kg).

The field experiment was conducted for one season by taking groundnut crop in randomized block design. Treatment consisted of four level of sulphur (0, 20, 40, 60 kg/ha) and four level of iron (control, 0.5% $FeSO_4$ at flowering stage, 0.5% $FeSO_4$ at peg formation, 0.5% $FeSO_4$ at flowering + peg formation stage to groundnut. The each experimental unit consisted of 3.15 x 4 m plots. The planting of crop involved one ploughing each with cultivator, disc harrow and thereafter planking was done. Before sowing, the seeds were treated with Bavistin @ 2g/kg seed to prevent from seed and soil borne insects, pests and diseases. The RG-425 (Raj Durga) variety (semi-spreading) of groundnut was sown on 3rd July 2017, using seed rate of kg/ha. The recommended dose of fertilizers amounting 20 kg N and 40 kg P_2O_5 /ha were applied to all the treatment as basal dose.

Five plants were randomly selected from each plot and used to calculate the no. of nodules per plant, leg haemoglobin in nodules no. of pods/plant and no. of kernels/pod. The no. of total nodules and effective nodules were calculated by uprooting plant and counted no. of nodules on roots of plant. The crop was harvested manually on 26 October 2017. The weight of harvested produce of each plot was recorded before threshing and expressed as biological yield in kg/ha. After threshing, winnowing and cleaning, the harvest of each plot was weighed separately and convert yield in kg/ha. For calculating seed index 100 kernels were counted and weighed. All the data recorded were analysed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1984) [6] for Randomized block design. The least significant test was used to decipher the effect of treatments at 5% level of significance.

Results and Discussion

Effect of sulphur and iron on nodulation:

Increasing dose of sulphur from 0 to 60 kg/ha significantly enhanced the total number of nodules per plant over lower levels (Table 1). Application of sulphur @ 60 kg/ha significantly increased the total nodules (61.9) per plant by 23.46, 12.95 and 6.40 percent over control, 20 kg and 40 kg S/ha, respectively. Foliar application of 0.5% $FeSO_4$ at flowering + peg formation was found significantly superior on the total nodules per plant at flowering stage over the rest of the treatments. Foliar application of 0.5% $FeSO_4$ at flowering + peg formation was significantly increased the total nodules (62.3) per plant by 23.09, 14.52 and 7.45 percent over control, 0.5% $FeSO_4$ at flowering and peg formation, respectively.

Effective nodules per plant were significantly increased with increasing levels of sulphur up to 60 kg S/ha at flowering stage (Table 1). Application of 60 kg S/ha increased the number of effective nodules per plant by 38.07, 17.86 and 7.80 percent over control, 20 kg S/ha and 40 kg S/ha, respectively. Foliar application of $FeSO_4$ increases no. of effective nodules/plant. Foliar application of 0.5% $FeSO_4$ at flowering + peg formation significantly increased the effective nodules per plant by 36.92, 22.47 and 9.38 percent over control, 0.5% at flowering and 0.5% at peg formation, respectively.

Sulphur is involved in the formation of S containing amino acids, vitamins and has direct role in root growth and nodulation (Jat and Ahlawat, 2009) [9]. The favourable effect of foliar application of fertilizers might be due to on account of improved photosynthetic efficiency and chlorophyll formation. This might be due to readily available Fe at critical stage of plant growth that facilitated maximum nodulation. Meena *et al*. (2013) [11] also hold similar view on the plant growth.

Table 1: Effect of sulphur and iron on total number of nodules and effective nodules at flowering stage

Treatments	Total number of nodules	Total number of effective nodules
Levels of sulphur (Gypsum)		
S_0 (Control)	50.2	38.3
S_{20} (20 kg S/ha)	54.9	45.0
S_{40} (40 kg S/ha)	58.2	49.1
S_{60}(60 kg S/ha)	62.0	52.9
SEm±	1.2	1.0
CD (P=0.05%)	3.4	2.8
Foliar spray of iron ($FeSO_4.7H_2O$)		
Fe_0 (Control)	50.6	39.1
Fe_1 (0.5% at flowering stage)	54.4	43.7
Fe_2 (0.5% at peg formation stage)	58.0	48.9
Fe_3 (0.5% at flowering + peg formation stage)	62.3	53.5
SEm±	1.2	1.0
CD (P=0.05%)	3.4	2.8

Effect of sulphur and iron on yield attributes

Application of sulphur 60 kg /ha significantly increased the no. of pods per plant over control, 20 kg and 40 kg S by 41.36, 22.08 and 9.53 percent respectively (Table 2). The application of 0.5% $FeSO_4$ at flowering + peg formation increased the number of pods over control, 0.5% at flowering and 0.5% at peg formation stage by 32.43, 18.45 and 7.30 percent, respectively.

Seed index of groundnut was significantly improved due to successive increase in level of sulphur up to 60 kg/ha. Sulphur fertilization @ 60 kg/S ha recorded the highest seed index (71.30 g) there by resulting a percent increase of 7.12, 13.40 and 24.06 percent, over 40, 20 and 0 kg S/ha, respectively. Application of 0.5% $FeSO_4$ at flowering + peg formation stage recorded the highest seed index (71.19 g) there by resulting a 5.54, 13.14 and 25.68 percent, over 0.5% at flowering, 0.5% at peg formation and control, respectively.

The improvement in yield attributes of groundnut might be due to better nutritional environment in the root zone for growth and development. The improved growth due to S fertilization coupled with increased photosynthesis on one hand and greater mobilization of photosynthates towards reproductive structures. On the other, might have been responsible for significant increase in yield attributes of groundnut. Besides, Sulphur is involved in the formation of S containing amino acids, vitamins and has direct role in root growth and development processes (Jat and Ahlawat, 2009) [9]. Duraisamy and Mani (2001) [4, 5] concluded that application of iron significantly increased pods per plant, seeds per pod and nodules per plant of horse gram as against the control. Similar results were also reported by Sakal *et al.* Yadav (2002), Gohari and Niyaki (2010) and Jokar, *et al*. (2015) [10].

Table 2: Effect of sulphur and iron on number of pods per plant and seed index of groundnut

Treatments	Number of pods per plant	Seed index (g)
Levels of sulphur (Gypsum)		
S_0 (Control)	27.22	57.47
S_{20} (20 kg S/ha)	31.52	62.87
S_{40} (40 kg S/ha)	35.13	66.56
S_{60} (60 kg S/ha)	38.48	71.30
SEm±	0.71	1.34
CD (P=0.05%)	2.04	3.88
Foliar spray of iron ($FeSO_4.7H_2O$)		
Fe_0 (Control)	28.30	56.64
Fe_1 (0.5% at flowering stage)	31.64	62.92
Fe_2 (0.5% at peg formation stage)	34.93	67.45
Fe_3 (0.5% at flowering + peg formation stage)	37.48	71.19
SEm±	0.71	1.34
CD (P=0.05%)	2.04	3.88

Effect of sulphur and iron on groundnut yield

Pod yield of groundnut was significantly improved due to successive addition in level of sulphur over preceding levels. The highest pod yield 2128 kg/ha was obtained with application of S @ 60 kg/ha there by resulting a percent increase of 84.88, 23.86 and 7.47 per cent over control 20 kg and 40 kg S/ha, respectively. The highest pod yield 2098 kg/ha was obtained with the application of 0.5% $FeSO_4$ at flowering + peg formation stage there by resulting a percent increase of 76.74, 19.68 and 8.25 per cent over control, 0.5% at flowering and 0.5% at peg formation stage, respectively.

Kernel yield was influenced due to graded levels of sulphur application (Table 3). The highest kernel yield 1531 kg/ha was obtained with application of S @ 60 kg/ha there by resulting a percent increase of 84.40, 23.94 and 7.50 per cent over control 20 kg and 40 kg S/ha, respectively. The highest yield of kernels 1510 kg/ha was obtained with the application of 0.5% $FeSO_4$ at flowering + peg formation stage there by resulting a percent increase of 76.72, 19.73 and 8.31 per cent over control, 0.5% at flowering and 0.5% at peg formation stage, respectively.

Table 3: Effect of sulphur and iron on pod, haulm, biological and kernel yield of groundnut

Treatments	Pod yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Kernel yield (kg ha^{-1})
Levels of sulphur (Gypsum)				
S_0 (Control)	1151	1888	3039	828.72
S_{20} (20 kg S/ha)	1718	2284	4002	1236.78
S_{40} (40 kg S/ha)	1980	2586	4566	1425.42
S_{60} (60 kg S/ha)	2128	2755	4883	1531.98
SEm±	48	47	107	31.13
CD (P=0.05%)	140	137	308	89.91
Foliar spray of iron ($FeSO_4.7H_2O$)				
Fe_0 (Control)	1187	1944	3131	854.89
Fe_1 (0.5% at flowering stage)	1753	2281	4034	1262.14
Fe_2 (0.5% at peg formation stage)	1938	2569	4507	1395.34
Fe_3 (0.5% at flowering + peg formation stage)	2098	2719	4817	1510.54
SEm±	48	47	107	31.13
CD (P=0.05%)	140	137	308	89.91

As per the result every increase in level of sulphur from 0 to 60 kg/ha produced significantly higher haulm yield of groundnut in comparison to lower levels (Table 3). It recorded the highest haulm yield (2755 kg/ha) that was 6.53, 20.62 and 45.92 percent higher than obtained with 40 and 20 kg S/ha and control, respectively. The highest haulm yield (2719 kg/ha) was recorded in foliar spray of 0.5% $FeSO_4$ at flowering + peg formation stage, that was 5.83, 19.20 and 39.85 percent higher than obtained with 0.5% at peg formation, 0.5% at flowering and control, respectively**.**

Perusal of data indicated that increasing levels of sulphur resulted in significantly higher biological yield over preceding levels up to 60 kg/ha (Table 3). It recorded the highest biological yield (4883 kg/ha), that was 6.94, 22.01 and 60.67 percent higher than obtained with 40 and 20 kg S/ha and control, respectively. The highest biological yield (4817 kg/ha) was recorded by foliar spray of 0.5% $FeSO_4$ at flowering + peg formation stage. The biological yield increased by 8.31, 19.73 and 76.72 percent higher than obtained with 0.5% at peg formation, 0.5% at flowering stage and control, respectively.

The improved growth due to S fertilization coupled with increased photosynthesis on one hand and greater mobilization of photosynthates towards reproductive structures. On the other, might have been responsible for significant increase in yield attributes of groundnut. Watering and Patrick (1975) [21] also reported that improvement in yield parameters was attributed to diversion of greater proportion of assimilates to the developing pods due to increased sink strength reflected through its larger demand of photosynthates. Supply of sulphur in adequate amount also helps in the development of floral primordial i.e. reproductive parts, which results in the development of pods and kernels in plants. Similar finding has also been reported earlier by Patel *et al*. (2009) [12] in groundnut. The increase in kernel and haulm yield with application of $FeSO_4$ may be attributed to the fact that it induces favourable nutritional environment in rhizosphre and higher absorption of nutrients by plant and consequently led to increased photosynthetic efficiency and higher production of assimilates and that might have favored efficient utilization of photosynthates in native and reproductive structures particularly the kernel which is an ultimate sink of photosynthates. Foliar application of nutrient is a good way for supplying optimum nutrition for crop to complete its reproductive phases for obtaining higher productivity from crop plants. The results of present investigation are in conformity with those of Guruprasad *et al.* (2009) [7], Zeidan *et al.* (2010), Qing *et al*. (2011) [13], Radhika *et al.* (2013) [15] and Sadeghi and Noorhosseini (2014) [17].

Conclusion
Based on the result of one year experimentation, it may be concluded that sulphur fertilization at 60 kg/ha and foliar spray of 0.5% $FeSO_4$. $7H_2O$ at both flowering and peg formation stage was found to be the most superior treatments for obtaining higher nodulation and productivity from groundnut. However, these results are only indicative and require further experimentation to arrive at more consistent and final conclusion.

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