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Effect of synergism on uptake of macronutrients at phenological stages of maize

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Abstract
Decision support for nutrient application remains an enigma if based on soil and plant nutrient analysis. If the crop could be used as an auxiliary indicator, the plant nutrient status during different growth stages could complement the soil test, improving the fertilizer recommendation. Variation of macronutrient level uptake of maize plant was studied at three different stages of growth namely 30, 60 and 90 days after planting. The objective of this study considers the temporal variation of the nutrient uptake rate, which should define crop needs as compared to the critical content in soil solution. Results obtained in this study show that the Requirement of essential nutrients for yield maximization of Pioneer Hybrid Maize 3369 was studied under field condition. The highest grain yield of maize of 4.8 t/ha was obtained with the application of micronutrient mixture along with recommended NPK. The levels of macronutrients in the plant were found to increase from early stage to the later stages of growth and the accumulation of nutrients is much faster from the first to the second stages of growth is much when compared with later stages and remaining constant or decreased within period.

Keywords: Maize, secondary nutrients, micronutrients, and uptake

Introduction
Being an important "Kharif" crop in India, maize is grown in 170.39 million hectares with a production of 883.46 million tonnes and productivity of 5.18 tonnes ha^{-1} (Anonymous 2016) [2]. Timsina and Majumdar (2010) [18] indicated that maize grain yields in India have been decreasing where maize was grown on the same land for the last 5 to 10 years. The yield of maize decline to imbalanced and inadequate nutrient application by farmers. For managing plant nutrients in maize systems N, P and K remain the major ones for increased and sustained productivity. However, cultivation of high yielding maize systems will likely exacerbate the problem of secondary and micronutrient deficiencies, not only because larger amounts are removed, but also because the application of large amounts of N, P and K to achieve higher yield targets often stimulates the deficiency of secondary and micronutrients (Johnston *et al.* 2009). Micronutrients are trace elements which are needed by the maize crop in small amounts and play an active role in the plant metabolic functions in shortage of which show deficiency symptoms and crop yields are reduced, they are therefore to be added into the soil before crop planting or applied directly to the crop to increase maize productivity (Adhikary *et al.* 2010) [1]. Until 1980, deficiencies of three nutrients viz. N, P and K were identified in Indian soils. In early 1980s, S and Zn deficiencies in rice are observed. In early 1980s, the B deficiencies of some crops are reported by Jahiruddin and Satter (2010) [10]. There is sporadic information of Cu, Mo and Mn deficiencies in crops (Ferdoush *et al.* 2003) [7]. Generally, micronutrient-deficient soils do not support optimum crop yields because plant growth becomes retarded by the deficiency, leading to low yields (Chude *et al*. 2004) [6]. Thus, the present research work was undertaken to examine the effect of secondary and micronutrients on the yield and nutrient concentration of maize and to find out the requirement of one or more micronutrients for maximization of maize yield.

Material and Methods
A field experiment was conducted on maize hybrid P3369, under irrigated conditions during *kharif,* 2015 on sandy loam soils of Agricultural College Farm, Mahanandi, Andhra Pradesh which was laid out in a randomized block design having nine treatments and replicated thrice. The treatments consisting of $T_{1:}$ Control, $T_{2:}$ RDF: 250-60-60 kg N-P_2O_5-K_2O ha^{-1}, $T_{3:}$ RDF + foliar application of one per cent $CaNO_3$, $T_{4:}$ RDF+ foliar application of one per cent $MgNO_3$,

T_5: RDF + foliar application of one per cent sulphur, T_6: RDF + foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and sulphur, T_7: RDF + foliar application of $ZnSO_4$ @ 0.2 per cent, T_8: RDF + foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and sulphur + foliar application of $ZnSO_4$ @ 0.2 per cent and T_9: RDF + micronutrient mixture @ 0.2 per cent. The crop was sown on ridges with spacing 75cm x 15cm on second fortnight of july 2015 and harvested on 23.11.2015. The amount of nitrogen was applied in three splits i.e., at sowing, at 30-35 DAS and remaining at 50-55 DAS in the form of urea and phosphorus and potassium was applied as di ammonium phosphate and muriate of potash were applied as basal dose at the time of sowing, Whereas secondary nutrients and zinc was was supplied as foliar spray at 20-25 DAS in the form of $CaNO_3$, $MgNO_3$, wettable sulphur and $ZnSO_4$ respectively. Micronutrient mixture consists of Boron (B) 1.5%, Copper (Cu) 0.5%, Iron (Fe) 3.4%, Manganese (Mn) 3.2%, Molybdenum (Mo) 0.05% and Zinc (Zn) 4.2%. Carbofuran 3G granules @ 5 kg ha^{-1} was applied to control the stem borers. All the cultural practices were taken up as per the recommendations made by ANGRAU.

Soil sampling: Soul samples (0-15cm) were collected from each row of the land of study and labeled, dated and sent to the laboratory, where they were air dried. The dried samples were then preserved in labeled polythene bags ready for analysis.

***Tissue samples*:** Plant samples were obtained by randomly harvesting whole plants from the net plot area at 30, 60 and 90 days after planting respectively. The samples were dried in an oven at 70 ^{0}C for about 48 hours and then ground by a grinding machine to pass through a 20-mesh sieve and preserved in labeled polythene ready for analysis.

***Determination of soil pH*:** The pH was measured using a standardized pH meter model 290. The pH was recorded as soil pH in water (Jackson, 1973) [9].

Particle size analysis: In the analysis of soil particle size, hydrometer method of Bouyoucos was employed using sodium hexamtaphosphate (calgon solution) as the dispersing medium Bouyoucos, (1951) [4].

Organic matter analysis: The method used was the Walkey-Black Wet Oxidation Method Walkley, and. Black (1934) [19]. The procedure was used to determine the amount of active or decomposed organic matter in the soil.

Total nitrogen analysis: The total nitrogen of the soul was determined by Kjedahl digestion method (Subbiah and Asija, 1956) [17], and the resulting ammonnium ion was measured calorimetrically on Technical II auto analyzer.

***Determination of K, Ca, Mg, P and S*:** Determination of the amount of K was done by flame photometry. Ca and Mg levels were determined by EDTA titration. The available P was extracted using Bray method of 1945 Bray and Kurtz, (1945) [5]. Available S was estimated by $BaCl_2$ extractant Turbidimetry method (Jackson, 1973) [9].

***Methods for plant analysis**:* Precisely, 1g of ground plant sample was transferred into a dry clean 250 ml conical flask. A 10 ml of diacid mixture (HNO_3: $HClO_4$ in the ratio of 5:1) was added to it and kept on low heat hot plate in digestion chamber. The flask is heated at a higher temperature until the dense red fumes of NO_2 ceases. The contents of the flask were evaporated until they became 3 to 5 ml clean and colourless. Except N, all the elements i.e. P, K, Ca, Mg and S were determined from this single digest extract.

Results

Some of physico-chemical parameters determined for are shown in table 1. The pH of the soil had the mean value of 7.58 this shows that the soil was neutral pH. From the soil analysis shown that soil texture was sandy loam from the valves. From the analysis data it shown that experimental site is medium in organic carbon (0.46%), N (287 kg ha^{-1}), P_2O_5 (149 kg ha^{-1}) and high in K_2O (742 kg ha^{-1}). Exchangeable calcium, magnesium (10.41 and 7.22 C mol. (P^+) kg^{-1}) and available sulphur (13 ppm) were sufficient in availability whereas, micronutrients availability (Fe, Mn, Zn, Cu, B and Mo) was more than their critical limits.

Table 1: Physio-chemical parameters of soil of experiment plot

Soil parameters	Values
Sand (%)	68.37
Silt (%)	10.91
Clay (%)	10.73
Soil pH (1: 2.5 soil water suspension)	7.58
Electrical conductivity (dS m^{-1})	0.08
Organic carbon (%)	0.46
Available Nitrogen (kg ha^{-1})	287.31
Available Phosphorus (kg ha^{-1})	149.76
Available Potassium(kg ha^{-1})	742.44
Exchangeable Ca (C mol.(P+)kg $^{-1}$)	10.41
Exchangeable Mg (C mol.(P+)kg $^{-1}$)	7.22
Available S (ppm)	13.22
Available Fe (ppm)	5.61
Available Mn (ppm)	3.17
Available Zn (ppm)	3.46
Available Cu (ppm)	0.59
Available B (ppm)	0.52
Available Mo (ppm)	0.18

Effect of secondary and micronutrients on primary nutrients (N, P and K) uptake of maize

Half dose of nitrogen (125 kg ha^{-1}),full doses of phosphorous(60 kg ha^{-1}) and potassium (60 kg ha^{-1}) in the form of urea (46 per cent N), di ammonium phosphate (DAP) (18 per cent N and 46 per cent P_2O_5) and muriate of potash (MOP) (60 per cent K_2O) was applied as basal at the time of sowing. The remaining half dose of nitrogen (125 kg ha^{-1}) was applied at 35 and 55 DAS in two equal splits. The adequate and split application of nutrients at different stages of crop resulted in higher growth and nutrient uptake due to release of sufficient amount of nutrients (Saragoni and Poss, 2000) [16] this results were confirmed by Ashok Kumar *et al.* (2008) [3].

The data regarding the nitrogen, phosphorus and potassium uptake by plants at 30, 60 and 90 DAS by whole plant indicated that uptake of primary nutrients increased from 30 to 90 DAS. Rate of uptake was higher between knee high stage to maturity stage. Adequate availability of nutrients ensures the greater level of absorption and translocation to the plant parts during growing period thereby increased quantities of nutrients in cob which shows higher values for the uptake of N, P and K by maize (Massey and Gaur, 2006) [13].

N uptake: With advance in age of the crop up to harvest the nitrogen uptake of maize was increased (Fig: 1). Maximum nitrogen uptake at 30 DAS was recorded with T_8 (RDF + Foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and Sulphur + $ZnSO_4$ @ 0.1 per cent) (20.02 kg N ha^{-1}) which was on par with T_4 (RDF + foliar application of one per cent $MgNO_3$). At 60 DAS more nitrogen uptake was noted with T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) (58.12 kg N ha^{-1}) which was at par with T_6 (RDF + Foliar application of 1 per cent each of $CaNO_3$, $MgNO_3$ and Sulphur) (57.95 kg N ha^{-1}). All the treatments with foliar application of nutrients had significantly increased the nitrogen uptake over the RDF (T_2). Maize at 90 DAS had taken maximum nitrogen (97.16 kg N ha^{-1}) from soil with the treatment T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) and was on par with T8 (RDF + Foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and sulphur + $ZnSO_4$ @ 0.1 per cent) and T_6 (RDF + Foliar application of 1 per cent each of $CaNO_3$, $MgNO_3$ and Sulphur). All treatments related to foliar application of secondary nutrients with RDF either with (or) without application of $ZnSO_4$ are superior over the RDF.

P uptake: Phosphorus uptake by maize crop increased with the crop growing period (Fig : 2). At 30 DAS T_8 (RDF + Foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and Sulphur + $ZnSO_4$ @ 0.1 per cent) (3.71 kg P ha^{-1}) registered maximum 'P' uptake which was on par with T_6 (RDF + Foliar application of 1 per cent each of $CaNO_3$, $MgNO_3$ and Sulphur), T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) and T_9 (RDF + Foliar application of one per cent 0.2 per cent micronutrient mixture). The data on 'P' uptake by maize at 60 DAS showed that significantly highest 'P' uptake was recorded by treatment T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) (20.57 kg P ha^{-1}). The foliar application of $ZnSO_4$ increased the phosphorus uptake by plants (Bukvic *et al.*, 2003). The treatment T_6 (RDF + Foliar application of 1 per cent each of $CaNO_3$, $MgNO_3$ and Sulphur) (19.95 kg P ha^{-1}) was superior over all the treatments of secondary nutrients as foliar application with RDF. At 90 DAS the treatment T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) recorded highest 'P' uptake (34.97 kg P ha^{-1}) which was on par with T_6 (RDF + Foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and Sulphur). Foliar application of micronutrient mixture with RDF (T_9) is on par with foliar application of 1 per cent each of $CaNO_3$, $MgNO_3$ and sulphur with RDF and $ZnSO_4$ (T_8).

K Uptake: At 30 DAS, the maximum potassium uptake (Fig: 3) was recorded by the treatment T8 (RDF + Foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and Sulphur + ZnSO4 @ 0.1 per cent) (21.85 kg K ha^{-1}) which was on par with T_6 (RDF + Foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and Sulphur) and T_9 (RDF + Foliar application of 0.2 per cent micronutrient mixture). At 60 DAS, T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) (68.52 kg K ha^{-1}) significantly showed better uptake over the treatments laid, among the remaining treatments T_8 (RDF + Foliar application of 1 per cent $CaNO_3$, $MgNO_3$ and Sulphur + $ZnSO_4$ @ 0.1 per cent) (66.41 kg K ha^{-1}) performed better. At 90 DAS the treatment T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) recorded highest 'K' uptake (103.49 kg K ha^{-1}) was significantly superior over all the treatments. Foliar application of 1 per cent $CaNO_3$ (T_3) (100.24 kg K ha^{-1}) was superior to the treatments of secondary nutrients. The higher uptake may be due to higher potassium concentration and drymatter production in these treatments. Significantly lowest potassium concentration and uptake at all stages of cop was observed with control (T_1) (9.51, 44.25, and 56.15 kg K ha^{-1} at 30, 60 and 90 DAS in respective recorded).

Effect of secondary and micronutrients on secondary nutrients (Ca, Mg and S) uptake of maize

In the present study, maize crop was supplied with foliar application of secondary nutrients in the form of $CaNO_3$, $MgNO_3$ and wettable sulphur. Foliar applicaton method transfers the nutrients very effectively to plant system than the soil application methods which will decreases the transformation and fixation losses observed in soil.

By the observation of data on calcium, magnesium and sulphur uptake at 30, 60 and 90 DAS indicated that uptake of secondary nutrients increased with advance in the age of the crop due to the increased dry matter production and demand in various plant metabolism. Rate of uptake was higher between 30 to 60 DAS and lower at 90 DAS.

Ca uptake: At 30 DAS, perusal of data (Fig: 4) on calcium uptake by plant shown that T_8 (RDF + Foliar application of 1 per cent $CaNO_3$, $MgNO_3$ and Sulphur + $ZnSO_4$ @ 0.1 per cent) recorded highest uptake (4.86 kg ha^{-1}) and was on par with T_6 (RDF + Foliar application of 1 per cent $CaNO_3$, $MgNO_3$ and Sulphur). Significantly lowest Ca uptake was noted with control (T_1) (1.40 kg ha^{-1}). At 60 and 90 DAS, T_7 (RDF + Foliar application of ZnSO4 @ 0.1 per cent) (24.76 kg ha^{-1}) recorded highest Ca uptake and was on par with T_6 (RDF + Foliar application of 1 per cent $CaNO_3$, $MgNO_3$ and Sulphur) (24.57 ha^{-1}) at 60 DAS. The combined application all secondary nutrients resulted in more Ca uptake when compared with the treatments of individual secondary nutrient foliar application along with RDF which all are superior over the RDF and control. The treatments with foliar application of micronutrients performed better when compared with the treatments of secondary nutrients. Synergistic effect was observed within the treatments of secondary and micronutrients

Mg Uptake: Magnesium uptake by maize crop was increased with advance in age of the crop (Fig: 5). At 30 DAS T_6 (RDF + Foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and sulphur) (3.30 kg Mg ha^{-1}) recorded maximum Mg uptake and was on par with treatments of foliar application of $ZnSO_4$ and all secondary nutrients with RDF (T_8) and foliar application of $MgNO_3$ with RDF (T_4). The data on magnesium uptake by maize at 60 DAS showed that T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) (13.08 kg Mg ha^{-1}) performed significantly better over all the treatments tried. Foliar application of all secondary nutrients with RDF (T_6) was on par with the treatment of foliar application of 0.2 per cent micronutrient mixture (T_9). At 90 DAS the treatment T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) recorded significantly highest Mg uptake (20.10 kg ha^{-1}). The foliar application of $MgNO_3$ with RDF (T_4) was noted as the next best treatment after the highest and was superior over the treatments which were designed with secondary nutrients along with RDF.

S Uptake: At 30 DAS, sulphur uptake (Fig: 6) was significantly highest with the treatment T8 (RDF + Foliar application of one per cent each of $CaNO_3$, $MgNO_3$ and Sulphur + $ZnSO_4$ @ 0.1 per cent) (3.43 kg S ha^{-1}). The treatments of T_9 (RDF + Foliar application of 0.2 per cent micronutrient mixture) and T_5 (RDF + foliar application of 1 per cent Sulphur) were found to be at par with each other. The sulphur uptake by the treatment with foliar application of all secondary nutrients with RDF (T6) is superior over the treatments with individual secondary nutrient foliar application with RDF and all these treatments were significantly superior over the RDF (T_2). At 60 DAS, T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) (13.44 kg S ha^{-1}) showed significantly better uptake over the treatments laid. Among the remaining treatments T_8 (RDF + foliar application of 1 per cent each of $CaNO_3$, $MgNO_3$ and Sulphur + $ZnSO_4$ @ 0.1 per cent) (12.38 kg S ha^{-1}) performed better next to highest treatment. At 90 DAS the treatment T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) recorded highest S uptake (22.34 kg S ha^{-1}) which was on par with T_7 (RDF + Foliar application of $ZnSO_4$ @ 0.1 per cent) and T5 (RDF + Foliar application of 1 per cent Sulphur). Lowest sulphur concentration and uptake was observed with control (T_1) (1.23, 5.97 and 12.02 kg S ha^{-1} at 30, 60 and 90 DAS in respective recorded).

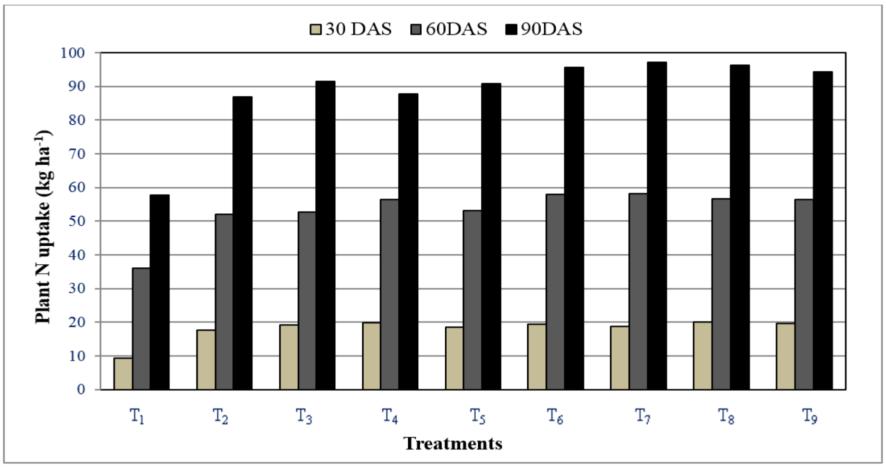

Fig 1: Effect of secondary and micronutrients on nitrogen uptake of maize

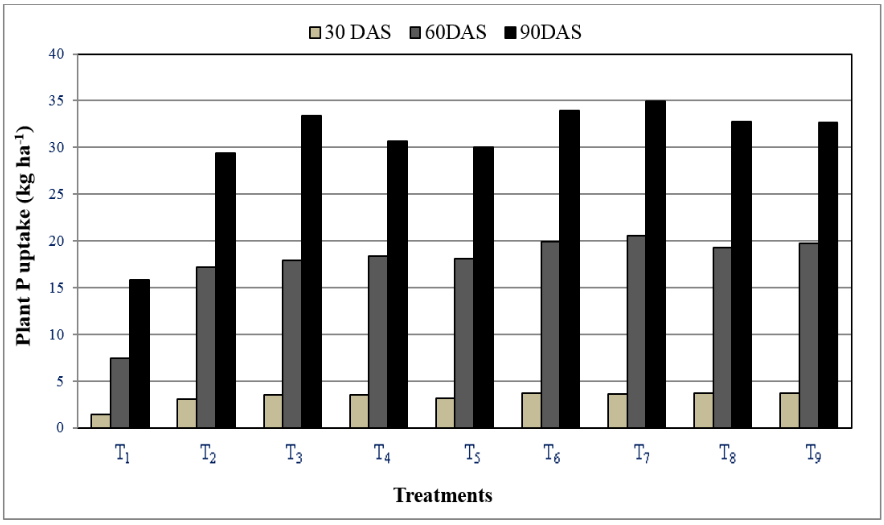

Fig 2: Effect of secondary and micronutrients on phosphorus uptake of maize

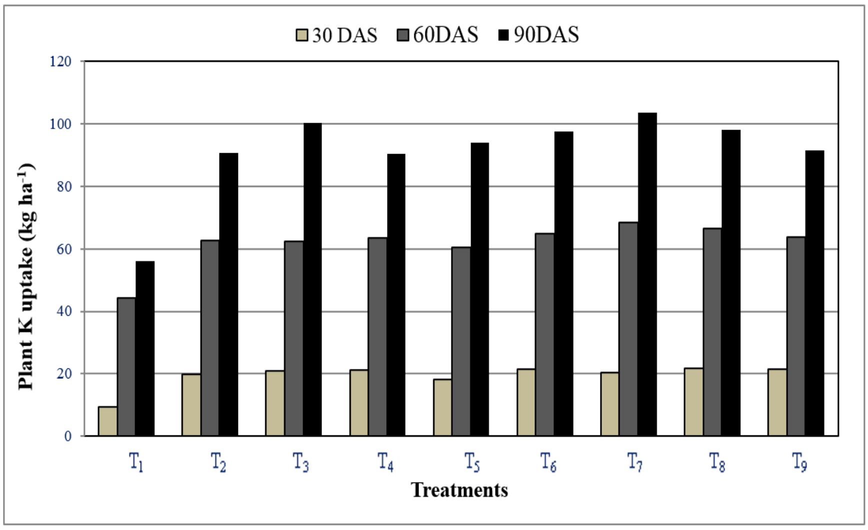

Fig 3: Effect of secondary and micronutrients on potassium uptake of maize

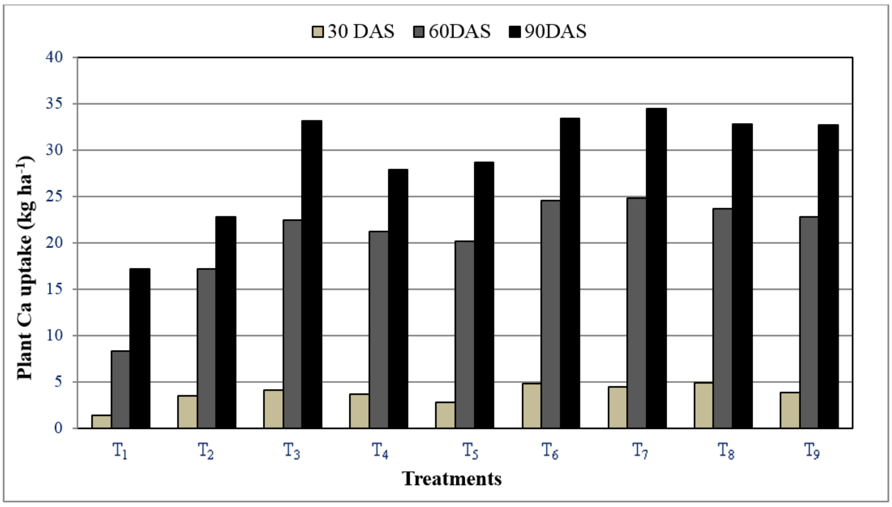

Fig 4: Effect of secondary and micronutrients on calcium uptake of maize

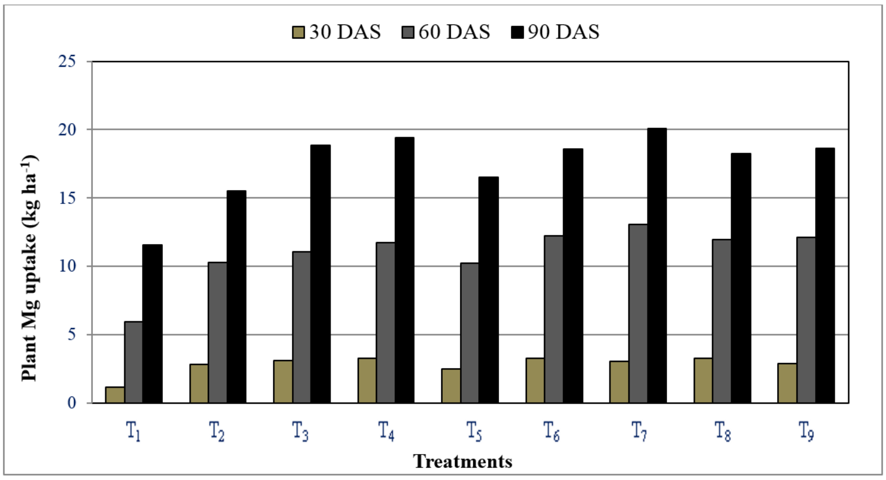

Fig 5: Effect of secondary and micronutrients on magnesium uptake of maize

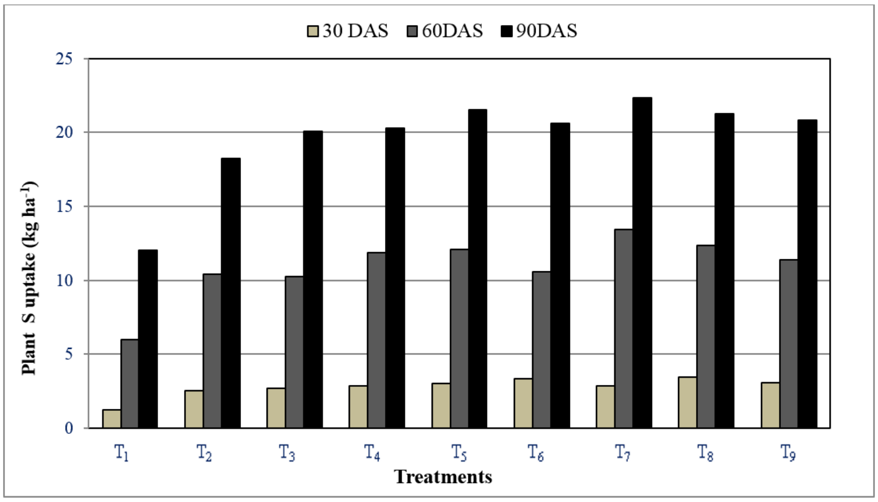

Fig 6: Effect of secondary and micronutrients on sulphur uptake of maize

Discussion

Nutrients uptake is vital in enhancing yield and nutrient content. Considerable increase in either nutrient content or in yield may increase the uptake. The uptake of any nutrient is the function of its content and dry matter production by the crop. Higher nutrient content in the produce and higher biomass production of maize might be the pertinent reason for higher uptake of nutrients. Application of micronutrients with not short of primary nutrients make the plant for better growth and development which will enhance the absorption of the nutrients. As per results obtained the nutrient uptake was more in the treatment (T7, T8 and T9) which has Zn and other micronutrients. The higher uptake of nitrogen was due to zinc aiding in activation of many enzymes and helped in uptake of nitrogen. The higher phosphorus uptake might be due to the mobilization of phosphorus in the presence of nitrogen in addition to applied phosphorus at recommended levels which ultimately resulted in better root growth and increased physiological activity of roots to absorb more phosphorus. Potassium has direct synergistic relationships with micronutrients like boron, copper, iron and zinc. Increased potassium uptake might be due to better plant growth leading to higher uptake of nutrients. These findings are in close agreement with the results reported by Patil *et al.* (2006) [14] and Rakesh Kumar *et al.* (2015) [15].

Conclusion

Although nutrient management is a complex process, improving our understanding of when, where, and how nutrients are used by corn plants provides opportunities to optimize fertilizer rates and application timings. Earlier research pertaining to primary macronutrient uptake, partitioning, and timing (Hanway, 1962, and Karlen *et al*., 1988) [8, 12] is likely unrepresentative of modern genotypes grown under current management practices. Unlike the other nutrients P, and S accumulation was greater during grain-fill than vegetative growth and as such, season-long supply of these nutrients is critical for balanced crop nutrition. Comparatively, availability of N, K, Ca and Mg at levels that can meet the maximum rates of uptake during early season vegetative growth would be expected to meet maize nutritional needs. Due to the immobility of nutrients, application timing and placement should include practices which favour uptake through maize roots. Nutrients needed in high quantities (N, P, K) or which have high harvest index (HI) values (P, N, S), are expected to be key nutrients for high-yield maize production. High total nutrient uptake necessitates accurate fertilization rates made at the right time and place. From the above vast discussion it is concluded that when all the nutrients were supplied at optimum level, the antagonistic effect between the nutrients will reduce and synergism between the nutrients will improved the growth, yield and nutrient uptake.

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