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Effect of Sulphur and Foliar Application of Micronutrients on Yield and Nutrient Uptake of Groundnut (*Arachis hypogaea L*)

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Abstract
A field experiment was conducted at village Raita, Taluka Kalyan, District Thane during Rabi 2023 on peanut crop (Arachis hypogaea L) in a medium black calcareous slightly alkaline soil. The experiment was carried out to study the effect of elemental Sulphur application at the rate of 60 kg/ha along with a foliar spray of micronutrients (Cu 1.0%, Zn 3.0%, Mn 1.0%, Fe 2.5%, B 0.5%, Mo 0.1%). The trial used a Randomized Block Design (RBD) with five treatments that were replicated five times each. T1 is the control, T2 is 100% RDF, or the recommended NPK 25:50:30 alone, T3 is the recommended NPK with 60 kg/ha of elemental S, T4 is the recommended NPK with 60 kg/ha coupled with foliar micronutrient spray, and T5 is the recommended NPK with foliar micronutrient spray. The yield and its attributes were significantly influenced when elemental Sulphur and foliar spray of micronutrients were applied. Plant height, number of pods/plant, and peanut seed output were significantly improved with the application of the prescribed fertilizer dose, 60 kg/ha of elemental sulphur, and a foliar spray of micronutrients (T4). The maximum plant height (56.1 cm), number of pods/plant (35.6), weight of pods/plant (92.1gm), weight of pod (1798.8 kg/ha), Haulm yield (2761.7 kg/ha), Dry weigh/plant (36.60gm), 100 seed weight (44.3gm) were all substantially greater in treatment (T4), Sulphur application of 60kg/ha significantly increased the content and uptake of primary nutrients and micronutrients by the plants at the harvested stage, as well showed a profound effect on soil physico-chemical properties.
Keywords: *Groundnut, Inductively Coupled Plasma Spectrophotometer (ICP-OES), Soil, Fertilizer, Elemental Sulphur (S), Micronutrient foliar application, RDF, RBD.*

1. Introduction
In the agricultural economy of India, oilseeds play a significant role, and India is the world's largest producer of oilseeds. One of the most significant sectors of India's agriculture industry is the edible oil industry. India is the world's largest importer and consumer of edible oils. (*Arachis hypogaea L*)., Groundnut, is one of India's most significant and commercial oilseed crops. It has a high oil content of around 45%, a protein content of 25%, and a carbohydrate content of 10%, making it a rich source of energy. India leads the world in groundnut acres, accounting for 55.6 lakh hectares of annual all-season coverage. It is also the world's second-largest producer, with 101 lakh tonnes of groundnuts produced in 2020–21 at a productivity of 1816 kg per hectare [1]. As per the latest survey in Maharashtra, 187500 hectares were planted in the Kharif groundnut crop in 2019. The crop produced 193827 tons overall, with a productivity of 1034 kg/ha. The most common groundnut cultivars grown in Maharashtra are TAG-24, JKG-194, AK-159, Phule Vyas, Phule Pragati, TG-26, and SB-11 [2]. Groundnuts are a good source of edible oil since they contain between 43 and 55 percent oil and 25 and 28 percent protein [3]. In addition to giving the

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plant the right quantity of each nutrient, balanced plant nutrition practices also maintain the proper proportion of nutrients in the soil [4]. In order to support growth, productivity, and quality in plants fertilizers play an important role in improving soil fertility and maximize key plant characteristics [5]. To improve food quality and population health, plant nutrients especially micronutrients must be readily available. Since peanuts are grown on calcareous soils and have a high soil bicarbonate content, they are lacking in a number of nutrients, including iron, zinc, and sulphur (S). Sulphur is gradually becoming regarded as the fourth most important nutrient after nitrogen, phosphorus, and potassium [6]. Numerous Indian states have been found to be deficient in sulphur; eighty-eight out of four hundred districts have been found to have varying degrees of deficiency. The repercussions of not adding sulphur to soil, or of having sulphur-deficient soil, are low yields and adverse effects on the agro-based economy [7]. According to a recent assessment, the depletion of accessible sulphur in the soil of groundnut-growing regions is caused by high-yielding cultivars of intense cultivation and insufficient application of sulphur-source fertilizers [8]. Micronutrient deficiencies or non-availability also affect groundnuts. Deficits in micronutrients can result in decreased agricultural yield and nutritional value. The condition of the plants acts as a gauge for the nutrients in the soil. Micronutrients are known to be important for improving photosynthesis and enzymatic activities and thus enhancing the grain weight [9]. The addition of elemental sulphur to soils has a major impact. The addition of sulphur fertilizers raises the soil's capacity to hold water and lowers its pH, electrical conductivity, and bulk density [10]. Micronutrients applied through the foliage have more benefits than those applied in soil because nutrient absorption is higher and the application rate is comparatively lower. Furthermore, when roots are unable to provide essential nutrients, foliar therapy is always an appropriate alternative [11]. In alkaline calcareous soils, the oxidation of *S* by biologically decomposing microorganisms yields sulphuric acid, which lowers pH and aids in solubilizing calcium carbonate ($CaCO_3$), improving the growth conditions for plants and boosting the availability of nutrients, proteins, chlorophyll, and vitamins [12].

2. Preparation of Mixture of Micronutrients

In accordance with the guidelines from the Maharashtra Gazette, a multi micronutrient fertilizer was prepared with Cu (1.0%), Zn (3.0%), Mn (1.0%), and Fe (2.5%). B (0.5%), Mo (0.1%). The chemicals used were $CuSo_4.7H_2O$ 4.49gm, $ZnSo_4.7H_2O$ 15.4 gm, $MnSo_4$ 2.71gm, $FeSo_4.7H_2O$, Boric Acid 2.86gm, Ammonium Molybdate 0.72gm, which were dissolved in demineralized water at 65°C-70°C for two hours. The volume was then made up to 100ml and the solution was filtered using Whatman filter paper no.42. This stock solution was diluted to 1ml in 1000ml of distilled water and used as a foliar spray on the crop. Table 1 displays details about the treatments.

3. Methodology

A field experiment was carried out during Rabi 2023 on the peanut crop (*Arachis hypogaea L*) in the village of Raita, Taluka Kalyan, District Thane in Maharashtra. The soil type was medium black calcareous slightly alkaline having a pH 7.5. The purpose of the experiment was to determine the impact of applying elemental sulphur (S) at a rate of 60 kg/ha in combination with the recommended dose of fertilizer RDF (NPK) and foliar spraying micronutrients on the quantity and quality of groundnut crop (*Arachis hypogaea L.*). Additionally, the Food and Agricultural Organization (FAO) technique [13, 14] was used to examine the physiochemical characteristics of soil and plant physical parameters. The experiment was

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laid out in randomized block design. Five treatments with five replicates were set up on a field for the winter. A total of 25 plants made up each replicate, which was about 18 meters in length and 18 meters in width, or 324 square meters. At the time of sowing, four treatments were applied: 25 kg/ha of nitrogen, 50 kg/ha of phosphorous, and 30 kg/ha of potassium as a basal dose. In addition, a basal dose of compost and elemental Sulphur as a source of sulphur were combined and applied. In addition the primary nutrients suphala (N15:P15:K15), urea and diammonium phosphate were utilized. After sixty days, during the blossoming stage, micronutrients were sprayed. Ten of the best plants were picked at random from each row in order to examine the chemical and physical parameters.

3.1 Plant and Chemical Analysis

The entire crop was completely harvested at physiological maturity stage, and samples of the soil and plants were taken for examination. The harvested plants from each treatment were sun dried. The parts of plants viz. root, stem leaves and fruit were separated. The micronutrients were extracted from the parts of plants through wet acid digestion method.

Table 1 Treatments Details

S. No	Treatment
1	Control
2	100% RDF
3	100% RDF + Elemental S
4	100% RDF + Elemental S + Micronutrient
5	100% RDF + Micronutrient

The filtrate was used for determining the micronutrients using an Inductively Coupled Plasma Spectrophotometer to determine the levels of several nutrients, including P, K, S, Cu, Zn, Mn, Fe, B, and Mo. The Kjeldahl method was used to determine the N content. The oil percentage (%) in groundnut seeds was determined by extraction utilizing the Soxhlet equipment and petroleum ether (Bp 60°C) as solvent. Using a spectrophotometer, the protein was estimated using Lowry's technique [14,15]. The treatment details are shown in table 1.

3.2 Statistical Methods

The data obtained was statistically analysed as per the procedures laid by Panse and Sukhatme (1985) [16].

3.3 Yield and Yield Attributes

Plant growth was recorded after sowing of groundnut, 10 plants per treatment were tagged and used for recording of different parts of groundnut parameter. A random sample of 10 plants from each plot were taken at harvesting time (110 DAS) to determine the following characters like height of plant, pod weight, seed weight, dry weight, 100 seed weight, oil content, and protein content.

4. Results and Discussion

The data presented in Table 2 illustrate the effect of treatment (T4) application of 60 kg/ha of elemental sulphur in conjunction with a foliar spray of micronutrients (Cu (1.0%), Zn (3.0%), Mn (1.0%), and Fe (2.5%) B (0.5%) and Mo (0.1%), has Exhibited the best attributes as evidenced by the height of plant, pod weight, seed weight, dry weight, 100 seed weight, oil content, and protein content. This was significantly superior to the 100% RDF, 100% RDF+Elemental Sulphur+100% RDF+ micronutrients, and the control. These observations are similar to the results obtained by Pancholi *et al* [17], and same results were also reported by Nagesh Yadav *et al* [18]. This might have resulted from the interplay between iron, zinc, and sulphur, which promotes the production of chlorophyll and the metabolism of auxins by Jasim *et al* [19]. The application of sulphur might have increased the solubility of micronutrients from the soil and thus higher uptake of nutrient by the crop was noticed. The higher nutrient uptake has increased vegetative growth of the plant that is ultimately enhancing photosynthesis and overall growth of the plant. The results obtained correspond with the finding of Sisodiya *et al* [20]. The treatment (T3) with only sulphur application without micronutrients addition, and treatment (T5) only micronutrient application did not show a significant influence on the crop yield, but the sulphur and foliar application of micronutrients Cu (1.0%), Zn (3.0%), Mn (1.0%), Fe (2.5%), B (0.5%) and Mo (0.1%) combination exhibited overall higher growth of the crop (T4). The T4 has shown highest plant height of (56.10 cm), No. of pods/plant (35.6), the weight of pod/plant (92.1gm), weight of pod yield (1798.8kg/ha), weight of haulm (2761.7kg/ha) dry weight /plant (36.6gm), 100 seed weight (44.3gm), whereas oil and protein content was found non-significant in (T4), followed by T3>T5>T2. While the total growth was found minimum in control (T1). While the dry weight (34.54gm) in (T3) that is 100%RDF+S is at par with T4 (36.60gm).

Table 2 Plant growth yield and yield parameters

S. No.	Treatment	Plant Height	No. of pod/ plant	Weight of pod/ plant (gm)	Weight of pod kg/ ha	Haulm yield kg/ ha	Dry wt/ plant (gm)	100 seed weight (gm)	% Oil content	% Protein content
1	control (T1)	41.22	22.8	80.9	1580.2	2167.9	26.94	31.2	42.8	22.7
2	100% RDF(T2)	50.64	27.8	85.9	1686.7	2324.3	32.11	37.0	42.9	23.1
3	100 % RDF + Elemental S (T3)	51.91	30.6	88.4	1730.0	2607.3	34.54	40.2	43.6	24.2
4	100 % RDF + Micronutrient + Elemental S (T4)	56.10	35.6	92.1	1798.8	2761.7	36.60	44.3	45.1	24.6
5	100 % RDF + Micronutrient (T5)	51.10	27.0	82.5	1611.7	2253.9	27.33	38.7	43.4	23.9
	SEM+_	0.52	0.93	1.16	14.35	31.33	0.72	0.63	0.69	0.48
	CD (.05)	1.56	2.79	3.46	43.03	93.92	2.17	1.88	N.S	N.S
	CV %	2.32	7.22	3.01	1.91	2.89	5.15	3.66	3.56	4.56

**T1: Absolute control, T2: RDF Alone, T3: RDF + elemental sulphur, T4: RDF+elemental sulphur+ foliar spray of Mixture of micronutrients, T5: RDF+ foliar spray of mixture of micronutrient.*

The application of elemental sulphur has resulted in the most significant plant height along with other plant growth parameters. In addition, micro nutrients also become available to the crop that are deemed crucial for plant development and growth. The increased plant height, enhanced pods per plant may have occurred due to the expansion of the photosynthetic surface resulting into more apical growth Dileep D *et.al* [21]. Mixture of micronutrient application not only improved the quality of kernel but also contributed towards substantial increase in pod yield. Similar results were reported by Thokannagari S *et.al* [22]. Dayanand *et al.*revealed that protein (23.36%) and oil content (44.97%) of groundnut kernel significantly increased up to 60 kg S ha- whereas higher oil yield (0.48 t ha-1) obtained at 40 kg S ha-1 [23]. Sulphur plays an important role in plant growth yield and development processes (Chaubey *et al* [24].

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The Table 2 depicts the effect of various level of sulphur and micronutrient addition on the growth and yield attributes of crop. The Figure 2 (a-i) show graphically the yield data. It is clearly seen that the treatment (T4) has shown a positive effect on the growth yield attributes of groundnut crop.

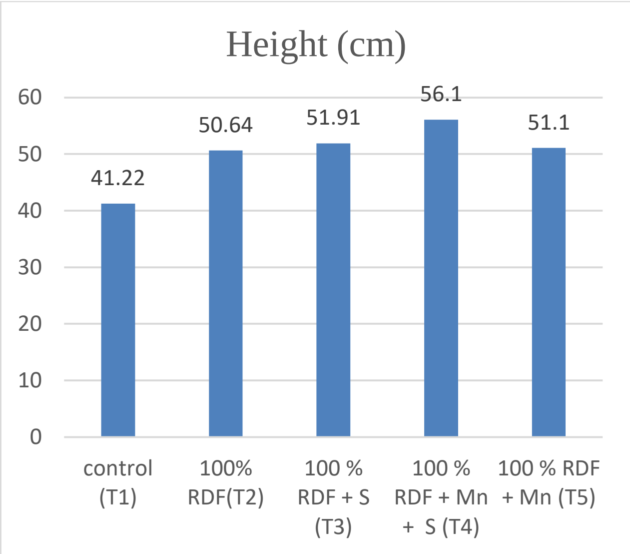

Figure 2a **Graphical Representation on Plant Height**

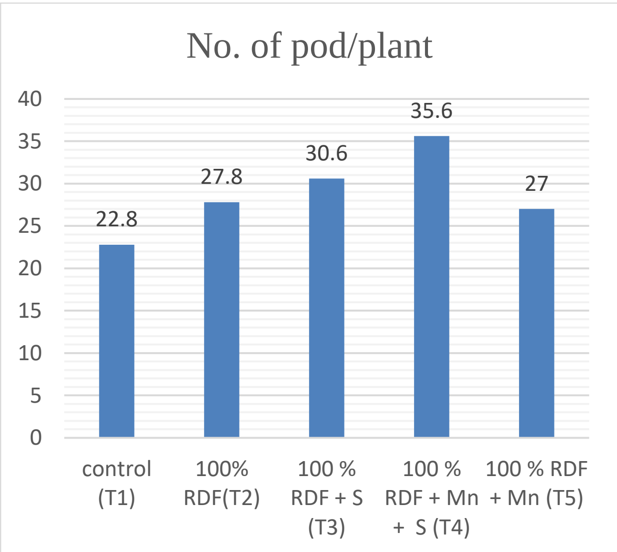

Figure 2b **Graphical Representation on No. of Pods/ Plant**

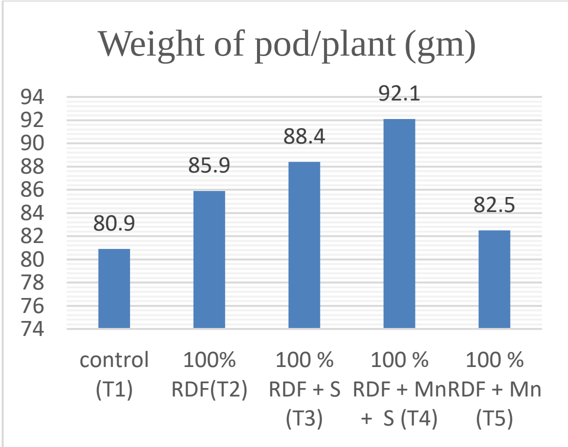

Figure 2c **Graphical Representation on Weight of Pods/ Plant**

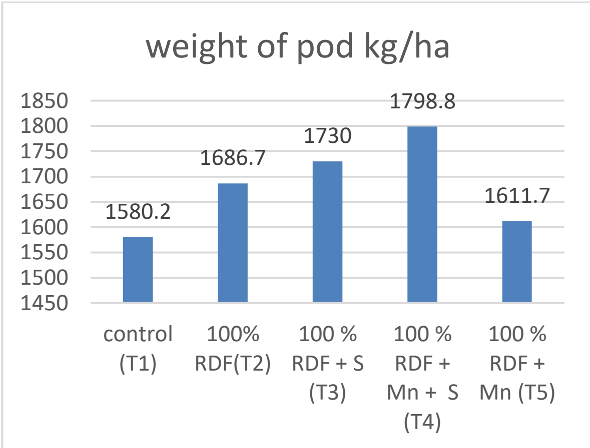

Figure 2d **Graphical Representation on Weight of Pod Kg/ ha**

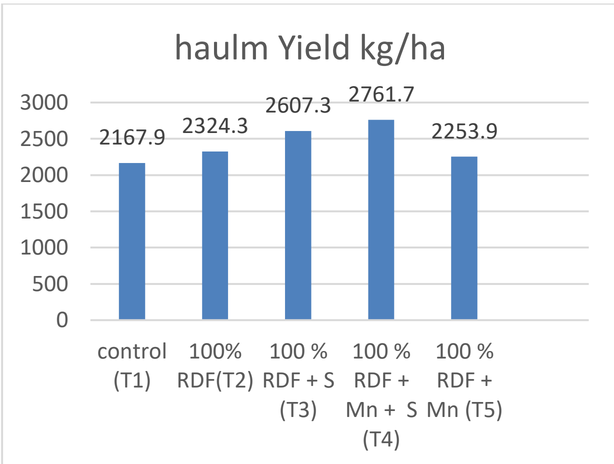

Figure e **Graphical Representation on Haulm Yield Kg/ ha**

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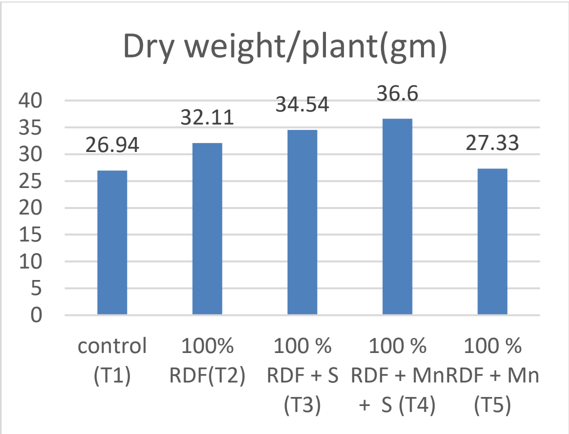

Figure 2f Graphical Representation on Dry Weight/ Plant

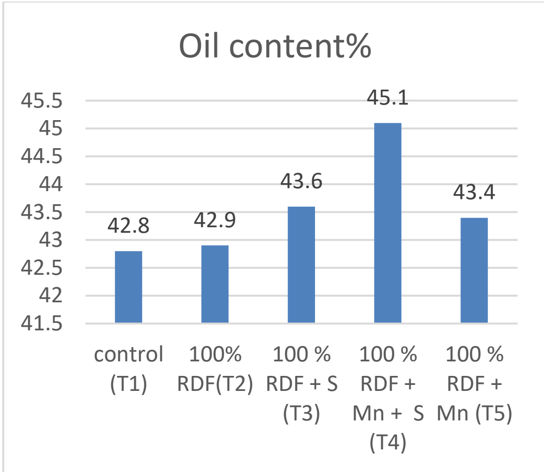

Figure 2h Graphical Representation on Percentage of Oil Content

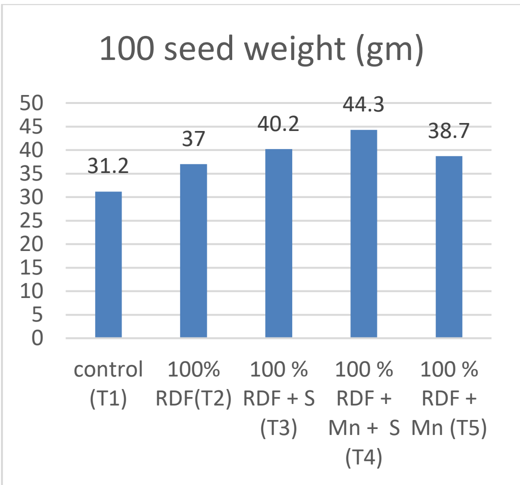

Figure 2g Graphical Representation on 100 Seed/ Plant

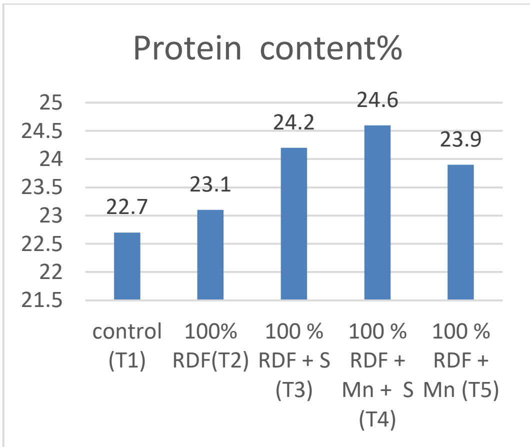

Figure 2i Graphical Representation on Percentage of Protein Content

Figure 2 (a-i) Graphical Representation of Physical Parameter of Groundnut Plant as Influenced by Sulphur Effect

These results confirm the symbiotic role of sulphur and micronutrients and are in line with the finding of Nayak A *et.al* [25], Rajitha G *et.al* [26] and Tejeswara R *et.al*.[27]. Applying sulphur to peanut plants causes a variety of alterations. First, the plant's leaves and stems develop more resistance to environmental factors like dehydration, disease, and insect damage. This occurs as a result of sulphur's ability to lessen plant stress. The increased availability of sulphur will also make the plant bushier and fuller. This is so that the plant can create more chlorophyll and other necessary chemicals, which results in thicker, greener leaves. Sulphur aids in this process. Additionally, sulphur contributes to the plant's general health improvement. It helps the plant absorb nutrients more effectively by raising the concentration of important minerals in the soil. This produces larger and healthier peanut.

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4.1 Effect of Physiochemical Characteristics

Table 3a Micronutrient Uptake by Groundnut Crop (Copper, Zinc, Manganese)

Treatment	Copper gm/ha				Zinc gm/ha				Manganese gm/ha			
	R	S	L	F	R	S	L	F	R	S	L	F
control (T1)	11.29	21.5	8.20	15.64	10.19	22.05	19.28	34.40	30.53	64.37	41.06	11.38
100% RDF(T2)	13.81	27.3	9.26	17.64	17.61	28.42	21.31	48.91	38.72	71.94	43.84	14.07
100 % RDF + Elemental S (T3)	15.6	33.7	11.20	22.37	15.9	32.62	27.85	66.0	45.01	78.84	47.87	16.79
100 % RDF + Micronutrient + Elemental S (T4)	21.09	36.1	14.69	26.97	32.72	35.07	32.64	87.73	65.25	98.98	52.81	18.29
100 % RDF + Micronutrient	12.07	24.7	11.79	18.76	17.56	29.04	24.26	52.98	39.03	68.03	43.61	13.40
SEM+	1.32	2.65	0.94	1.26	0.98	1.18	2.23	2.20	4.09	3.55	1.29	0.61
CD (*P*=0.05)	3.97	7.96	2.83	3.77	2.95	3.53	6.67	6.60	12.26	10.65	3.86	1.82
CV %	20.04	20.71	19.15	13.85	11.69	8.96	19.85	8.49	20.93	10.39	6.27	9.20

Table 3b Micronutrient Uptake by Groundnut Crop (Iron, Boron, Molybdenum)

Treatment	Iron gm/ha				Boron gm/ha				Molybdenum gm/ha			
	R	S	L	F	R	S	L	F	R	S	L	F
control (T1)	864.5	2829.9	691.4	249.2	8.25	49.11	24.06	23.80	1.68	2.97	1.58	0.36
100% RDF(T2)	1040.6	3455.6	920.6	268.9	12.54	57.74	30.03	27.01	1.91	3.01	1.5	0.41
100 % RDF + Elemental S (T3)	1256.6	3654.2	1061.0	309.7	18.99	64.91	35.71	33.06	2.37	3.70	1.83	.0.48
100 % RDF+ Micronutrient + Elemental S (T4)	1750.5	3991.9	1276.5	355.7	28.81	77.23	45.57	42.29	2.61	4.28	2.23	0.59
100 % RDF + Micronutrient	951.9	2904.9	983.5	255.6	18.05	57.04	32.93	29.16	1.49	3.43	1.76	0.39
SEM+	38.54	1795.83	22.36	7.69	0.88	3.59	2.75	1.77	0.11	0.17	0.10	0.02
CD (*P*=0.05)	115.55	N.S	67.04	23.07	2.62	10.76	8.24	5.30	0.34	0.52	0.29	0.06
CV %	7.35	103.82	5.07	5.98	11.3	13.12	18.27	12.72	12.42	11.07	12.28	10.47

**R=Root, S=Stem,L=Leaves, F=Fruit*

**T1: Absolute control, T2: RDF Alone, T3: RDF + elemental sulphur, T4: RDF+elemental sulphur+ foliar spray of Mixture of micronutrient, T5: RDF+ foliar spray of mixture of micronutrients.*

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The data demonstrates the effect of elemental sulphur on the physicochemical characteristics of experimental soil. The pH of the soil decreased from 7.5 to 6.1, which is slightly acidic and thus favourable for oil-seed crops.

4.2 Micronutrient Uptake

Data on micronutrient uptake shown in Table 3a & 3b that micronutrients uptake in different parts of groundnut crop like root, stem, leaves and fruit at harvesting stage was significantly affected by different treatments. The total micronutrient increased by applying 60 kg/ha of elemental sulphur with 100% RDF and sprinkling micronutrients Cu (1.0%), Zn (3.0%), Mn (1.0%), Fe (2.5%), and B (0.5%), Mo (0.1%) on groundnut. Maximum uptake of micronutrient was noticed in different part of groundnut in treatment T4 at harvesting stage. This was significantly superior to the 100% RDF, 100% RDF+Elemental Sulphur, 100% RDF+ micronutrients, and the control. Where minimum micronutrient uptake recorded in control plot. The nutrient uptake was calculated by multiplying nutrient concentration (%) with dry matter yield

Copper Uptake: Results in Table 3a & 3b showed that copper uptake by groundnuts is maximum in T4. Copper uptake in stem was higher in T3 (33.7 gm/ha) at harvesting stage, it remaining at par with T4 (36.1gm/ha). Copper was found maximum in stem and minimum uptake in leaves (14.69gm/ha), followed by fruit (26.97gm/ha), root (21.09gm/ha). While the minimum uptake of copper was found in control T1.

Zinc Uptake: Zinc uptake was maximum recorded in T4, fruit (87.73gm/ha). Zinc uptake in stem T3 (32.62 gm/ha) and in leaves (27.85 gm/ha) during the harvesting stage and remained at par to T4 in stem (35.07 gm/ha) and in leaves (32.64gm/ha). Zinc uptake in root is (32.72 gm/ha). While the minimum uptake of zinc was found in control T1.

Manganese Uptake: The maximum uptake of manganese was found in T4, in stem (98.98 gm/ha) and minimum in fruit (18.29gm/ha), T3 had a higher Manganese level in fruit (16.79 gm/ha) at harvesting stage, and it remained at par with T4 (18.29 gm/ha). Uptake by root (65.25gm/ha) and in leaves (52.81gm/ha) of manganese. While the minimum uptake of manganese was found in control T1.

Iron Uptake: In Treatment (T4) in different part of groundnut crop at harvesting stage, iron was significantly superior over other treatments. Iron uptake found maximum in stem (3991.9 gm/ha), and minimum by fruit (355.7gm/ha), followed by Root (1705.5gm/ha), and Leaves (1276.5 gm/ha), While the minimum iron uptake was found in control T1.

Boron Uptake: In Treatment (T4) highest uptake of boron was recorded in different part of groundnut crop at harvesting stage, it was significantly superior over other treatments, among all the part maximum uptake was found in Stem (77.23gm/ha), and minimum uptake was found in root (28.81gm/ha) followed by leaves (45.57gm/ha) and fruit (42.29gm/ha). While the minimum uptake of boron was found in control T1

Molybdenum Uptake: In treatment T4 highest uptake of molybdenum was recorded in stem (4.28 gm/ha) and minimum in fruit (0.59gm/ha), T3 had a higher molybdenum uptake by root (2.37 gm/ha) and it remained at par with T4 and (2.61 gm/ha), molybdenum uptake in leaves (2.23gm/ha). While the minimum uptake of molybdenum was found in control T1.

These observations are inline to the experimental data published by Chitdeshwari T *et al*. (on groundnut) [28], Sisoodiya R *et al*. (on groundnut) [29]. Similar findings have been reported by Abd EL-Kader *et.al* on groundnut [30]. Arunachalam *et al*.noted that micronutrient application not only improved the quality of kernel but also contributed for substantial increase in pod yield [31]. Wenger *et al*. reported that applying elemental sulphur to plants enhanced the solubility of micronutrients for plant uptake, which in turn led to improved oilseed crop yields [32]. The utilization of elemental sulphur in calcareous soils, resulting in a decrease in soil pH and and increase in P, Fe, Mn, Zn, and Cu availability, was documented by Karimizarchi *et al.* [33]. Elayaraja *et a* observed that necessity of NPK along with the micronutrients supplement improving the soil physico chemical properties and enzymatic activities along with enhanced yield and nutrient uptake of groundnut [34].

Conclusion

The present work of research suggests that the application of application of 60kg/ ha of elemental sulphur along with RDF and foliar application of mixture of micronutrients Cu 1.0%, Zn 3.0%, Mn 1.0%, Fe 2.5%, B 0.5%, and Mo 0.1% as at bud initiation stage leads to higher growth and yield components and greater uptake of micronutrients. The treatment devoid of sulphur and micronutrients has shown lowest yield characteristics as well uptake. Additionally, it also shows that copper, Manganese, Iron, Boron and Molybdenum found maximum uptake in stem. Zinc uptake was found maximum in fruit. These findings confirm the role of elemental sulphur in enhancing the uptake of micronutrients by crop. By implementing the finding of the experiment the yield of groundnut can be increased substantially. The average yield received in Treatment 4 is 1798.8kg/ha this yield is comparable to global average yield 1648kg/ha [FAOSTAT,2021], and higher to the Indian average 806kg/ha [FAOSTAT,2021], in view of this if the practice of using the above combination can assure an increased productivity and higher returns to the farmer.

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Abbreviations

RDF	-	Recommanded Dose of Fertilizers
RBD	-	Randomized Block Design
N:P:K	-	Nitrogen,Phosphorous,Potassium
DAS	-	Days after sowing
kg/ ha	-	kilogramme per hectare

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