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Growth Attributes of Maize (*Zea Mays L*) Crop and Nutrient Uptake as impacted by Sulphur and Micronutrients Application

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Abstract
Maize, also known as the "queen of cereals," is a highly nutritious crop that requires a significant amount of nutrients to grow. It is particularly sensitive to deficiency of sulphur. It plays a significant role in the synthesis of chlorophyll, oil, and protein. A field experiment was conducted at Rashtriya Chemicals and Fertilizers Limited in Mumbai, Maharashtra, during the Kharif season 2023, to assess the impact of elemental sulphur application and foliar spray of multi micronutrient on maize plant growth and uptake of nutrients by maize as well as the post-harvest status of soil. The experiment was laid out in Randomized Block Design (RBD) with five treatments that were replicated six times each. T1 is the absolute control, T2 is 100% RDF, T3 is the RDF NPK with 45 kg/ha of elemental S, T4 is the RDF NPK with 45 kg/ha coupled with foliar spray of multi micronutrient, and T5 is the RDF NPK with foliar spray of multi micronutrient. The results indicated that application of 45 kg of S per hectare, in combination with a foliar spray of multi micronutrients, resulted in remarkable growth parameters of maize crops. These included plant height, cob height, yield (in kg/ha), dry weight per plant and also the uptake of essential nutrients. This was markedly higher when compared to the other treatments. Except 100 grain weight which was at par with other treatments. While girth of cob and protein content were found non-significant. The study reports suggest that the combined use of S and multimicronutrient in maize crop positively impact the uptake of nutrients and growth attributes.

Keywords: *Maize, Inductively Coupled Plasma Spectrophotometer (ICP-OES), Soil, Fertilizer, Elemental sulphur(S), Micronutrient foliar application, RDF, RBD.*

1. Introduction
Maize is considered the third most important crop, following wheat and rice. It stands out amongst all grain crops due to its ability to yield higher productivity in a shorter duration. This versatile and prominent crop can thrive under various agro-climatic conditions, making it a widely adaptable option. Furthermore, maize is the only cereal crop that can be successfully cultivated during different seasons such as Rabi, Kharif, and spring. This could potentially result in a doubling of farmers' income, as each part of maize holds its own economic value. Maize is a rich source of protein (9-10%), starch (71-72%), fibre (4-45%), sugar (2-3%), and minerals (1.4%) of dry matter (Ganesh kumar koli et al.,2022) [1]. Maize is a versatile crop that serves as a fundamental raw material for a vast array of industrial products, including starch, oil, protein, alcoholic beverages, pharmaceuticals, food sweeteners, cosmetics, gum, films, textiles, packaging materials and paper. Its numerous uses make maize an essential component in multiple industries [2]. India ranks seventh among the top maize-producing countries worldwide. Furthermore, it holds the fourth position in terms of the total area dedicated to maize cultivation. As per the data provided by Agricultural statistics at a glance, its production was 33.62 million tonnes from an area of 10.04 million ha with productivity

3.3 tonnes/ha (2021-2022). The maize growing states are Karnataka (15.87%), Madhya Pradesh (13.98%), Maharashtra (12.90), Tamil Nadu (3.99%). The country has exported 3,453,680.58 MT of maize to the world for the worth of Rs. 8,987.13 crores/ 1,116.17 USD Millions in 2022-23 (Apeda 2023) [3, 4]. Sulphur is typically classified as a secondary nutrient, but it is now being recognized as the fourth macronutrient alongside Nitogen, Phosphorous and potassium (Tondon et al 2002) [5]. According to report by the Sulphur institute (TSI,2020) [6]. 40 percent of arable land in India suffer from extreme Sulphur deficiency (Singh et al.,2001) [7]. Sulphur deficiency is a widely observed issue resulting from the absence of organic manure incorporation, soil leaching, erosion, intense cropping practices, and the use of Sulphur-deficient fertilizers (R Arirman et al., 2020) [8]. The utilization of S in agriculture has gained significant attention for its crucial role in enhancing crop quality and yield. This is especially important as there is an increasing trend towards the use of S-free fertilizers and a decrease in the application of organic manures (Raina et al., 2005) [9]. Improving plant nutrition management is crucial for boosting maize production, as mismanagement in this area is considered to be the primary issue. In order to achieve higher yields, it is imperative that we improve this key aspect of production technology. A fundamental element of effective nutrient management is balanced fertilization, which plays a critical role in enhancing crop productivity. This involves applying a well-balanced mix of essential nutrients such as nitrogen, phosphorus, potassium, and sulfur to support major processes in plant development and yield formation. (Randhawa et al., 2000; Saleem et al., 1984) [10]. When Sulphur combined with the recommended dose of fertilizers, these help combat multinutrient deficiency and improve nutrient uptake, efficiency and production (Akhilesh kumar et al.,2012; Bharathi. C et al., 2008; Raman K et al., 2011) [11-13]. Sulphur is a crucial component of amino acids such as cysteine, cysteine, and methionine, making it essential for the formation of proteins. Therefore, it plays a significant role in protein synthesis (Jamel et al., 2010) [14]. Yellowing of young or newly formed corn leaves is a common sign of Sulphur deficiency, causing interveinal chlorosis and reddish stems and leaves. Older leaves may remain green despite deficiency (Tiwari,K.N et al., 2006) [15]. A lack of sulfur can result in a notable decrease in cereal crop productivity (Zhao FJ et al 2001) [16]. Micronutrient deficiency is a global issue affecting soil and plants, affecting growth, flowering, fruit set, higher yield, quality and post-harvest life of horticultural products. (Raja,E.M.et al 2009; Ram,R.A. et al 2000 ; Shekhar C et al 2010) [17-19]. While inadequate quality leads to decreased productivity (Karuna,S, et al 2019; Zagade,P.M et al 2017) [20, 21]. During adverse conditions, soil application alone may not sufficiently fulfill the nutrient needs of crops. In such situations, foliar spraying of micronutrients is required for nutrient supplementation (Oosterhuis,D et al2009) [22]. The factors affect like Soil types, crop plant nature, and soil management practices significantly impact the concentration of available S and micronutrients in soils (Fageria,N.K, et al2002; Scherer,H.W et al2001) [23, 24].

2. Methodology

A field experiment was executed at the premises of Rashtriya Chemicals and Fertilizers Limited, Mumbai Maharashtra during the kharif season of 2023 on maize crop (*Zea mays L*). The objective of this experiment was to investigate the impact of applying elemental sulphur at a rate of 45 kg/ha, in combination with a foliar spray of micronutrients (Cu 1.0%, Zn 3.0%, Mn 1.0%, Fe 2.5%, B 0.5%, Mo 0.1%) on the growth and total nutrient uptake by maize plants in a red slightly alkaline soil. Soil analysis was carried out both at the beginning (April) and after harvest (August) using the Food and Agricultural Organization (FAO) [25, 26] method to assess the physicochemical properties of soil and plant physical parameters. The experiment was laid out in randomized block design. Five treatments with six replicates were set up on a field for the summer. A total of 30 plants made up each replicate, each replicate had one square meter area.

Each plot had five plants. At the time of sowing, four treatments were applied: 120 kg/ha of nitrogen, 60 kg/ha of phosphorous, and 40 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. Furthermore, the primary nutrients of Suphala (N15:P15:K15), urea, and diammonium phosphate were also employed. After a period of sixty days, during the blossoming stage, micronutrients were applied through spraying. Following this stage, a random selection of twelve plants from each treatment was chosen for analysis of their chemical and physical properties.

2.1. Plant and Chemical Analysis

The entire crop was completely harvested at physiological maturity stage (120 DAS), 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. 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.[Miller *et al.*,2013] [27]. The Kjeldahl method was used to determine the N content. Using a spectrophotometer, the protein was estimated using Lowry's technique [28]. The treatment details are as shown in Table 1.

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

2.2. Statistical Methods

The data obtained was statistically analyzed as per the procedures laid by Panse and Sukhatme (1985) [29].

2.3. Physico-Chemical Properties of Pre-Sowing Soil

Before conducting experiment, a composite soil sample at 0-15 cm depth was taken for determination of soil physico-chemical properties presented in Table 2. The experimental soil was characterized with slightly alkaline pH, normal in conductivity, low in nitrogen and medium in phosphorous. In addition, soil had high potassium content but deficient of Sulphur nutrient and micronutrients like zinc, iron, boron, and molybdenum, and had sufficient copper and manganese content (Table 2).

Table 2 Initial Soil Properties of Experimental Site

S. No	Parameters	Values
1	pH	7.1
2	Ec	110.1ds/ms
3	Nitrogen	162.53 kg/ha
4	Phosphorous	20.65 kg/ha
5	Potassium	412.5kg/ha
6	Sulphur	16.52 kg/ha
7	Copper	1.93 mg/kg
8	Zinc	1.09mg/kg
9	Manganese	32.85mg/kg
10	Iron	13.62 mg/kg
11	Boron	0.24 mg/kg
12	Molybdenum	0.39 mg/kg

3. Results

3.1. Yield and Yield Attributes

Plant growth was recorded after sowing of Maize, 12 plants per treatment were tagged and used for recording of different parts of maize parameter. A random samples of 12 plants from each treatment were taken at harvesting time (120 DAS) to determine the following characters like height of plant, height of cob, girth of cob, 100 seed weight, yield kg/ha, dry weight, and protein content.

Table 3 Plant Growth Yield and Yield Parameters

S. No	Treatment	Plant Height	Height of cob	Girth of cob	100Seed wt/ plant (gm)	Dry wt/ plant (gm)	Yield kg/ha	% Protein content
1	control (T1)	110.2	10.6	3.57	32.69	117.8	4990	8.61
2	100% RDF(T2)	142.5	13.8	3.91	35.96	129.5	5891.7	8.71
3	100 % RDF + Elemental S (T3)	159.3	17.3	4.12	39.88	145	7053.3	8.85
4	100 % RDF + Micronutrient + Elemental S (T4)	**170.9**	**19.5**	**4.25**	**41.22**	**155.5**	**8191.7**	**9.29**
5	100 % RDF + Micronutrient (T5)	162.8	17.2	4.01	37.95	143.1	6451.7	8.69
	SEM+_	**1.48**	**0.24**	**0.23**	**0.44**	**2.18**	**151.11**	**0.27**
	CD (.05)	**4.36**	**0.71**	**NS**	**1.30**	**6.42**	**445.76**	**NS**
	CV %	**2.43**	**3.76**	**14.42**	**2.87**	**3.86**	**5.68**	**77.48**

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 data presented in Table 3 highlights the impact of different treatments on the growth and yield characteristics of maize crops. The application of 45 kg/ha of elemental sulphur in conjunction with a foliar spray of multi 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, height of cob, yield kg/ha, dry weight, 100 seed weight. This was significantly superior to the 100% RDF, 100% RDF+Elemental Sulphur+100% RDF+ micronutrients, and the control.

Plant Height: There was a statistically significant difference ($P<0.05$) observed among the various individual treatments in their impact on the plant height. Notably, T4 (NPK+S+Mn) showed the most favorable results in this regard. The highest plant height (170.90cm) followed by T5 (162.8cm), T3 (159.3cm), T2 (142.5cm) and T1 (110.2cm). The findings from our experiment are in line with the previous results reported by Raghu *et al*.,2017on sunflower.

Height of Cob: In terms of cob height, there was a statistically significant difference ($p<0.05$) observed among the various treatments used. T4 (NPK+S+Mn) showed the most superior results in other treatments. The highest cob height (19.5cm) followed by T3 (17.3cm), T5 (17.2cm), T2(13.8cm) and while the control having minimum height of cob T1 (10.6). This finding aligns with the data reported by Pavithra *et al*.,2018 [30, 31].

100 seed weight/plant: Application of Sulphur along with the foliar application of multimicronutrients had significantly ($p<0.05$) affected among the various treatments. Results in Table 3 showed that 100 grain weight in maize was higher in T3 (39.88gm) at harvesting stage, it remaining at par with T4 (41.22gm). While the minimum 100 grain weight was found in control T1 (32.69 gm). Our results are matched with Bhararhi *et al*.,2008 who stated application of 45kg/ha of Sulphur significantly influence the 100 grain weight.

Dry weight/plant: Table 3 displays the dry weight per plant, which was significantly ($p<0.05$) impacted by the different treatments. Among all the treatments, T4 (NPK+S+Mn) exhibited the most superior results. The highest dry weight per plant was recorded in T4 (155.5gm), followed by T3 (145gm), T5 (143.1gm), and T2 (129.5gm), while the control group had the lowest dry weight per plant of T1 (117.8gm). Pandey *et al*.,2008 and

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Rahman *et al.*,2011 reported that application of elemental sulphur significantly increase the dry weight [32, 33]. Similar result were reported by Kumar *et al* 2014 [34].

Yield kg/ha: The data shows in Table 3, the yield of maize was a statistically significant difference ($p<0.05$) among the different treatments used. Specifically, T4 (NPK+S+Mn) showed the most superior results compared to other treatments. The maximum yield of T4 was 8191.7kg/ha, followed by T3 at 7053.3kg/ha, T5 at 6451.7kg/ha, and T2 at 5891.7kg/ha. The lowest yield was observed in the control group, T1, with a yield of only 4990 kg/ha. Maurya et al., documented a significant increase in yield attributes with 45 kg/ha of sulphur application than control, same report were documented by Rego *et al*.,2007 and Enas E. *et al*..2023 that the addition of Zn and other micronutrients has been shown to result in an increase in maize grain yield [35-37].

Protein: The data of protein content are given in Table 3. It showed no significant effect on protein ($p<0.05$) among the different treatments used. The comparison of individual treatments showed the content of protein in range from 8.61% to 9.29%.

Girth of Cob: The data of girth of cob are given in Table 3. It showed no significant effect on girth of cob ($p<0.05$) among the different treatments used. The comparison of individual treatments showed the girth of cob in range from 3.57cm to 4.25cm.

3.2. Total Nutrient Uptake

Data on primary, secondary and micronutrient uptake by whole maize plant is shown in Table 4. It is clear from Table 4 that nutrients uptake in different part of maize like root, stem, leaves and fruits at harvesting stage was significantly ($p<0.05$) affected by different treatments. The results in total uptake by maize was significantly highest in T4 (RDF application of 45 kg/ha of sulphur along with foliar spray of (Cu (1.0%), Zn (3.0%), Mn (1.0%), and Fe (2.5%) B (0.5%) and Mo (0.1%), for all the nutrients in Table 4.

Table 4 **Total Nutrient Uptake by Plant**

S. No	Treatment	N Kg/ha	P kg/ha	K kg/ha	S kg/ha	Cu gm/ha	Zn gm/ha	Mn gm/ha	Fe gm/ha	B gm/ha	Mo gm/ha
1	control (T1)	369.05	17.38	58.48	8.78	246.82	481.83	301.55	4956.25	106.15	1.60
2	100% RDF(T2)	449.67	23.27	88.65	14.38	356.71	682.22	412.97	5267.817	136.87	2.32
3	100 % RDF + Elemental S (T3)	554.28	28.51	116.87	21.32	489.00	796.97	576.10	6758.3	179.90	3.36
4	100 % RDF + Micronutrient + Elemental S (T4)	**688.97**	**35.13**	**126.82**	**23.49**	**564.99**	**919.55**	**612.52**	**7112.1**	**215.43**	**4.26**
5	100 % RDF + Micronutrient (T5)	520.05	29.86	98.06	16.22	471.57	873.18	464.18	5847.133	203.77	4.05
	SEM+_	12.12	0.58	1.69	0.81	8.49	16.39	12.34	162.55	4.08	0.07
	CD (.05)	35.75	1.72	4.99	2.40	25.04	48.35	36.41	479.53	12.03	0.21
	CV %	5.75	5.31	4.24	11.84	4.88	5.35	6.39	6.65	5.93	5.68

Total Nitrogen Uptake: Results in Table 4, showed that N uptake by maize crop is significantly ($p<0.05$) affected by different treatments. Sulfur application and foliar spray of multi micronutrients

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by different methods. From the data it is clear that maximum N uptake (688.97 kg/ha) was resulted from the Treatment T4 where followed by T3 (554.28kg/ha), T5 (520.05 kg/ha), T2 (449.67 kg/ha), while lowest uptake (32.02 kg ha-1) was calculated in control plot. According to Sakal's (2000) report, the increased uptake of nutrients can be attributed to the rising sulfur levels leading to an increase in nitrogen content within plants [38].

Total Phosphorous Uptake: Data on phosphorous uptake in Table 4 showed that total phosphorous uptake by maize is maximum in T4 at harvested stage. Phosphorous uptake was higher in T4 (35.13kg/ha). Followed by T5 (29.86 kg/ha), T3 (28.51kg/ha), T2 (23.27 kg/ha) respectively. While the minimum uptake of phosphorous was found in control (17.38kg/ha). Sulphur application resulted in improved root development and enhanced phosphorous uptake. Same results were finding by Basumatary and talukdar (2011) [39].

Total potassium Uptake: The Results in Table 4 showed that total potassium uptake by maize is maximum in T4 at harvested stage. Potassium uptake (126.82kg/ha).was noted higher in T4 Followed by T5 (29.86 kg/ha), T3 (28.51kg/ha), T2 (23.27 kg/ha) respectively. While the minimum uptake of phosphorous was found in control (17.38kg/ha). While the minimum uptake of potassium was found in control (58.48kg/ha). It may be due to the Interaction effect between Sulphur and potassium resulted in the positive influence of on nutrient uptake by crop. Similar finding were reported by Dwivedi *et al* (2002) and Talaab *et al* (2008) [40, 41].

Total Sulphur Uptake: Results in Table 4 showed that sulphur uptake in maize was higher in T3 (21.32 kg/ha) at harvesting stage, it remaining at par with T4 (23.49 kg/ha). Followed by T5 (16.22 kg/ha), T2 (14.38 kg/ha). While the minimum uptake of sulphur was found in control (8.78kg/ha). The higher Sulphur uptake in maize resulted in greater uptake of Sulphur in plant. Similar findings are reported by Duraiswami,V.P *et al*., (2007) [42].

Total Copper Uptake: The findings in Table 4 demonstrate that maize exhibits the highest total copper uptake in T4 at the harvest stage.copper uptake was higher in T4 (564.99gm/ha). Followed by T3 (489.0gm/ha),T5 (471.57gm/ha),T2 (356.71gm/ha). While the minimum uptake of copper was found in control (246.82gm/ha). According to Etang *et al* foliar application of copper to maize has been shown to not only improve production, but also increase tissue content [43].

Total Zinc Uptake: According to the data presented in Table 4, it was observed that maize plants in T5 had a significantly higher zinc uptake of Zinc (873.18gm/ha) at the harvesting stage, It remaining at par with T4 (919.55gm/ha). Followed by T3 (796.97 gm/ha), T2 (682.22 gm/ha) While the minimum uptake of zinc was found in control T1 (481.83 gm/ha). The results of uptake of zinc in T5 increases may be due to foliar application of multi micronutrient. Our results are finding with Borges 2009 maize crop were observed maximum zinc content at physiological maturity.

Total Manganese Uptake: Results in Table 4 showed that manganese uptake in maize was higher in T3 (576.10gm/ha) at harvesting stage, it remaining at par with T4 (612.52gm/ha). Followed by T4 (464.18 gm/ha), T2 (412.97 gm/ha). While the minimum uptake of manganese was found in control T1 (301.55gm/ha). According to Gurpreet Kaur Gill *et al*, similar results have been documented on soyabean [44]**.**

Total Iron Uptake: The data in Table 4 indicates that the highest level of Iron uptake in maize occurs in T4. at harvested stage. Iron uptake was higher in T4 (7112.1gm/ha). Followed by T3 (6758.3 gm/ha),T4(5847.13 gm/ha), T2 (5267.81gm/ha). While the minimum uptake of Iron was found in control (4956.25/ha). Similar findings are reported by Ravi S et al on safflower.

Total Boron Uptake: Results in Table 4 showed that boron uptake in maize was higher in T5 (203.77gm/ha) at harvesting stage, it remaining at par with T4 (215.43gm/ha). T4 (179.90 gm/ha), T2 (136.87 gm/ha), While the minimum uptake of boron was found in control T1 (106.15gm/ha). Samota *et al* documented that foliar spray of micronutrients increases the uptake of boron [45].

Total Molybdenum Uptake: Results in Table 4 showed that molybdenum uptake in maize was higher in T5 (4.05gm/ha) at harvesting stage, it remaining at par with T4 (4.26gm/ha). Followed by T3(3.36gm/ha), T2 (2.32gm/ha) While the minimum uptake of molybdenum was found in control T1 (1.60gm/ha). Steiner and ZoZ revealed that the elevated level of Mo (molybdenum) found in maize leaves suggests that these plants possess efficient mechanisms for absorbing this nutrient through their foliage [46, 47].

4. Discussion

4.1. Effect of NPK and Elemental Sulphur along with Foliar Spray of Multimicronutrient on the Yield of Maize

Based on the collected data, it was determined that the majority of the study's parameters were more positively impacted by the application of 45kg/ha of elemental Sulphur along with NPK and foliar spray of multi micronutrients (Cu (1.0%), Zn (3.0%), Mn (1.0%), and Fe (2.5%) B (0.5%) and Mo (0.1%). This application showed promising performances with respect to its effect on height of plant, height of cob, girth of cob,100grain weight, dry weight/plant, yield kg/ha, and protein compared to the other treatments. RDF alone (T2) cannot completely satisfy the requirements of plants. The addition of only S (RDF+45kg/ha) also did not have a significant effect on the crop yields, but the foliar application of micronutrients Cu (1.0%), Zn (3.0%), Mn (1.0%), and Fe (2.5%). B (0.5%), Mo (0.1%) improved the overall growth of the crop, making it better than the (RDF+micronutrients). These observations are similar to the results obtained by Bavug,A *et al.*,2023 and Duraiswami *et a.,l* 2007on maize, [48, 49]. And same results were also reported by (Nayak A., *et al* 2023) and (Abd EL-Kader *et al.*,2013) on Peanut and (EL.sayed *et al.*,) on garlic, (Gurpreet k *et al.*,2010) on soyabean [50-53]. A lack of sulphur can negatively impact crop yields, as it affects the availability and utilization of important nutrients such as nitrogen, phosphorus, and potassium by the crops. Micronutrient elements such as Cu, Zn, Mn, Fe, Bo and Mo are known to be essential for plant growth. Furthermore, Adekayode *et al.*,2010 and reported that numerous studies highlight the necessity of utilizing various essential nutrients, including nitrogen (N), phosphorus (P), potassium (K), sulphur (S), and trace elements, to enhance crop productivity. As reported by Al-Bayati *et al.*,2009 the use of agricultural sulphur resulted in a significant increase of in plant height compared to the control group [54]. This can be attributed to several factors, including improved soil fertility, enhanced nutrient solubility, and decreased nitrogen loss through volatilization. The application of 45kg/ha of elemental Sulphur along with NPK and foliar spray of multi micronutrients (Cu (1.0%), Zn (3.0%), Mn (1.0%), and Fe (2.5%) B (0.5%) and Mo (0.1%) in T4 has shown a profound effect on plant growth and yield.. According to Zhang *et al.*,2016 applying a balanced fertilizer causes plants to develop faster, making them taller and greener [55]. The grain and stover yield increase may be due to the additional availability of multi micronutrient as foliar application, which had an advantageous impact on growth, metabolism, physiological functions, and other factors that directly contribute to increased grain output. Gahlout *et al.* (2010) found that sulphur application enhances maize yield attributes through improved vegetative structures, nutrient absorption, photosynthesis, reproductive structures, and assimilate production., this was further supported by Srinivas Rao *et al.* (2010) [56, 57]. Also, Zinc (Zn) and iron (Fe) are critical micronutrients essential for promoting optimal plant growth, as highlighted by Muthukumararaja *et al.*2012 and Kumar *et al.* 2012 [58, 59]. According to Kassab *et al.*,2004 and Zeiden *et al.*,2010 it has been reported that micronutrients have a positive synergistic effect on biochemical and physiological processes, as well as plant growth [60, 61]. Bhagyalakshmi *et al* 2010 added that he elongation of the cob could potentially be attributed to the enhancement of protein metabolism caused by the application of sulphur [62]. However, using a well-balanced mixture of secondary nutrients, such as sulphur and a multi micronutrient combination, in addition to RDF improved the quality and amount of the yield by increasing its uptake. Pavithra.M *et al* 2018 and Jeet,S. *et al* 2012 stated that application 45 kg/ha of elemental sulphur enhanced the overall growth of the maize [63, 64]. According to Jasim. M *et al.*,2023 the increased chlorophyll production and auxin metabolism observed in this studies could be attributed to the interaction between iron, zinc, and sulfur [65]. This enhancement led to improved plant growth as treatment T4 effectively provided the necessary nutrients for plant development. The presence of sulfur appears to have a significant impact on enhancing the metabolic utilization of sulfur in plants, leading to increased mitotic activity and promoting greater apical growth and photosynthetic surface area. These findings are in accordance with previous study by *Raja et al.*,2007 [66]. However, using a well-balanced mixture of secondary nutrients, such as sulphur and a multi micronutrient combination, in addition to RDF improved the quality and amount of the yield by increasing its uptake. Increase in plant height and dry weight may be attributed to the application of sulphur and foliar spray of micronutrients, as these substances have been shown to have positive impact on metabolic and photosynthesis activities. Additionally the reduction of nitrates and sulphates may have contributed to the overall growth of the plants (Maize in tropic). According to Rop *et al*, 2017 the combined use of NPK and secondary micronutrients maximizes nutrient absorption and improves overall plant performance [67]. Sisodiya *et al*.,2017and Chaudhary *et al.*,1996 observed that addition of sulphur has positive effects via reducing soil pH and enhancing soil physical condition. This enhanced nutrient uptake has led to increased vegetative growth, ultimately enhancing photosynthesis and overall plant growth [68, 69].

4.2. The Combined Impact of NPK Fertilizer and Elemental Sulfur, alongside Foliar Application of A Multi Micronutrient Spray, on the overall Nutrient Uptake of Maize Plants

Data on primary, secondary and micronutrient uptake by whole maize plant as described in Table 4 it clearly shown that total nutrients uptake in different parts of maize crop like root, stem, leaves and fruit at harvesting stage was significantly affected by different treatments. The increased uptake was attributed to both improved nutrient availability through fertilization and higher yields of grain and straw in the treated group, as compared to the control. The results on total uptake by maize was significantly higher in T4 (RDF + application of 45 kg/ha of elemental sulphur along with a foliar spray of multi micronutrients (Cu (1.0%), Zn (3.0%), Mn (1.0%), and Fe (2.5%) B (0.5%) and Mo (0.1%), for all the nutrients (Table 4). Except Zn, Mn, B and Mo they are at par with the other treatments. The treatment T3 (RDF + application of 45 kg/ha of elemental sulphur considered as next best treatment which shown better uptake of nutrients. The uptake of nutrients by a whole crop is dependent on the plant's nutrient content and the dry matter production per unit area. Through the application of fertilizers, there has been a gradual increase in nutrient uptake by crop. Foliar application of micronutrients has the potential to enhance the nutrient status and physiological performance of maize plants (Havlin,J *et al.*,2003) [70]. The utilization of micronutrients in conjunction with macronutrients has been shown to enhance crop yield and promote better nutrient uptake, surpassing the effectiveness of standard fertilization methods that do not incorporate micronutrients (BakrY,M.A, *et al*.,2009) [71]. The addition of fertilizers containing NPK and secondary micronutrients has been shown to enhance the photosynthesis process in maize plants, resulting in improved growth and overall health. The rise in overall N, K, and Zn uptake can be ascribed to the synergistic effect of N and Zn, as well as the beneficial interaction between K and Zn. These results are consistent with the findings of Ashoka *et al.*, 2008 [72]. Onwudiwe *et al* 2014 reported that the presence of micronutrients, specifically zinc and copper, may enhance the ability of maize plants to defend against threats [73]. According to Ashoub *et al.* 1998 the application of manganese resulted in increased dry weight per plant, grain yield, stover yield, and Mn uptake in crops [74]. Micronutrients like B enhance pollen tube germination, grain metabolism, root growth, protein and carbohydrate synthesis, leading to increased grain yield, as demonstrated by Moeinian *et al.*,2011 [75]. Zinc, iron, and manganese are positively charged ions that must be transferred from the soil solution into the roots. These essential micronutrients are subsequently distributed among various parts of the plant [Bennett, E.J *et al.*,2011] [76]. There may be a correlation between the higher availability of plant nutrients from the soil reservoir and the increase in nutrient uptake. This could also be attributed to the additional supply of nutrients through foliar application and chemical fertilizers.

Conclusion

The present work of research suggests that the of application of 45kg/ ha of elemental sulphur along with RDF and foliar application of multi micronutrients Cu 1.0%, Zn 3.0%, Mn 1.0%, Fe 2.5%, B 0.5%, and Mo 0.1% at bud initiation stage leads to higher growth and yield components and greater uptake of micronutrients. The sole application of NPK resulted in a significant increase in maize yield and its related parameters. However, it was the combined incorporation of secondary nutrients, micronutrients, and NPK that truly made a notable impact on the research outcome. The result of this treatment showed that the combine effect of secondary nutrient and foliar spray of multimicronutrient along with NPK had a very positive impact on the height of plant, length of cob, girth of cob,100grain weight, dry weight/plant, yield of cob, protein content. The utilization of balanced fertilizers has been proven essential in achieving maximum yield, as demonstrated by the experimental control treatment. The treatment devoid of sulphur and micronutrients has shown lowest yield characteristics as well uptake. These findings confirm the role of elemental sulphur in enhancing the uptake of micronutrients by crop. Implemention of the finding of the experiment the yield of maize can be increased substantially.

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Abbreviations

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

References

[1]. Ganesh Kumar Koli et al., (2022) Status and Scope for Maize in India. Volume: 02, Issue: 01
[2]. https://farmer.gov.in/
[3]. Agricultural statistics at a glance; 2022
[4]. Apeda, 2023. Maize agriculture and processed food products export development.
[5]. Tandon HLS, Messick DL. Practical sulphur guide. washington, DC: Sulphur Institute; 2002
[6]. The sulphur Institute. (2010) About Sulphur. The Sulphur Institute, Washington DC 2010.
[7]. Singh MV.(2001) Importance of sulphur in balanced fertilizer use in India. Ferti News;46:55- 58.
[8]. R Ariraman et al.,(2020) Effect of sulphur nutrition on growth parameters, yield parameters, yield, nutrient uptake, quality and economics of maize. Journal of Pharmacognosy and Phytochemistry 1632-1636
[9]. Raina A K and Tanawade S K. (2005). Delineation of sulphur deficient areas of Maharashtra and crop response sulphur application. Indian J. fert. **1** : 61-64
[10]. Randhawa, P.S and Arora, C.L. (2000)"Phosphorus-sulfur interaction effects on dry matter yield and nutrient uptake by wheat", Journal of Indian Society of Soil Science, 48(3), 536-540.
[11]. Saleem, M.S., A. Roshdy and M.S. Baza. 1982. Effect of N and Zn onyield and yield components of maize. Annuals Agric. Sci., Moshtohor, 18,47-63.

[12]. Akhilesh Kumar Upadhyay (2012) Effect of Sulphur and Zinc on yield, Uptake of nutrients and Quality of Mustard. Ann. PI. Soil Res 14(1): 42-45
[13]. Bharathi C and S. Poongothai. (2008) Direct and Residual Effect of Sulphur on growth, Nutrient Uptake, Yield and its Use Efficiency in Maize and Subsequent Greengram. Research Journal of Agriculture and Biological Sciences, 368-372.
[14]. Kumar Raman, Trivedi S. K. (2011) Effect of levels and sources of sulphur on yield, quality and nutrient uptake by mustard (Brassica Juncea) indianjournals.com 58-6.
[15]. Jamal A, Yong SM, Abdin MZ. (2010) Sulphur-a general overview and interaction with nitrogen. Australian J crop Sci; 4:523-552.
[16]. Tiwari KN, Gupta BR. (2006) Sulphur for sustainable highly yield agriculture in Uttar Pradesh. Indian J Fert; 1(11):37-52.
[17]. Zhao FJ, McGrath SP, Hawkesford MJ (2001). Sulphur nutrition and the sulphur cycle. Institute of Arable Crops, Research report. Rothamsted Experimental Station, UK.
[18]. Raja, E.M. (2009) Importance of micronutrients, in the changing horticultural scenario. J. Hort. Sci., 4(1), 1-27,.
[19]. Ram, R. A., Bose, T. K. (2000) Effect of foliar application of magnesium and micronutrients on growth, yield and fruit quality and mandarin orange (Citrus reticulate Blanco). Indian Journal of Horticulture, 57(3), 215-220.
[20]. Shekhar C, Yadav A.L., Singh H.K., Singh M.K. (2010) Influence of plant growth, yield and quality of papaya fruit (Carica papaya L.) ev. Washington. Asian J. Hort. 5 (2): 326-329.
[21]. Karuna, S., Misra, S., Topwal, M., Singh, V.K. (2019) A Research Review on Use of Micronutrient in Fruit Crops. Int.J.Curr.Microbiol.App.Sci. 8(08), 3014-3025.
[22]. Zagade P.M. Munde G. R. Shrisath A.H. (2017) Effect of foliar application of micronutrients on yield and quality of Guava (Psidium guajava L.) Cv. Sardar. Journal of Pharmacy and Biological Sciences 12(5), 56-58.
[23]. Oosterhuis D. (2009) Foliar fertilization: mechanisms and magnitude of nutrient uptake. In 'Proceedings of the Fluid Forum'. 15-17, Phoenix, Arizona.
[24]. Fageria, N. K., Baligar, V. C. & Clark, R. B. (2002) Micronutrients in crop production. Adv. Agron. 77,185-250. https://doi.org/10.10.16/S0065-2113(02)77015-6.
[25]. Scherer HW. (2001)Sulphur in crop production – invited paper. Eur J Argon; 14:81-111
[26]. FAO. Food and agriculture Oraganisation, (2020) fertilizer and plant. Nutr Bull. chapter 3 soil analysis,19:(44-75).
[27]. Miller, R.O.; Gavlak, R.; Horneck, D. 2013,Soil, Plant and Water Reference Methods for the Western Region (WREP-125), 4th ed.; Colorado State University: Fort Collins, CO, USA.
[28]. Lowry DH, Roseborrough NT, Fam AL, Ronald RJ, (1951) Protein measurement with the folin phenol reagent. Journal boil. Chem.193:265-275.
[29]. Panse VG, Sukhatme PV. (1985) Statistical methods for agricultural workers. New Delhi: Indian Council of Agricultural Research.
[30]. Raghu MS et al 2017, Effect of secondary and micronutrients on growth, yield parameters and nutrient uptake of sunflower (Helianthus annus L.), International journal of medicinal plants Research;6(3):328-331.
[31]. Pavithra M, Prabhakara Reddy G, Chandrika V, Umamahesh V. (2018) Nitrogen and sulphur nutrition for enhancing the growth and yield of quality protein maize (QPM). Journal of Pharmacognosy and Phytochemistry;7(6):142-144.

[32]. Pandey, R. N. Girish, B. H. and Brajendra, (2008) Influence of sulphur application on dry matter yield and sulphur nutrition of maize (Zea mays L.) in major soil orders in India. Ann. of Agric. Res., 23(2): 263-270 82.

[33]. Rahman, M. M., Soaud, A. A., AlDarwish, F. H., Faruq Golam and SofianAzirun, M., (2011) Growth and nutrient uptake of maize plants as affected by elemental sulfur and Nitrogen fertilizer in sandy calcareous soil. African J. Biotechnol., 10 (60) : 82-89 94.

[34]. Kumar R, Bohra JS, Kumawat N, Singh AK. (2015) Fodder yield, nutrient uptake and quality of baby corn (Zea mays L.) as influenced by NPKS and Zn fertilization. Res on Crops 2015;16(2):243-249.

[35]. Maurya KL, Sharma HP, Tripathi HP. (2005) Effect of nitrogen and sulphur application on yield attributes, yield and net returns of winter maize (Zea mays L.). Sher Singh Haryana J Agron c;21(2):115-116

[36]. Rego, T. J., Sahrawat, K. L. Wani, S. P. and Pardhasaradhi, G. (2007). Widespread deficiencies of sulfur, boron and zinc in Indian semi-arid tropical soils: onfarm crop Journal of Plant Nutrition, 30: 1569-1583.

[37]. Enas E. et al. (2023), Effect of Sulfur, Boron, Zinc and Iron on Canola under Salt Affected Soils, Egyptian journal of soil science. Egypt J. Soil Sci. Vol 63, 475-487

[38]. Sakal R, Singh AP. (1997) In Proceedings of the National Symposium on Sulphur in Balanced Fertilization (B. C. Biswas, N. Prasad and S. Das, Eds.), FAI, New Delhi, P. SI-I(1-6).

[39]. Basumatary A and Talukdar M C. (2011) (Integrated effect of sulphur and farm yard manure on yield, quality of crops and nutrient status under Rapeseed-Rice cropping system in Fluventic Dystrochrept. J. Indian Soc. Soil Sci. **59**: 397-400.

[40]. Dwivedi S K, Singh R S and Dwivedi K N.(2002). Effect of sources of Sulphur on performance of maize in Kanpur. J. Indian Soc.Soil Sci.50: 70-74.

[41]. Taalab A S, Hellal F A and Abou Seeda M A. (2008), Influence of phosphate fertilizers enriched with sulphur on phosphorus availability and corn yield in calcareous soil in arid region. Ozean J. Appl. Sci. 1:12.

[42]. Duraiswami V. P., et al., (2007) Effect of micronutrients and sulphur on yield and nutrient uptake by maize in an alfisol. Madras Agricultural Journal 283-288

[43]. Eteng E, Demian Okwudiri Asawalam, Anthony Osinachi Ano, (2014), Effect of Cu and Zn on maize (Zea mays L.) yield and nutrient uptake in coastal plain sand derived soils of southeastern Nigeria. Open Journal of Soil Science. 2014; 4:235-245.

[44]. Borges ID, Renzo Garcia Von Pinho, (2009) José Luiz de Andrade Rezende Pereira. Micronutrients accumulation at different Maize development stages Ciência Agrotecnologia, Lavras; 33(4):1018-1025.

[45]. Gurpreet Kaur Gill*, Sucheta Sharma. (2017) Effect of sulphur supplementation on micronutrients, fatty acids and sulphur use efficiency of soyabean seeds. International Joournal of Environment, Agriculture and Biotechnology (IJEAB) Vol-2, Issue-4, 2456-1878.

[46]. Ravi S, (2008) Effect of sulphur,Zinc and Iron Nutrition on growth,yield, Nutrient uptake and quality of safflower (Carthamus tinctorius L),Karnataka J.Agric.Sci.,21(3)

[47]. Samota MK, Navnage NP, Bhatt L. (2017) Role of macro and micronutrients in the development and growth of the plant. Trends in Biosciences.;10(18):3171-3173.

[48]. Steiner, F., and Zoz, T. (2015). Foliar application of molybdenum improves nitrogen uptake and yield of sunflower. Afr. J. Agric. Res. 10, 1923–1928.

[49]. Bavug Abednego et al (2023) Effect of primary,secondary and micronutrients on maize yield in the wenchi municipality,Ghana Annual Research & Review in Biology 38 (8) : 21-23

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e ISSN: 2584-2137
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https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2024.0127

[50]. Nayak A, Singh R, Pradhan A, Thakur I. (2023) Effect of sulphur and foliar spray of micronutrients on yield and economics of Zaid groundnut (Arachis hypogaea L). Int J Environ Clim Change.;13(9):3244-9,
[51]. Abdel Abd EL-Kader MG. (2013) Effect of sulphur application and foliar spraying with zinc and boron on yield, yield components, and seed quality of peanut (Arachis hypogaea L.). J Agric Biol Sci.;9(4):127-35.
[52]. El Sayed, Hameda E. A., Abdullah. H. A. El-Morsy and Hanan Saleh Al Othaimen. (2015) The role of Sulphur and Certain Foliar Spray Levels of Micro-nutrients on Garlic (Allium sativum L.) Plant. Int. J. Curr. Res. Biosci. Plant boil. 76-87.
[53]. Adekayode, F. O., and Ogunkoya, M. O. (2010). Effect of quantity and placement distances of inorganic 15-15- 15 fertilizer in improving soil fertility status and the performance and yield of maize in a tropical rain forest zone of Nigeria. AmericaEurasian J. Agric. And Environ. Sci., 7(2): 122-129.
[54]. Al-Bayati Ali Hussein Ibrahim, Bashir Hamad Abdullah Solagh and 204 Waleed A.T. El-Fahdawi, Firas W. Ahmed and Saddam H. Cheyed Muayyad Hadi al-Ani 2009. Effect of plant density and the level of agricultural sulfur application on the growth and yield of sunflower under arid conditions in Iraq. The Arab Journal for Arid Environments (3): 27-43.
[55]. Zhang, Y., Li, C., Wang, Y., Hu, Y., Christie, P., Zhang, J., & Li, X. (2016). Maize yield and soil fertility with combined use of compost and inorganic fertilizers on a calcareous soil on the North China Plain. Soil and Tillage Research, 155, 85-94.
[56]. Gahlout B, Singh R, Lal GM. (2010), Effect of levels of nitrogen and Sulphur on growth and yield of maize (Zea mays L.) Journal of Maharashtra Agriculture. University; 35 (1):149-151
[57]. Srinivas Rao Ch, Masood Ali, Venkateshwaralu S, Rupa TR, Singh KK, Sumanta Kundu S et al. (2010) Direct and residual effects of integrated Sulphur fertilization in maize (Zea mays) Chickpea (Cicer arietinum) cropping system on Typic Ustochrept. Indian Journal of Agronomy; 55(4):259-263.
[58]. Muthukumararaja, T., and Sriramachandrasekharan M. V. (2012). Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice. J. Agri. Tech,; 8(2): 551–561.
[59]. Kumar, S. A. M., Meena, M. K., and Upadhyaya, A. (2012). Effect of Sulphur and Zinc on Rice Performance and Nutrient Dynamics in Plants and Soil of Indo Gangetic Plains. J. Agri. Sci.; 4(11)
[60]. Kassab, O.M., H.A.E. Zeing and M.M. Ibrahim, 2004. Effect of water deficit and micronutrients foliar application Int.J.Curr.Microbiol.App.Sci (2018) 7(7): 1125-1131 1131 on the productivity of wheat plants. Minufiya J. Agric. Res., 29: 925-932
[61]. Zeidan, M.S., M.F. Mohamed and H.A. Hamouda, 2010. Effect of foliar fertilization of Fe, Mn and Zn on Statistical wheat yield and quality in low sandy soils fertility. World Journal of Agricultural Sciences, nd 6 (6): 696-699
[62]. Bhagyalakshmi T, prakasha H C and Sudhir K2010. Effect of different sources and levels of Sulphur on the performance of rice and maize and properties of soils. Mysore j. Agric.Sci.44:79-88.
[63]. Jeet S, Singh JP, Kumar R, Prasad RK, Kumar P, Kumari A, Prakash P. (2012) Effect of nitrogen and sulphur levels on yield, economics and quality of QPM hybrids under dry land condition of eastern Uttarpradesh, India. Indian J Agri Sci ;4(9):31-38.
[64]. Jasim, Muqdad & Mustafa, Atheer. (2023) Effect of Sulfur and Spraying with Boron on some Yield Characteristics Oil Percentage and Total Oil Yield of Sunflower Crop Helianthus annuus L. IOP Conference

e ISSN: 2584-2137
Vol. 02 Issue: 04 April 2024
Page No: 907 - 919
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2024.0127

Series: Earth and Environmental Science.;1158.

[65]. Raja A., Omar Hattab, K., Gurusawmy, L., Vembu, G., Suganya, K. S., (2007). Sulphur application on growth, yield and quality of sesame varieties. Int. J. Agric. Res., 2, 599-606. 15. Ravikumar, C

[66]. Maize in tropic (Phenology & Physiology) (2004). Directorate of maize research, Rusa campus, NewDelhi;342.

[67]. Rop, K., Karuku, G. N., Mbui, D., Njomo, N., &Michira, I. (2019). Evaluating the effects of formulated nano-NPK slow release fertilizer composite on the performance and yield of maize, kale and capsicum. Annals of Agricultural Sciences, 64(1), 9-19.

[68]. Sisodiya R.R.,Babaria N.B.,Parmar T.N., and Parmar K.B. (2017) Effect of sources and level of sulphur on yield and micronutrient (Fe,Mn,Zn and Cu) absorption on yield groundnut (Arachis hypogaea L). International Journal of Agriculture Sciences.32 (9): 4465-4467.

[69]. Choudhary, H. P., and Das, S. K. (1996). Effect of P, S and Mo application on yield of rain-fed blackgram and their residual effect on safflower and soil and water conservation in eroded soil. J. Indian Soc. Soil Sci., 44: 741-745.

[70]. Havlin, John L, Beaton, James D, Tisdale, Samuel L. Nelson, et al. (2003) Soil fertility and fertilizers Sixth Edition.Published by Pearson Education (Singapore) Pvt. Ltd.

[71]. Bakry MA, Soliman YR, Moussa SA. (2009) Importance of micronutrients, organic manure and bio-fertilizer for improving maize yield and its components grown in desert sandy soils. Res. J Agric. and Biol. Sci.; **5**:16-23.

[72]. Ashoska M P,Desai BK(2008).Effectofmicronutrients with or without organic manures on yield of babycorn-chickpeasequence.KārJ.Agric.Sci.2008;21(4) :485–487.

[73]. Onwudive N, Benedict OU, Ogbonna PE, Ejiofor EE. (2014)Municipal solid waste and NPK fertilizer effects on soil physical properties and maize performance in Nsukka, Southeast Nigeria. African journal of biotechnology,13(1):68-75.

[74]. Ashoub MA, Esmail AM, Osman AO, Osman AS, (1998) Effect of some microelements application methods under irrigation regime on growth and yield of maize. Arab Universal Journal of Agricultural Sciences, Ain Shams University. Cairo; 6(1):183-192.

[75]. Moeinian, M. R., Zargari, K., Hasanpour, J. 2011. Effect of boron foliar spraying application on quality characteristics and growth parameters of wheat grain under drought stress. Amer. Eur. J. Agric. Environ. Sci. 10, 593-599.

[76]. Bennett, E.J.; Roberts, J.A.; Wagstaff, C. The role of the pod in seed development: Strategies for manipulating yield. New Phytol. 2011, 190, 838–853.