Original Research Article

Effect of Application of Secondary Nutrients on Growth, Yield and Quality of Maize (*Zea mays* L.)

ABSTRACT

A field experiment was conducted during *Rabi* 2022 at the Agriculture and Horticulture Research Station, Honnavile, Shivamogga on sandy clay loam soil to study the response of maize to secondary nutrients application. The experiment was laid out in Randomized Complete Block Design (RCBD) and consisted of nine treatments replicated three times. The treatments consisted of package of practice (POP) (T_1), POP + soil application of two levels of calcium, *i.e.,* 25 and 50 kg ha^{-1} through lime (T_2 and T_3), dolomite (T_4 and T_5,which amount to 15.02 and 30.04 kg ha^{-1} of magnesium, respectively) and gypsum (T_6 and T_7, which amount to 19.96 and 39.91 kg ha^{-1} of sulphur, respectively). Treatments T_8 and T_9 consisted of POP + combined application of all three secondary nutrients through lime, magnesium sulphate and bentonite sulphur to meet the same level of nutrient as treatments T_2 to T_7. Among the treatments, application of POP + calcium @ 25 kg ha^{-1} through lime + 15.02 kg ha^{-1} of Mg + 19.6 kg ha^{-1} of S (T_8) showed significantly higher values for growth parameters *viz.*, plant height (196.65 cm), leaf area (4804.70 cm^2), leaf area index (5.55) total dry matter (273.80 g $plant^{-1}$) and yield parameters *viz.,* cob length (16.93 cm), number of grains cob^{-1} (511.08), kernel yield (6772 kg ha^{-1}) and stover yield (8221 kg ha^{-1}). Similarly the same treatment recorded significantly higher grain protein content (8.99%) compared to other treatments. However the test weight, harvest index and oil content of maize remained unaffected due the applied secondary nutrients.

Keywords: Maize; secondary nutrients; calcium and magnesium; gypsum

1. INTRODUCTION

Maize (*Zea mays* L.) is the third-most important crop in the world after rice and wheat. It holds a significant space in the agro-industries and is recognized as a leading commercial crop of great agro-economic value. In India, maize is the third most significant cereal crop and is used for a variety of uses, including food, fodder and feed. Various industrial goods, such as protein, starch, oil, alcoholic beverages, food sweeteners, medicines, cosmetics and biofuels are also produced using it as a raw material. Globally maize is cultivated in an area of 205 million hectare with a production of 1210.23 million metric tonnes and 5.8 metric t ha^{-1} productivity [1]. In India, the crop occupies an area of 9.95 million hectare with a production of 33.73 million tonnes and average productivity of 3387 kg ha^{-1} [2]. Karnataka, Maharashtra and Madhya Pradesh are three largest maize producing states. In Karnataka maize is cultivated in 1.59 million hectares with production of 5.22 million tonnes and average productivity of 3279 kg ha^{-1} [2]. In India it contributes 15.99 and 15.47 per cent of total area and production, respectively.

Calcium (Ca), magnesium (Mg) and sulphur (S) are referred to as "secondary" nutrients since plants require them in smaller quantities than nitrogen, phosphorus, and potassium. However, compared to micronutrients these nutrients are needed by plants in greater amounts. In soils with favourable pH and organic matter levels, secondary nutrients are typically sufficient. In addition to serving as soil amendments, substances that contain one or more of these minerals are frequently employed to supplement plant nutrition. Calcium is an essential mineral for plant growth and plays several important roles. It plays a crucial role in the development and stability of the cell walls of plants, giving them the rigidity and strength needed to support them [3][4]. In addition, calcium enhances nutrient availability, maintains an appropriate pH level, and neutralises acidity in the soil. Magnesium is considered as an essential element due to its multiple vital functions in plant growth. It is an integral part of chlorophyll, which enables plants to carry out photosynthesis and generate energy [5]. It is important for the uptake and transport of phosphorus, which is necessary for plant growth. It plays a role in respiration, phosphate metabolism, and the activation of enzyme systems. Since maize produces a lot of dry matter, it needs additional sulphur than other crops. For the growth of chlorophyll and photosynthesis in plants, as well as the production of the amino acids like cystine (27% S), cysteine (26% S), and methionine (21% S) sulphur is crucial. Sulphur is essential for the primary metabolism of higher plants and helps some plant species to produce secondary metabolic products [6]. It is necessary for the synthesis of glutathione, coenzyme A, vitamin B1, biotin and the activation of papainases. It also aids in the development of glucosides and glucosinolates, which are key components of oils.

When crops are grown intensively and at high rates of N, P, and K fertiliser application, the secondary nutrient reserves of the soil tend to be depleted more quickly and lead to deficiencies in the soils. Crop productivity may be adversely impacted by these inadequacies. To correct the nutrient imbalances and promote healthy plant growth, soil amendments and fertilisation techniques can be used. For example, lime can be used to treat calcium deficiencies, magnesium deficiencies can be treated with magnesium sulphate or dolomite, and sulphur deficiencies can be treated with elemental sulphur or sulphate-containing fertilisers. Monitoring soil nutrient levels and implementing appropriate nutrient management practices are crucial in managing these deficiencies. In the light of above it is planned to carry out an investigation on secondary nutrient fertilization to maize crop.

2. METERIALS AND METHODS

2.1 Site description

The field experiment was conducted at the Agriculture and Horticulture Research Station, Honnavile during *Rabi* 2022. The experimental field was geographically located at 13.930° N latitude and 75.568° E longitude with an altitude of 570 meters above mean sea level and comes under the Southern Transition Zone of Karnataka. The experimental soil was sandy clay loam in texture (59.2 % sand, 9.10 % silt and 31.7 % clay), acidic in nature (pH 5.62) with a medium salt load (EC 0.16 dS m^{-1}). It has a medium status for organic carbon (6.24 g kg^{-1}) and a low status of available nitrogen (235.55 kg/ha), while the status of available phosphorous (79.59 kg/ha) and available potassium (186.75 kg/ha) were high and medium, respectively.

2.2Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design. The nine treatments were replicated thrice. The experimental plot was divided into three blocks. Each block was subdivided into nine-unit plots. Thus, the total number of unit plots was 27 (9 treatment × 3 replication). The experimental treatment details are as following T_1- POP (Package of practice), T_2- POP + calcium @ 25 kg/ha applied through lime, T_3- POP + calcium @ 50 kg/ha applied through lime, T_4- POP + calcium @ 25 kg/ha applied through dolomite (Mg supplied @ 15.02 kg/ha), T_5- POP + calcium @ 50 kg/haapplied through dolomite (Mg supplied @ 30.04 kg/ha), T_6- POP + calcium @ 25 kg/ha applied through gypsum (S supplied @ 19.96 kg/ha), T_7- POP + calcium @ 50 kg/ha applied through gypsum (S supplied @ 39.91 kg/ha), T_8- POP + calcium @ 25 Kg/ha through lime + 15.02 kg/ha of Mg +19.96 kg/ha of S and T_9- POP + calcium @ 50 Kg/ha through lime + 30.04 kg/ha of Mg + 39.91 kg/ha of S. Mg (Magnesium) and S (Sulphur) in treatments T_4 to T_7 were the contributions from applied dolomite and gypsum, respectively and in treatments T_8 and T_9, Mg and S were applied through the magnesium sulphate and bentonite sulphur, respectively. All the sources of secondary nutrients are applied as a basal application at the time of sowing according to the treatments.

2.3Datacollection

2.3.1 Growth parameters

For recording various biometric observations, a sample consisting of five plants was selected at random from net plot of 3.6 m × 3 m and tagged in each treatment and same plants were used to record the observations on growth components. Plant height at harvest of five tagged plants was measured from the base of the plant to the base of the fully opened top leaf using a measuring scale and was averaged. From the tagged five plants, length of the third fully opened leaf from the top of the plant was measured from the base to the top of the leaf and breadth was measured at the widest point of the leaf lamina. The product of leaf length and breadth was multiplied by factor 0.75 *i.e.*, leaf area = L× B × 0.75 × number of leaves retained by the plant was recorded at 90 days after sowing. The leaf area index was calculated by dividing leaf area with land area as suggested by Sesteket al. [7]. Destructive samples were collected from border rows and were dried at 65 to 75 ^{o}C in hot air oven until a constant dry weight was obtained and dry matter production was recorded.

2.3.2 Yield parameters

Harvesting was done after the crop had reached physiological maturity. Grain yields in each treatment were determined from a net plot of 3.6 m x 3 m. The cobs were removed and cob length of five random plants was recorded from base to tip of the cob, number of grains per cob was counted and recorded. After drying to 12.5% moisture content, the test weight and the final dry weight (yield) of grains was determined and recorded.The maize stover weight in each treatment was weighed and recorded.

2.3.3 Quality parameter

Nitrogen content in the grain was determined by Kjeldal's Method as described by Jackson [8] and protein content in grains was worked out by multiplying the nitrogen content with a factor 6.25. Oil contents maize was determined by using Soxhlet apparatus according to the method described by Ajayi et al*.* [9]. 15 g of each accession was placed in a thimble and placed in chamber which was 2/3 filled with n-hexane. After running 15-20 cycles of n-hexane, the oil extraction was stopped and oil and n-hexane were separated on a rotary evaporator. The oil contents obtained were weight and percentage was found by using the following formula.

$$\text{Oil Percentage (\%)} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Total weight of sample}} \times 100$$

2.4 Statistical analysis

Experimental data obtained on various parameters were subjected to statistical analysis by adopting Fisher's method of analysis of variance (ANOVA) as given by Gomez and Gomez [10]. The results have been discussed at the probability level of five per cent. The level of significance used in "F" test was *P* = .05. CD (Critical difference) values were calculated wherever the "F" test was found significant. Otherwise, against CD values abbreviation NS (Non-significant) was indicated.

3. RESULTS AND DISCUSSION

3.1 Effect of application of secondary on growth parameters of maize

3.1.1 Plant height

The result of the study revealed that the growth attributes, *viz*. plant height, leaf area, leaf area index and total dry matter of maize were positively influenced by the application of the secondary nutrients. Among the different treatments, treatment T_8 consisted of combined application of all three secondary nutrients (calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg +19.96 kg/ha of S) along with POP recorded significantly higher plant height (196.65 cm) which was on par with treatments T_9 (186.91cm), T_5 (179.87 cm) and T_6 (176.34 cm) consisted of a combined application of all three secondary nutrients (Ca + Mg+ S) along the POP and application of calcium and magnesium (Ca + Mg) or sulphur (Ca + S) together (Table 1). Calcium might have aided in promoting cell elongation and cell division, which would have promoted better plant growth. The increase in plant height can also be attributed to increased cell division and cell elongation induced by the interaction between Ca and auxin [11]. Noor et al*.* [12] reported that calcium application as lime along with the magnesium @ 20 kg/ha had significantly increased plant height in maize. The application of magnesium increased the chlorophyll content and photosynthetic rate of the plants, which would have increased the leaf production rate, as reported by Chen et al. [13]. Ertiftik and Zengin [14] recorded the highest maize plant height by the application of magnesium @ 40 kg/ha. Application of sulphur @ 20 kg/haincreased the plant height, which may be attributed to the multiple roles of sulphur in protein and carbohydrate metabolism, activating many enzymes which influence photosynthesis and shoot length [15]. These results are in line with the findings of Bhagyalakshmi et al*.* [16] and Choudhary et al.[17].

3.1.2 Leaf area and LAI

The maximum leaf area (7487 cm^2 $plant^{-1}$) and LAI (5.55) at 90 DAS in maize was obtained with the treatment T_8 consisted of a combined application of the secondary nutrients (POP + calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg + 19.96 kg/ha of S) along with POP which was statistically on par with treatments T_9, T_5 and T_6 (leaf area of 6948, 6534 and 6483cm^2 $plant^{-1}$, respectivelyand LAI of 5.15, 4.84 and 4.80, respectively.) at 90 DAS (Table 1). This might be due to adequate calcium supply enhancing cell wall structure, cell expansion and division, leading to larger and healthier leaves. Longkumer and Gohain [18] reported that the application of calcium increased the leaf area and LAI in sesame crop and similar findings were obtained from Rajashree and Pillai [19] in fodder legume. Magnesium application increases chlorophyll content, improving photosynthetic efficiency and promoting larger leaf area. Sufficient sulphur supply positively affects maize growth by enhancing photosynthetic activity and nutrient uptake, contributing to a larger leaf area and healthier plants. These results are similar to the findings of Rao et al. [20], Tanveer et al.[21] and Thirupathi et al.[22]. The increase in LAI may also be due to sulphur application, which increased nutrient uptake thereby enhancing the rate of photosynthesis and leaf expansion.

3.1.3 Total plant dry matter

Plant growth and yield depend on the dry matter accumulation rate, which serves as a crucial indicator of overall resource utilization and light interception efficiency [23]. Treatment T_8 consisted of the application of all three secondary nutrients (calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg + 19.96 kg/ha of S) along with the POP recorded significantly higher dry matter production at harvest (273.80 g plant^{-1}) which was statistically on par treatments T_9, T_5 and T_6 (268.05, 265.90 and 264.89 g plant^{-1}, respectively) (Table 1). The larger photosynthetic area and prolonged photosynthesis due to leaf area index and number of leaves per plant lead to higher dry matter production because of a balanced supply of all primary and secondary nutrients.Braga et al.[24] and Pedro et al.[25] noticed higher dry matter production in different crops with the application of lime or calcium. El-Zanatyet al.[26] recorded the highest dry weight accumulation in wheat with 60 kg $MgSO_4$ ha^{-1} application. Channabasammaet al.[27] also cited that the application of sulphur at the rate of 30 kg/ha increased the dry matter production in maize, which might be due to enhanced nitrogen fertilizer use in soil and positive effects on plant metabolism. However, significantly lower growth attributes *viz*., plant height (158.78 cm), leaf area (5052 cm^2 plant^{-1}), leaf area index (3.74) and total plant dry matter (243.90) was recorded by the treatment T_1 consisted of nutrient application based on POP. Thus the optimal balance of secondary nutrients in the soil is critical for maximizing plant growth. Adequate availability of primary and secondary nutrients fosters efficient nutrient uptake, enhances plant health and supports various growth processes, resulting in increased growth of the plant.

3.2 Effect of application of secondary on yield attributes and yield of maize

3.2.1 Yield attributes

In the present study, soil application of calcium, magnesium and sulphur along with POP have shown a positive and significant influence on the yield attributes and yield of the maize. Significant differences were observed with respect to cob length, number of grains cob^{-1}, grain and stover yield of maize. There was no significant difference in the case of test weight and harvest index due to the application of secondary nutrients (Table 2). The results revealed that the significantly higher yield attributes like cob length (16.93 cm) and number of grains cob^{-1} (511.08)were obtained by the treatment T_8 (POP + calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg + 19.96 kg/ha of S) consisted of combined application of all three secondary nutrients together along with the POP which was statistically on par with T_9, T_6 and T_5 (cob length of 16.82, 16.15 and 16.13, respectively and number of grains cob^{-1} of 500.55, 429.72 and 426.41,respectively). The fact that the yield attributing traits were

Table 1. Effect of application of secondary nutrients on plant growth parameters of maize

Treatments	Plant height (cm)	Leaf area (cm^{-2} plant^{-1})	LAI	Dry matter (gplant^{-1})
T_1 :POP (Package of practice)	158.78	5052	3.74	243.90

T_2 :POP + calcium @ 25 kg/ha applied through lime	166.21	5143	3.81	247.57
T_3 :POP + calcium @ 50 kg/ha applied through lime	168.39	5330	3.95	249.01
T_4 :POP + calcium @ 25 kg/ha applied through dolomite	172.79	6325	4.69	253.58
T_5 :POP + calcium @ 50 kg/haapplied through dolomite	179.87	6534	4.84	265.90
T_6 :POP + calcium @ 25 kg/ha applied through gypsum	176.34	6483	4.80	264.89
T_7 :POP + calcium @ 50 kg/ha applied through gypsum	175.28	6015	4.46	251.85
T_8 :POP + calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg +19.96 kg/ha of S	196.65	7487	5.55	273.80
T_9 :POP + calcium @ 50 kg/ha through lime + 30.04 kg/ha of Mg + 39.91 kg/ha of S.	186.91	6948	5.15	268.05
S. Em ±	6.88	343	0.25	6.57
C D (5%)	20.63	1031	0.76	19.70

**Magnesium and sulphur in treatmnets T_8 and T_9 are supplied through magnesium Sulphate and bentonite sulphur respectively*

increased by applying all three secondary nutrient elements indicated a synergistic effect not only when only two of them were applied together but also when all three were applied together. Lime application gradually raised soil pH, decreased exchangeable Al^{3+} and H^+ and increased CEC, resulting in nutrient availability and increased yield attributing traits [28]. The increase in yield parameters can be attributed to the positive impact of sufficient magnesium (Mg) supply on various plant functions. Mg plays a crucial role in activating enzymes and regulating photosynthesis, resulting in the production of an ample amount of assimilates. These assimilates are then effectively transported to different plant storage parts, leading to higher production of rows per cob, grains per cob, and the mean number of grains per row in maize [29]. However, the lowest cob length (14.22 cm) and number of grains per cob (352.37) was recorded in POP treatment (T_1). The test weight remained non-significant among different treatment combinations mainly due to resource mobilization capacity to that of the sink and accounted as a genetic trait that doesn't vary due to other factors.

3.2.2 Grain and stover yield

The grain and stover yield of maize crop were significantly increased by the application of secondary nutrients. Significantly higher grain (6772 kg/ha) and stover yield (8221 kg/ha) were observed in treatment T_8 with the application of calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg + 19.96 kg/ha of S along with POP, which was statistically on par with Treatment T_9 (6654 and 8095 kg/ha, respectively), T_5 (6594 and 8032 kg/ha, respectively) and T_6 (6558 and 8029 kg/ha, respectively). The data in table 2 clearly indicated that the yield of maize was increased with increasing levels of application of calcium and magnesium through lime and dolomite (T_2 to T_5). The application of basic cations to soil before sowing of crops brought about an increase in the contents of exchangeable Ca and Mg of soils and hence, an increase in base saturation of soils with consequent increase in pH of soils. Among the gypsum applied treatments (T_6 and T_7), the higher values were obtained when sulphur was applied at nearly 20 kg/ha; beyond that, there was decreasing trend observed with respect to yield attributes, grain and stover yield of maize. A higher rate of applied S causes adverse or detrimental effects on crop growth and yield [30]. These results indicated that the increase in seed and stover yield was related to the availability of nutrients in the soil. This was evident through notable increases in metrics like the cob length and number kernels per cob, leading to a higher kernel yield compared to the POP. The increase in grain and stover yield by the application of secondary nutrients was up to 13.83 and 11.56 per cent, respectively over POP (T_1). Hakim et al. [31] stated that integrated liming significantly increased maize grain yield from 51 to 128 per cent compared to control. Comparable results were also evident in experiments conducted by Hossain et al.[32] in wheat and Longkumer and Gohain [18] in sesame. The harvest index (HI) is a calculated measure. There was no notable difference in the HI values across various treatment combinations

3.3 Effect of application of secondary on quality of maize

The application of secondary nutrients significantly affected the protein content in maize grain. Significantly higher grain protein content (8.99 %) was recorded in treatment T_8 (POP + calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg + 19.96 kg/ha of S). It was statistically on par with T_9, T_7 and $T_6$with protein of 8.72, 8.17 and 8.03 per cent respectively. The per cent N content in harvested grains was more in T_8, T_9, T_7 and T_6 resulted in the highest protein content. An increase in protein content might also be due to the increased availability and uptake of nitrogen and sulphur upon the addition of magnesium and sulphur to the soil, which are an integral part of a protein [33][34]. Moreover, Mg is a component of ribosome structure and it stabilizes the particles of the ribosome in the configuration necessary for protein synthesis and sulphurinvolved in the nitrate reductase process necessary for the conversion of nitrate to amino acids in plants. These results are in line with the findings of Sakal et al*.* [35] and Dwivedi et al*.* [36] for sulphur and Singh (2001) for magnesium application. There was no significant difference observed with respect to seed oil content among the different treatments. However, the highest oil (3.63 %) content was recorded in treatment $T_7$and the lowest with T_1 (3.52 %) treatment.

Table 2. Effect of application of secondary nutrients on yield attributes and yields of maize.

Treatments	Cob length (cm)	No. of grains cob^{-1}	Test weight (g)	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Harvest index (%)
T_1 :POP (Package of practice)	14.22	352.37	23.18	5949	7369	44.63
T_2 :POP + calcium @ 25 kg/ha applied through lime	14.43	388.15	23.41	6061	7511	44.66

T_3 :POP + calcium @ 50 kg/ha applied through lime	14.77	407.47	23.32	6103	7542	44.71
T_4 :POP + calcium @ 25 kg/ha applied through dolomite	15.27	416.49	23.23	6207	7708	44.59
T_5 :POP + calcium @ 50 kg/haapplied through dolomite	16.13	426.41	24.18	6594	8032	45.09
T_6 :POP + calcium @ 25 kg/ha applied through gypsum	16.15	429.72	24.05	6558	8029	44.96
T_7 :POP + calcium @ 50 kg/ha applied through gypsum	15.04	417.48	23.60	6169	7656	44.62
T_8 :POP + calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg +19.96 kg/ha of S	16.93	511.08	24.13	6772	8221	45.15
T_9 :POP + calcium @ 50 kg/ha through lime + 30.04 kg/ha of Mg + 39.91 kg/ha of S.	16.82	500.55	23.96	6654	8095	45.11
S. Em ±	0.54	29.78	0.68	185.52	173.56	0.20
C D (5%)	1.62	89.28	NS	556.23	520.36	NS

**Magnesium and sulphur in treatmnets T_8 and T_9 are supplied through magnesium Sulphate and bentonite sulphur respectively*

Table 3. Effect of application of secondary nutrients on quality of maize.

Treatments	Protein (%)	Oil (%)
T_1 :POP (Package of practice)	7.39	3.52
T_2 :POP + calcium @ 25 kg/ha applied through lime	7.60	3.54
T_3 :POP + calcium @ 50 kg/ha applied through lime	7.62	3.57
T_4 :POP + calcium @ 25 kg/ha applied through dolomite	7.85	3.54
T_5 :POP + calcium @ 50 kg/haapplied through dolomite	7.91	3.56

T_6 :POP + calcium @ 25 kg/ha applied through gypsum	8.03	3.61
T_7 :POP + calcium @ 50 kg/ha applied through gypsum	8.17	3.63
T_8 :POP + calcium @ 25 kg/ha through lime + 15.02 kg/ha of Mg +19.96 kg/ha of S	8.99	3.58
T_9 :POP + calcium @ 50 kg/ha through lime + 30.04 kg/ha of Mg + 39.91 kg/ha of S.	8.72	3.57
S. Em ±	0.33	0.04
C D (5%)	0.97	NS

**Magnesium and sulphur in treatmnets T_8 and T_9 are supplied through magnesium Sulphate and bentonite sulphur respectively*

4. CONCLUSION

Based on the results obtained in this investigation it is concluded that the response of maize to applied secondary nutrients was significant. Application of all three (Ca + Mg + S) or any of the two (Ca+ Mg) or (Ca + S) secondary nutrients along with the recommended package of practice significantly increased growth and yield of maize. Protein content of maize kernels also got significantly increased by the application of secondary nutrients. However, oil content of the content of maize kernels not significantly affected by the applied secondary nutrients. Hence, the application of secondary nutrients along with the recommended package of practice becomes a more balanced nutrient management practice in order to enhance the yield in maize.

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