SOIL TEST BASED FERTILIZER PRESCRIPTIONS FOR TOMATO (*Solanum lycopersicum* L.) IN MAGNESIUM DEFICIENT ULTISOLS OF KERALA

By

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(2015-11-043)

THESIS

Submitted in partial fulfilment of the

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DECLARATION

I hereby declare that the thesis entitled **"Soil test based fertilizer prescriptions for tomato (*Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that the thesis entitled **"Soil test based fertilizer prescriptions for tomato (*Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala"** is a record of research work done independently by **Ms. Ramya K. N.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of **Ms. Ramya K. N. (2015-11-043)**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Soil Science and Agricultural Chemistry**, agree that the thesis entitled **"Soil test based fertilizer prescriptions for tomato (*Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala"** may be submitted by **Ms. Ramya K. N.** in partial fulfilment of the requirement for the degree.

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Ramya K. N.

AFFECTIONATELY DEDICATED TO

MY FATHER SRI.

NARAYANASWAMY, MOTHER SMT.

RAJAMMA

AND

BROTHER RAVI

LIST OF ABBREVIATIONS

%	-	per cent
°E	-	Degree east
°N	-	Degree north
a.i	-	Active ingredient
ANOVA	-	Analysis of Variance
$BaCl_2$	-	Barium chloride
BD	-	Bulk density
B : C	-	Benefit : Cost ratio
Ca	-	Calcium
CD	-	Critical Difference
cm	-	Centimeter
Cu	-	Copper
DAT	-	Days after transplanting
DAS	-	Days after sowing
DMRT	-	Duncan's Multiple Range Test
$dS\ m^{-1}$	-	Deci Siemens per meter
EC	-	Electrical Conductivity
Fe	-	Iron
g	-	Gram
ha	-	Hectare
HCl	-	Hydrochloric acid

IPNS	-	Integrated Plant Nutrient System
K	-	Potassium
K_2O	-	Potash
kg	-	Kilogram
L	-	Litre
m	-	Meter
M	-	Molar
m^2	-	Meter square
m^3	-	Meter cube
Mg	-	Magnesium
mg	-	Mili gram
mm	-	Mili meter
N	-	Nitrogen
NS	-	Non significant
OC	-	Organic carbon
P	-	Phosphorus
POP	-	Package of Practices Recommendations
RBD	-	Randomized Block Design
S	-	Sulfur
sp.	-	Species
t	-	ton
WASP	-	Web based Agricultural Statistics Software Package
WHC	-	Water holding capacity

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

Introduction

1. INTRODUCTION

Indiscriminate and imbalanced use of fertilizers has led to deterioration of soil fertility in India. For meeting the economic needs of farmers as well as for maintaining sustainable production, integrated use of organic and inorganic nutrition has become a requisite. Balanced application of nutrients to crop is very important, not only for crop growth and development but also to maintain soil fertility status. Hence soil test crop response correlation based fertilizer prescription equation for nutrients is related to yield and nutritional requirements of crop, per cent contribution from soil available nutrients and applied fertilizers. This methodology has the specific advantage that the fertilizer doses can be fixed according to the resources available with the farmers for attaining a targeted yield.

Tomato is an important vegetable crop, known as protective food because of its incredible phytochemical properties, nutrient supplementing compounds and also due to its wide spread production. Tomato, a pulpy nutritious fruit, is grown worldwide in an area of 4.5 million hectares with annual production of 152.9 million tons with productivity of 32.8 t ha^{-1}. In India, it ranks third after potato and onion and is cultivated in an area of 3,50,000 hectares with an annual production of 5.3 million ton and productivity of 19.5 t ha^{-1} (Indian Horticulture Database, 2011).

Tomato is a rich source of minerals, vitamins, essential amino acids and dietary fibers. As it is a short duration crop and gives high yield, it is important from economic point of view and so area under its cultivation is increasing day by day. Tomato has great scope in preserved food products also. The productivity of tomato mainly depends on its nutrient requirement and management. Hence judicious use of fertilizers and organic manures based on soil test values is very much important.

Magnesium is an essential plant nutrient which is the central atom of chlorophyll molecule. It is involved in various biochemical functions *viz.*, photosynthesis, carbohydrate formation and carbohydrate partitioning. It functions as mobile ion and has role in functional nucleic acid and protein biosynthesis (Geredas and Fuhrs, 2013). Magnesium deficiency occurs in the soils of the tropics because high precipitation and temperature lead to leaching loss of soil magnesium. The utilization of high analysis fertilizers and intensive cropping systems led to deficiencies in both secondary and micronutrients in soil. This necessitates the use of fertilizers which can supply secondary nutrients, in addition to major nutrients.

The total magnesium reserves in Kerala soils are poor and therefore magnesium can be considered as a critical element in the acid soils of Kerala. In Kerala, a hefty portion (80 per cent) of the cultivated soils is deficient in available magnesium and in many cases, crop growth is found to be limited by magnesium deficiency (State Planning Board, 2012). Therefore, application of magnesium fertilizers has been an accepted management practice for specific crops in the state.

Crops cultivated in Kerala respond to the application of magnesium since there is inadequacy in soil magnesium. Application of potassium to an inherently magnesium deficient soil increases magnesium deficiency because of the antagonism between these nutrients in plants and soils.

Research in fertilizer projects was done on soil properties, particularly on its characteristic ability to supply nutrients to crops. Ramamoorthy (1993) reported that the real balance for maximum yield depended on the relative contribution from soils and fertilizers. Soil test information should be correlated with nutrient uptake by crops for making efficient fertilizer recommendations. From this method, fertilizer prescription equations are inferred for a particular crop in a specific soil. The derived equations are then examined under farmers' field conditions for their reproducibility before they are summed up for large scale adoption (Sankar *et al.,* 1989). Such soil test based fertilizer prescriptions dodge the wastage or under usage of fertilizers.

The prescription equations formulated for tomato at AICRP on STCR, Vellanikkara can be test verified and compared with POP recommendations of KAU. Since the prescription equation is based on major nutrients alone, a modified prescription equation can be formulated based on different levels of Mg application. Hence the study will be helpful to decide the rate of magnesium to be applied along with major nutrients for maximizing the yield in Mg deficient Ultisols of Kerala.

In this context, the present study entitled "Soil test based fertilizer prescription for tomato (*Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala" was carried out at the STCR plot, College of Horticulture, Vellanikkara with the following objectives:

1. To validate the formulated fertilizer prescription equations for tomato.
2. To identify optimum rate of magnesium to be applied along with recommended fertilizer package for maximizing the yield.

Review of literature

2. REVIEW OF LITERATURE

Whenever there is significant depletion of plant nutrients in soil, crop production systems are not sustainable. Building up and maintenance of soil fertility with provision for balanced nutrition to crops are keys to sustain long term crop productivity. The fertilizer application by the farmers in the field without knowledge of soil fertility status and crop nutrient requirement usually leads to adverse effect on soil and crop. So, soil test based fertilizer use helps to realize higher yield as the nutrients are used in accordance with the deficiency of a particular nutrient in soil. A detailed review of the research works done in this area is given in the following sections.

2.1 Different approaches used in soil fertility studies

2.1.1 Nutrient index approach

Based on soil test values (STVs), soils were classified as low, medium and high categories. This is helpful for recommendation of fertilizers for crops. Fertilizer recommendation based on soil test values are generally done by soil testing laboratories in India and, such classification decreases the complexity of fertilizer recommendation (Parker *et al.*, 1951).

The nutrient index is arrived by multiplying the number of samples in each class by the respective weightage of that class. Totaling the sum of three classes thus arrived and dividing it by the number of samples analyzed, the nutrient index is obtained.

$$\text{Nutrient Index Value (NIV)} = \frac{(N_l \times 1) + (N_m \times 2) + (N_h \times 3)}{\text{Total number of samples } (N_l + N_m + N_h)}$$

Where N_l, N_m and N_h are the number of samples falling in low, medium and high categories of nutrient status respectively. Nutrient indices are calculated for nitrogen, phosphorus and potassium. The nutrient index value ranging from 1.67 to 2.33 was used for medium fertility classes and less than 1.67 and more than 2.33 for low and high fertility classes respectively.

In order to find the simplified procedure for studying the relation between STVs and maximum per cent yield, the critical limits of available nutrients were established by adopting graphical procedure (Cate and Nelson, 1965), statistical procedure (Cate and Nelson, 1971) and linear response plateau (LRP) model (Anderson and Nelson, 1975).

Mitscherlich (1909) built up a model for expression of the growth rate for various levels of essential immobile nutrients in the soil. He expressed that increase in yield per unit of the added nutrient was proportional to the difference between maximum attainable and the actual yield. Bray (1948) modified the concept by acquainting efficiency coefficients with soil test and applied form of nutrients and so called as Mitscherlich – Bray model.

Singh and Sharma (1994) revealed that nutrient index approach helps to formulate the soil test values beyond which fertilizer application is not required. It does not give information in terms of how much fertilizer has to be applied but gives probability of yield response for a particular crop.

2.1.2 Site Specific Nutrient Management

Site-specific nutrient management (SSNM) can be defined as the dynamic, field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their differences in cycling through soil-plant system (Dobermann and White, 1999). The SSNM concept is developed with the aid of different models such as QUEFTS (Janssen *et al.*, 1990) and it takes into account, the nutrient interactions also unlike other approaches of fertilizer recommendations.

In India, this concept has been calibrated and validated for a number of crops including wheat, rice, cassava, sweet potato, elephant foot yam, tea and pearl millet-wheat and pearl millet-mustard sequence (Pathak *et al.*, 2003; Tiwari, 2007; Dwivedi *et al.*, 2011; Byju *et al.*, 2012, 2016a, 2016b and Princekumar *et al.*, 2016). All the above studies clearly indicated the superiority of the SSNM concept in increasing the yield, income as well as nutrient use efficiencies.

2.1.3 Soil test based fertilizer recommendations through targeted yield approach based on inorganic fertilizers alone and along with IPNS

It is necessary to choose proper yield targets and fertilizer use practices for maintaining soil fertility and for getting maximum yield. The yield targets and required fertilizer doses can be calculated from the equation 1) $t = n.s / (m-r)$ 2) $Fd = - r.m.s / (m-r)$ where, t is yield target (q ha^{-1}), 'n' is the ratio between per cent contribution from soil and fertilizer nutrient, 'r' is nutrient requirement (kg per 100 kg), 'm' is the ratio between nutrient requirement and contribution from fertilizer nutrient, 's' is soil test value (kg ha^{-1}) and 'Fd' is fertilizer dose (kg ha^{-1}).

To overcome the loop holes of multiple regression model, the 'prescription procedure' for recommendation of fertilizers for desired yield targets, soils and climatic conditions was given by Truog (1960) and modified by Ramamoorthy *et al.* (1967). Yield targeting is an interesting and unique method among different fertilizer recommendation methods. It not only gives information about the soil test based fertilizer recommendations, but also the level of yield that the farmer can hope to achieve (Velayutham, 1979).

Ramamoorthy and Pathak (1969) detailed that the fertilizer application based on the target yield concept would be the most economical approach. The target yield equations developed for a specific crop variety for a specific soil type can be appropriately extrapolated to different varieties of the sample crops and to comparable soils (Velayutham, 1979). The targeted yield equations have been accounted by Reddy *et al.* (1985) for groundnut in Bavasinagar, Hyderabad (red soil), Rahuri (dark soil) and Dholi (alluvial soil). Raniperumal *et al.* (1987) revealed that the fertilizer modification equation developed for rice *var.* Barathi was also applicable to varieties like IR 50, ponni and paiyur-1 in similar soil types. The soil test based fertilizer prescription equations developed for ragi *var.* CO11 is also suitable for *var.*

CO 12 (Duraiswami *et al.*, 1989). The targeted yield model was helpful for computing fertilizer doses for varying soil test values for getting diverse yield targets.

Reddy and Ahmed (1999) recommended that, for obtaining a given yield, a definite quantity of nutrients must be taken up by the plant. This forms the basis for fertilizer recommendation for targeted yield of a crop. In Hisar, Singh *et al.* (2000) developed targeted yield equation for mutated wheat, barley and cotton.

This procedure considers the nutrient requirement (NR) of a crop for production per unit quantity of economic produce, the per cent contribution of nutrients from soil (Cs) and the per cent contribution of nutrients from the added fertilizer (Cf). These three parameters are used to calculate yield target (T) with soil nutrients (S) and fertilizer nutrients (FD) as below:

FD = {(NR x 100 T) / Cf} – {(Cs x S) / Cf}

Under IPNS situations, the fourth parameter *viz.,* the per cent contribution of nutrients from the added organic manures or biofertilizers (Co) is also used to relate with the yield target (T), ON is nitrogen supplied through organic sources and SN is soil available nitrogen, then the equation can be represented as indicated below.

FN = {(NR x 100 T) / Cf} – {(Cs x SN) / Cf} – {(Co x ON)} / Cf}

This approach combined with Inductive methodology is termed as "Inductive cum Targeted yield approach". Based on this approach, field trials have been conducted in all the co-operating centers of AICRP on STCR and fertilizer prescription equations under NPK alone and IPNS were developed for various crops (Subbarao and Srivastava, 2001a & b, Muralidharudu *et al.*, 2007 & 2011).

Soil test based fertilizer recommendations resulted in efficient fertilizer use and maintenance of soil fertility. Among the various methods of fertilizer recommendations, the one based on yield targeting (Ramamoorthy *et al.*, 1967) is unique as it not only indicates soil test based fertilizer dose but also the level of yield that can be obtained if appropriate practices are followed in raising the crop. Fertilizer application based on target yield approach is economical (Ramamoorthy and Pathak, 1969). The STCR approach recorded higher Agronomic Efficiency (AE) and Apparent Nitrogen Recovery (ANR) in groundnut - maize cropping system (Reddy *et al.*, 2004).

The various soil test based fertilizers recommendations put forth by soil scientists aim at utilizing both soil and fertilizer nutrients judiciously and efficiently in a manner best suited to different soil-crop-climatic condition in the block/state/country. The functional relationship between different inputs and crop yield should be quantified, to know the yield levels at different fertilizer levels for obtaining either the maximum yield or economic yield. Efficient prediction models are quite imperative for the prediction of crop yield and optimization of fertilizers (Sankar, 1986).

Derivations of the fertilizer prescription equations for desirable yield targets for different crops are being done in the various centers of AICRP on STCR in India. In Kerala, Hassan *et al.* (2001) specified the necessity for alternative soil test crop response correlation based recommendations instead of the already prevailing techniques in the state. In KAU, soil test crop response study was conducted and prescription equations were developed for cassava (Swadija, 1997), ginger (Jayalakshmi, 2001), coleus (Nagarajan, 2003), groundnut (Sidha, 2005) and oriental pickling melon (Lamina, 2009). Soil test crop response correlation studies have been conducted by STCR centre, Vellanikkara for banana, rice, sweet potato, ash gourd, bitter gourd, snake gourd, amaranthus, turmeric (IISS, 2007), chilli (KAUa, 2010) and watermelon (KAUb, 2011) in lateritic soils. Sajnanath (2011) carried out detailed studies on nutrient requirement of salad cucumber based on targeted yield approach and prescription equations were formulated.

2.2 Impact of fertilizers and different soil test approaches on physical and chemical properties of soils

2.2.1 Influence of N, P and K on soil physico-chemical properties

Singh *et al.* (1980) conducted a study to find out the effect of continuous application of FYM and chemical fertilizers on soil properties. Continuous application of farmyard manure and chemical fertilizers resulted in decrease in soil pH by one unit compared to initial value, which was due to organic matter decomposition and mineralization. However Formali and Prasad (1979) reported that continuous application of FYM for three years in rice – wheat crop rotation, resulted in decrease in soil pH from 8.8-8.6, whereas application of phosphorus and potassium had no effect on soil pH.

Continuous application of mineral fertilizers year after year in maize – wheat rotation resulted in significant change in soil pH but not much change have been noticed with respect to salt content of soil (Kapor *et al.,* 1986). Whereas Chaudhary *et al.* (1981) and Rahman (1986) reported that application of major nutrients (NPK) through mineral fertilizers to finger millets grown in Ultisols showed increase in both soil pH and electrical conductivity.

Sudhir *et al.* (1996) reported that repeated application of chemical fertilizers alone resulted in significant decrease in soil pH of an Alfisol compared to the treatment which consisted of application of fertilizers and organic manures. Srikanth *et al.* (2000) concluded that there was a decrease in pH of soil by treatment with farmyard manure (7.08) and vermicompost (7.04) compared to initial soil pH of 7.24. This was correlated with the acidifying effect of organic acid produced at the time of decomposition of organic materials.

Malhi *et al.* (1998) conducted a field trial in brome grass hay in order to study the effect of long-term N fertilizer-induced acidification and impact of liming on micronutrients in soil. Results showed significant decrease in the soil pH of top 10 cm soil depth by long term application of nitrogenous fertilizers. Continuous application of NPK and organic fertilizers decreased the soil pH (Singh and Nambiar, 1986).

Subramanian and Kumaraswamy (1989) noted significant increase in the electrical conductivity of the soil when farmyard manure was applied in combination with chemical nutrients/ fertilizers. Slight increase in the salt content of soil occurred due to the effect of 100 per cent N, P_2O and K_2O supplied through chemical fertilizers (Santhi *et al.,* 1999).

Significant increase in the soil organic carbon (SOC) of Alfisols was observed when soil was enriched with recommended dose of fertilizers (RDF) and SOC was further increased in soil with RDF + organic manures like FYM, green manures and vermicompost in rice - wheat intercropping (Bhandari *et al.*, 1992). In the same manner, Sudhir and Siddaramappa (1995) observed an increase of 17.8 and 78.3 per cent organic carbon in NPK and NPK+ FYM treated plot respectively compared to control.

Jatav *et al.* (2010) conducted a study in order to analyze the chemical properties of soil by supplying phosphorus and potassium from different sources under potato - radish cropping sequence in a brown hill soil. Results revealed that treatment with application of 100 per cent P and K by organic manures showed increase in soil pH compared to treatment that received 50 per cent organic P, K along with 50 per cent inorganic P and K fertilizers.

Ashok (2012) reported that increase in pH in the treatment, STCR along with INM for targeted yield of 10 t ha^{-1} (5.70) whereas lowest pH was noticed in SSNM through fertilizers for targeted yield of 10 t ha^{-1} (5.23) in maize crop. Whereas application of different levels of chemical fertilizers alone or in combination with organics resulted in no change in soil pH in rice (Chandrakumar, 2001).

Srinivasarao *et al.* (2012) concluded that application of organic amendments alone or coupled with mineral nutrients resulted in more input of carbon and therefore more built up of different carbon pools under finger millet cropping system.

Hussain *et al.* (2015) conducted a field trial in maize crop in order to study the interaction between potassium sulphate and diammonium phosphate in saline sodic soils. Results highlighted increased soil reaction and salt content in post-harvest soil samples compared to pre crop soil samples.

2.2.2 Available nitrogen, phosphorus and potassium

Prasad *et al.* (1983) revealed that increase in the application of 150 per cent of recommended nitrogen, phosphorus and potassium showed significantly higher available N (368 kg ha^{-1}), P_2O_5 (60.2 kg ha^{-1}) and K_2O (142 kg ha^{-1}) in soils compared to control with 200, 10.1 and 102 kg N, P_2O_5 and K_2O ha^{-1} respectively under multiple cropping system. In the same manner, Reddy (1988) recorded highest available N content in the soil which received highest dose of 150 per cent of nitrogen, phosphorus and potassium fertilizers in finger millet.

Repeated application of P fertilizers of 100 per cent and more than 100 per cent in every season during crop production of finger millet resulted in sustainable built up of total phosphorus in an Alfisol (Lokeshwarappa, 1997).

Application of 100 per cent of nitrogen, phosphorus and potassium fertilizers in combination with FYM resulted in increased soil available P_2O_5 content both in surface and subsurface layers in continuous cropping system (Acharya *et al.,* 1998). Similarly highest amount of available potassium content was noticed in the treatment with major nutrient fertilizers and farmyard manure in rice – wheat system of Mollisols (Singh *et al.,* 1999). In the same way, increase in the available nutrient pool by the application of farmyard manure and potash fertilizers was noticed over control in sorghum (*Sorghum bicolor*) – cumbu (*Pennisetum glaucum*) in rotation in Vertisols (Suresh *et al.,* 1999).

Band placement of nitrogen, phosphorus and potassium in STCR recommendations at the rate of 164, 13.36 and 353 kg ha^{-1} NPK and farmyard manure at the rate of 2 t ha^{-1} resulted in increase of available nutrient pool over farmers practice and absolute control in finger millet (Jagathjothi *et al.,* 2008).

Kalaichelvi (2008) conducted an experiment in order to study the available nutrient status in the soil after the harvest of cotton crop. Results revealed that application of nitrogen, phosphorus and potassium at the rate of 200, 100 and 100 kg ha^{-1} showed higher N and P status in soil. Yu *et al.* (2009) concluded that application of nitrogen, phosphorus and potassium as fertilizers increased soil fertility and also exchangeable potassium over initial values in soybean - maize crop rotation.

Hemalatha and Chellamuthu (2011) reported that inorganic phosphorus fractions were higher in the treatment which gave 150 per cent of N, P_2O_5 and K_2O

fertilizers followed by 100 per cent of N, P_2O_5 and K_2O and farmyard manure in finger millet – maize cropping sequence. But highest available phosphorus was noticed in treatment with 100 per cent N, P_2O_5 and K_2O and farmyard manure.

Shankar *et al.* (2011) conducted a study with different combinations of fertilizers with or without organic matter addition. Work revealed that application of 10 t ha^{-1} FYM and 100 per cent N, P_2O_5 and K_2O increased the soil organic carbon by 0.45 per cent, available nitrogen, phosphorus and potassium by 204 kg ha^{-1}, 68.6 kg ha^{-1} and 107 kg ha^{-1} respectively over years in rainfed finger millet in semi-arid Alfisol. In maize residue block, addition of maize residue at 5 t ha^{-1} + 100 per cent N, P_2O_5 and K_2O gave a significantly higher organic carbon (0.39%), available nitrogen (190 kg ha^{-1}), available phosphorus (47.5 kg ha^{-1}) and available potassium (86 kg ha^{-1}).

Sharma and Paliyal (2014) conducted an experiment by using different levels of fertilizers. Results revealed that phosphorus content was increased in all treatments which received phosphorus and farmyard manure. Highest P (39.0 kg ha^{-1}) was noticed in 100 per cent N, P_2O_5 + FYM followed by 100 per cent N, P_2O_5 and K_2O treatment (34.20 kg ha^{-1}). The P content showed a decline over the initial phosphorus level in the treatments where only nitrogenous fertilizers were added, either alone or along with FYM treatment in rainfed maize-wheat cropping system.

Mazur and Mazur (2015) studied the influence of long-term, annually applied fertilizers along with manure and slurry, on the accumulation of total and available forms of phosphorus and potassium. They concluded that the increase in total phosphorus and potassium content under the influence of fertilizers application was significant when compared to the control and determined it as P-21.8 per cent, K-36.2 per cent in lessive soil and P - 24.7 per cent in brown soil.

2.2.3 Available calcium, magnesium and sulfur

Intensive cropping and manuring resulted in increased water soluble sulfur and maximum available sulfur, whereas decline in magnesium levels were noticed in treatments with application of 150 per cent nitrogen, phosphorus and potassium + FYM (Swarup and Ghosh, 1979). Yadhuvansi *et al.* (1985) found that long term application of chemical fertilizers and farmyard manure increased exchangeable Ca and Mg levels in soil. He concluded that decline in Ca and Mg levels by the addition of chemical fertilizers only, was due to H^+ and Al^{3+} released to soil solution in an Alfisol.

Significant increase in the level of calcium and magnesium in continuously fertilizer applied acid soils under multiple cropping systems was noticed with the application of farmyard manure because of biomass incorporation over control (Prasad *et al.,* 1996). Chandravanshi (1998) conducted a study on physical, chemical and microbiological properties of an Alfisol subjected to permanent manuring and cropping schedule. They reported that application of chemical fertilizers along with farmyard manure increased soil available sulfur over control. Similarly Singh *et al.* (1999) reported that application of NPK fertilizers with FYM resulted in significantly higher sulfate-S content than other fertilizer treatments and control. The use of both organic and inorganic fertilizers in combination significantly increased the available sulfur content in the soil after the harvest of crop in rice – wheat cropping system in Mollisols.

Long term fertilizer trial with the application of only straight fertilizers (NPK) without sulfatic fertilizers showed decrease in the available pool of SO_4^{2-} in an Alfisol. Application of NPK fertilizers coupled with the addition of farmyard manure increased available stock of sulfur (Nega *et al*., 2001). Addition of 100 per cent recommended dose of fertilizer showed low calcium content whereas treatment with addition of farmyard manure irrespective of levels of chemical fertilizers showed more exchangeable calcium content because of organic matter mineralization in soybean cropping system (Shashi, 2003). Addition of zinc enriched organic manures applied to rice crop increased the available calcium content of soil (Veeranagapapa, 2009).

Application of nutrients at different forms increased exchangeable calcium and magnesium in maize crop (Santhosha, 2013). Addition of farmyard manure, chemical fertilizers and cow dung slurry increased available sulfur (28.5%) and magnesium (57.4%) over control (Mazur and Mazur, 2015).

The secondary nutrients like Ca, Mg and S play an important role in the growth, yield and quality of crops, but there was no recommendation for applying these nutrients (Sangamithra and Menon, 2014). The availability of Ca and Mg is very low in Kerala soils due to leaching by rainfall. About 80 percent of soils of Kerala are deficit in available Mg content (Rajashekaran *et al.*, 2013). The inherently low CEC leads to low retention capacity for basic cations like Mg. Magnesium is having great role not only in improving quality of crop but also in human nutrition (Goladi and Agbenin, 1997).

2.2.4 Available micronutrients (Fe, Mn, Zn, Cu and B)

Biswas *et al.* (1977) conducted long term fertilizer experiment in maize to study the interaction between phosphorus and zinc. Results revealed that increased application of phosphatic fertilizers decreased the availability of zinc and addition of potassium fertilizers increased zinc status in soil. Rao and Singh (1985) reported that addition of phosphatic fertilizers showed decline in the availability of Zn and Fe in case of *kharif* rice grown in Andhra Pradesh. Whereas Kapor and Rana (1986) conducted an experiment in order to study available zinc and manganese status of a Toll wol loamy sand as influenced by continuous use of different levels of fertilizers. They observed decreased Zn and Mn content in the soil with increase in N and P level. This might be due to the crop removal, but K did not show any influence on the Mn content of soil. Malhi *et al.* (1998) observed increased extractable Fe concentration at 0-5 and 5-10 cm depth which was closely associated with increased N rate or decreased pH, no strong correlation was observed between Fe concentration in soil and N rate in brome grass hay.

Huang and Snapp (2004) reported that application of boron (300 mg L^{-1}) decreased the incidence of shoulder neck crack in tomatoes. Davis *et al.* (2003) reported that application of boron increased the uptake of potassium, magnesium and boron by tomato plants.

Atheefa (2007) conducted a long term fertilizer application trial in finger millet – maize cropping sequence to study the antagonistic behavior between major and micronutrients. Results revealed that application of 100 per cent nitrogen, phosphorus and potassium in combination with farmyard manure increased zinc content whereas addition of nitrogen and phosphorus together and nitrogen alone increased copper and manganese content respectively.

Kumar and Babel (2011) observed that increased soil organic matter resulted in increased availability of micronutrients. They also noticed that availability of micronutrients decreased with increase in pH and $CaCO_3$ content. Ali *et al.* (2014) reported that phosphorus had negative correlation with copper, zinc and boron in alkaline calcareous soil. Combined application of farmyard manure, pig manure and poultry manure increased the availability of zinc over control in rice (*Oryza sativa*) – wheat (*Triticum aestivum*) sequence in Vertisols (Kulhare *et al.,* 2014).

2.3 Yield and quality attributes of tomato as influenced by application of different nutrients

Increase in the dry matter of tomato by 0.38% was noted with the application of magnesium along with recommended dose of fertilizers (NPK) (Kabu and Toop, 1970). Sainju *et al.* (1999) reported that 90 kg N ha^{-1} produced higher tomato yield, dry matter weight, and N uptake compared with no application of N. But 180 kg N ha^{-1} decreased tomato yield. Hao and Papadopoulos (2004) reported that application of N, P and K significantly increased fruit yield of tomato over control. Application of balanced fertilizer application resulted in increased tomato yield (42.0 t ha^{-1}) over farmers practices (23.5 t ha^{-1}) (Tiwari *et al.*, 2006).

Herath *et al.* (2010) reported that maximum tomato yields and the highest net profit was obtained by the treatment with highest level of N, P and K (150 % N, 75 % P and 75 % K) when compared with the treatment having optimum levels of N, P and K. Adeniyi and Ademoyegun (2012) conducted an experiment to determine the effect of different fertilizers on growth and yield of tomato. They observed that 120 kg N ha^{-1} supplied by 15:15:15 NPK mixture recorded highest yield (32.97 t ha^{-1}) while that of control (no fertilizers) recorded lowest yield (4.07 t ha^{-1}).

Jadhav *et al.* (2013) reported that tomato yield in soil test based fertilizer applied plot ranged from 56.77 to 78.27 t ha^{-1} with a mean of 67.52 t $ha^{-1}$and in control plots, the yield ranged from 14.63 to 20.51t ha^{-1} with a mean of 17.57 t ha^{-1}. Mishra *et al.* (2013) reported that highest yield of tomato (175.8 q ha^{-1}) was recorded in treatment receiving highest level of N, P and K nutrition over control (149.4 q ha^{-1}). Application of soil test based fertilizers resulted in increase in the yield of tomato (68.04 t ha^{-1}) while it was minimum (40.39 t ha^{-1}) in farmers practice in acidic soils of Sylhet (Nazrul and Khan, 2016).

2.4 Effect of STCR methodology on growth, yield and crop uptake

Dhillon *et al.* (1997) developed targeted yield equations for rice in Punjab. They noticed that there was wide variation among different treatments; mean grain yield was 66.3 and 78.5 q ha^{-1} against the yield targets of 65 and 80 q ha^{-1} respectively.

Ray *et al.* (2000) reported that application of high doses of nitrogen and phosphorus in soil helped in increased uptake of potassium by jute crop. They also observed that basal application of potassium caused the release of available potassium from unavailable form in native soil sources in Typic Ustochrept. Bangar (2001) conducted a study in Maharashtra on modifying yield targets in sorghum and results revealed that uptake of nitrogen and phosphorus was increased by 13.66 and 15.46 per cent respectively in the first year, 14.49 and 13.38 per cent respectively in the second year at a target yield of 18 q ha^{-1}.

Reddy *et al.* (2004) observed that application of recommended dose of fertilizer (RDF) in maize gave highest yield parameters *viz.*, cob girth (17.78 cm), cob length (19.27 cm), number of grains per cob (518), 1000 grain weight (228.30 g) and grain yield per plant (119.72 g) by STCR approach. Prabhuraj *et al.* (2006) reported that application of fertilizers through soil test crop response approach in Alfisol under irrigated condition gave yield of mulberry leaves, 33.29 t ha^{-1} per year with less fertilizers 257:112:60 kg $N:P_2O_5:K_2O$ ha^{-1} per year whereas RDF of 300:120:120 kg $N:P_20_5:K_2O$ ha^{-1} produced yield of 35.79 t ha^{-1} per year.

Ashwini (2007) conducted a study by STCR methodology in finger millet at Bangalore, she reported that nutrient use efficiency was more in the treatment receiving fertilizers as per package of practice recommendations (POP) for finger millet followed by STCR with target yield of 50 q ha^{-1}.

Gayathri *et al.* (2009) conducted a study in hilly tracts of Nilgiris district and reported highest yield of potato tubers (40.38 t ha^{-1}) in plot receiving STCR-IPNS treatment for target yield of 40 t ha^{-1}. This was followed by STCR-NPK treatment with target yield of 40 t ha^{-1} (38.77 t ha^{-1}) compared to blanket (26.44 t ha^{-1}) and control plot (12.55 t ha^{-1}). Apoorva *et al.* (2010) reported that addition of nutrients on soil test crop response basis in combination with dual microbial culture recorded higher grain yield (3740.5 kg ha^{-1}) and straw yield (9485.9 kg ha^{-1}) in finger millet over other treatment combinations and control.

Santhi *et al.* (2010) reported that inorder to produce one ton dry roots of ashwagandha, 77.6, 31.7 and 113.3 kg of N, P_2O_5 and K_2O ha^{-1} were required. The per cent contribution of nutrients from soil, fertilizer and FYM were 19.03, 31.30 and 23.14 for nitrogen; 20.26, 17.30 and 6.38 for phosphorus; 11.08, 62.53 and 30.39 for potassium respectively under soil test crop response based integrated plant nutrition system in Inceptisols.

Suri *et al.* (2010) reported that number of grain rows per cob, 1000 seed weight, grain yield and stover yield in maize were highest in the treatment that received NPK + VAM cultures at a target of 40 t ha^{-1}. They noticed that VAM cultures increased phosphorus level in soil by 25 to 75 per cent and hence high biological yield was obtained.

Basavaraja *et al.* (2011) observed that addition of major nutrients through inorganic fertilizers for target yield of 75 q ha^{-1} of aerobic rice recorded highest uptake of NPK and lowest uptake was recorded in treatment with target yield of 50q ha^{-1}. Uptake of NPK (157.53, 31.63 and 151.10 kg ha^{-1}) by cotton plants receiving STCR treatment recorded highest yield over RDF (137.85, 27.11 and 138.03 NPK kg ha^{-1}) in cotton- chickpea cropping sequence (Gudadhe *et al.*, 2011).

Vidyavathi *et al.* (2012) reported that highest seed weight (29.8 q ha^{-1}) and dry matter yield (48.8 q ha^{-1}) of cotton were recorded in soil test crop response approach followed by 50 % NK + 25 % P which recorded 27.9 q ha^{-1} of cotton seed and 44.8 q ha^{-1} of dry matter. Kleiber *et al.* (2012) reported that magnesium application at the rate of 100kg ha^{-1} enhanced the yield of onion (4.85 kg m^{-2}) over control. Nutrient removal by tomato crops *viz.*, 140.4, 23.4 and 50.4 kg NPK ha^{-1} gave maximum yield under soil test based fertilizer prescriptions in an *Ustochrept* of Odisha (Mishra *et al.*, 2013).

Gowda (2012) reported that highest yield of maize (177.8 q ha^{-1}) was noticed in the SSNM treatment with maximum uptake of major nutrients. Similarly, SSNM for target yield, 10 t ha^{-1} in maize recorded highest nutrient removal (504.7, 103.1 and 212.3 kg N, P_2O_5 and K_2O ha^{-1}) followed by STCR methodology for target yield, 10 t ha^{-1} (433.47, 82.9 and 184.5 kg N, P_2O_5 and K_2O ha^{-1}) over rest of the treatments (Ashok and Jayadeva, 2013).

Jadhav *et al.* (2013) conducted a work to formulate yield target equation for tomato *var.* dhanashree. Results revealed that uptake of nitrogen, phosphorus and potassium at the rate of 168.74, 53.28 and 211.42 kg ha^{-1} respectively produced highest yield (67.52t ha^{-1}) by STCR approach over control, which yielded 17.57 t ha^{-1} in an Entisol.

Praveena *et al.* (2013) conducted a study on soil test based fertilizer prescriptions for cotton in Vertic Ustropept of Tamil Nadu, which revealed that treatment that received STCR+IPNS approach recorded highest yield of 4.14 t ha^{-1} at target of 4 t ha^{-1} against control (1.81 t ha^{-1}). Similarly Basavaraja *et al.* (2014) observed highest yield (47.35 q ha^{-1}) in STCR + IPNS approach against yield target of 90 q ha^{-1} over control (34.43 q ha^{-1}) in hybrid maize under dry land condition.

Gowdappa *et al.* (2014) conducted STCR based on drill sown onion in Karnataka and results revealed that application of STCR based fertilizers after soil testing, recorded highest yield parameters *viz.*, bulb weight (63.51 g), bulb length (4.47 cm), higher bulb diameter (5.82 cm) over rest of the treatments without STCR based fertilizer application. Whereas Praveena *et al.* (2014) observed that highest plant height (140.8 cm), sympodial branches (27.5), monopodial branches (3.4), number of bolls per plant (55.6), boll weight (5.8 g $boll^{-1}$) and yield (4.14 t ha^{-1}) was obtained by STCR-IPNS treatment with target yield of 4.0 t ha^{-1} in cotton.

Yeshpal *et al.* (2014) conducted a work in Mollisols in order to study the effect of N, P_2O_5 and K_2O fertilizers on the yield of *Brassica campestris* L. at GBPUAT, Pantnagar. The response data was statistically subjected to various calibration systems for formulating soil-test based fertilizer recommendations, *viz.*, targeted yield approach, regression model, Mitscherlich's equation and soil testing laboratory recommendations followed in the area. The results showed that targeted yield approach was found to be the most suitable fertilizer recommendation for *Brassica campestris* L. in Mollisols.

Mishra *et al.* (2013) observed highest agronomic nutrient use efficiency and recorded highest tomato yield of 175.8 q ha^{-1} over control (149.4 q ha^{-1}) in STCR approaches. Significantly highest agronomic use efficiency of NPK in maize was recorded with STCR treatment at target of 90 q ha^{-1} with IPNS approach (10.86 kg kg^{-1}) compared to STCR treatment along with IPNS with yield target of 110 q ha^{-1} using inorganic fertilizers alone (3.09 kg kg^{-1}). Among the different fertilizer application techniques, STCR methodology, yield with target of 90 q ha^{-1} with IPNS has achieved higher agronomic nutrient use efficiency in hybrid maize (Basavaraja *et al.*, 2014). Similarly, Nazrul and Khan (2016) reported that nutrient use efficiency and yield was highest in STCR methodology in tomato (68.04 t ha^{-1}) compared to farmers' practice.

2.4.1 Effect of different nutrients on quality attributes of tomato

Pujos and Morard (1997) reported that reduction in potassium content of plant tissues of tomato was compensated by the application of higher dose of magnesium to soil (K-Mg antagonism). Dumas *et al.* (2003) reported that higher doses of nitrogen decreased ascorbic acid content, which was substantiated by shade effect because of more canopies in heavily nitrogen applied plots. Similarly Mozafer (1993), Muller and Hippe (1987) observed lower level of ascorbic acid content in tomato fruits in higher nitrogen treated plots. Hamner *et al.* (1945) noticed more ascorbic content (25.8 mg $100g^{-1}$) under sunshine whereas it was low under shaded condition (15.5 mg $100g^{-1}$). Puspha (2004) recorded the highest titratable acidity in tomato under 100 per cent RDF (NPK) in combination with biofertilizers in Alfisol of Bangalore.

Toor *et al.* (2006) conducted a work on seasonal variations in the antioxidant composition of greenhouse grown tomatoes, and reported that antioxidant components of tomato were influenced by different fertilizers. Results revealed that antioxidant components was 17.5 per cent more in plots treated with chicken manure, but ammonia treated plot showed very low antioxidant property.

Salman *et al.* (2010) observed highest pulp weight (88.14%), dry matter content (5.34%), total soluble sugars (4.50%), acidity (0.47%), ascorbic acid content (10.95 mg $100g^{-1}$), lycopene level (112.00 μg $100g^{-1}$), chlorophyll-a (41.00 μg 100 g^{-1}), chlorophyll-b (56.00 μg $100g^{-1}$) and highest shelf life (16 days) with combined application of 2.5 kg boron + 6 kg zinc ha^{-1} along with recommended dose of NPK fertilizers (253, 90, and 125 NPK kg ha^{-1}) in tomato. Highest chlorophyll a and chlorophyll b content was noticed in treatment that received recommended dose of fertilizers and Zn in tomatoes grown in Harayana (Yadav *et al.*, 2001).

Application of higher levels of phosphorus and potassium did not show any significant difference in TSS and titratable acidity of tomato over control. However application of nitrogen at the rate of 100kg ha^{-1} showed significant change in quality of tomato fruits by increasing TSS and titratable acidity (Etissa *et al.*, 2014). Titratable acidity was more in fertilizer applied plots compared to no fertilizer applied plots (Saravacos *et al.*, 1958).

2.5 Importance of magnesium on crop yield and quality

Magnesium is an important component of the chlorophyll molecule and is associated with rapid growth, cell division, carbohydrate metabolism, synthesis of amino acids and cell proteins. Magnesium has a number of key functions in plants. Particular metabolic processes and reactions that are influenced by Mg are photophosphorylation (such as ATP formation in chloroplasts), photosynthetic carbon dioxide (CO_2) fixation, protein synthesis, chlorophyll formation, phloem loading, partitioning and utilization of photo-assimilates, generation of reactive oxygen species, and photo-oxidation in leaf tissues. Consequently, many critical physiological and biochemical processes in plants are adversely affected by Mg deficiency, leading to impairments in growth and yield. In most cases, the involvement of Mg in metabolic processes relies on numerous Mg activating enzymes. An important Mg-activated enzyme is the ribulose - 1, 5 bisphosphate (RuBP) carboxylase, which is a key enzyme in the photosynthesis process and the most abundant enzyme on earth (Cakmak and Yazici, 2010). Insufficient plant magnesium is the main reason for increasing the rate of primary carbon decomposition due to photorespiration (Shaul, 2002). It is well documented that Mg is required for effective release of organic acid anions from roots to modify an Al-toxic rhizosphere (Yang *et al.*, 2007). Magnesium deficiency symptoms may occur when Mg is limited, but they may also be associated with an antagonistic relationship between Mg ions (Mg^{2+}) and other cations. The competition of Mg with other cations for uptake ranges from highest to lowest as follows: K > NH_4^+ > Ca > Na (Penalosa *et al.*, 1995; Mills *et al.*, 1996). Magnesium deficiency in crops has become an urgent concern due to the overuse of chemical NPK fertilizers, introduction of high yielding varieties and depletion of soil Mg pool after long-term crop harvest and limited application of Mg fertilizers (Cakmak, 2015 and Guo *et al.*, 2015).

2.5.1 Role of magnesium in crop yield

Craighead and Martin (2001) reported that application of Mg fertilizers to wheat may be justified in order to improve soil Mg status for subsequent crops that are more sensitive to low soil Mg levels and for pasture where low herbage may affect animal performance. The effect of Mg fertilization on crop yield increment significantly differed among crop types. On an average, crop yield increment by Mg fertilizer application was 6.5, 14.3, 17.4, 19.6 and 20.1 per cent for cereals, cash crops, oil and tea crops, fruits and vegetables, respectively. Such differences were partly due to their genetic sensitivity and tolerance to Mg deficiency (Marschner, 2012 and Shaul, 2002).

An experiment was conducted to study the response of maize to magnesium and to find out the residual effect of Mg and green manure (GM) on transplanted aman (*T. aman*) rice in the maize – GM – *T. aman* cropping pattern. The response of maize to Mg was quadratic, which resulted in maximum yield of 10.50 t ha^{-1}. The residual effect of Mg along with GM and reduced dose of chemical fertilizer resulted in significant increase in grain yield of rice (Noor *et al.*, 2015).

2.5.2 Significance of magnesium on crop quality

Klein *et al.* (1982) observed that application of magnesium sulphate at the rate of 115 kg ha^{-1} increased the firmness and cooking quality of potatoes. Addition of $MgSO_4$ @ 100 kg ha^{-1} increased strarch content and dry matter of potatoes (Poberezny and Wszelaczynska, 2011). Borkowski and Szwonek (1986) observed that tomato plants supplied with magnesium at the rate of 500 – 100 mg L^{-1} recorded highest marketable and quality yield. Magnesium enhanced the flavor characteristics of fresh market tomatoes.

Love *et al.* (1994) reported that magnesium nutrition increases nitrogen metabolism and thereby helped in accumulation of glycol-alkaloid in potato tubers. Similarly, Mondy and Ponnampalam (1985) and Klein *et al.* (1982) observed an increased nitrogen and protein concentration in potatoes due to magnesium application. Hartz *et al.* (1999) reported that potassium efficiency disorders like internal white tissue and yellow shoulder was decreased in plots treated with magnesium and potassium rather than the plots treated with potassium alone.

Gulshan *et al.* (1991) evaluated nine tomato cultivars for biochemical properties. They observed that ascorbic acid content (16.2 mg 100 g^{-1}) was more in treatment that received RDF + $MgSO_4$ @ 50 kg ha^{-1} and lowest in control plot (8.8 mg 100 g^{-1}). Significant increase was observed in carotenoid content in magnesium treated plot over control (Nguemezi and Valgere, 2010).

Shibli *et al.* (1995) conducted an experiment by using three open pollinated cultivars of tomato. They noticed only 0.3 per cent titratable acidity in non-magnesium treated plots. Kingsly (2002) reported that the tomato fruits produced in control had TSS content of 4.72 ^{o}B and fruits produced under varying levels of fertigation had a mean TSS content of 4.94 ^{o}B. Bose *et al.* (2006) reported that highest lycopene content was noticed in the treatments with $MgSO_4$ at 50 kg ha^{-1} and they also noticed that potassium deficiency in soil could decrease lycopene level in tomato fruit. Red fruiting cultivars of tomato had higher lycopene content compared to yellow or orange fruiting cultivars (Cox *et al.*, 2003 and Dumas *et al.*, 2003). Rosales *et al.* (2006) and Toor *et al.* (2006) reported that lycopene content of tomato also varied with seasons and antioxidant levels of fruits.

Degradation of anthocyanin was observed in magnesium treated plots of red grapes (Shaked-Sachray *et al.*, 2002). Magnesium application increased average length and width of pineapple fruit over control (Velezramos and Borges, 1995). Hermans *et al.* (2004 & 2005) reported that magnesium supply increased photosynthesis and assimilate translocation in sugar beet. The application of magnesium increased sugar concentration in sugar beet (Draycott and Farley, 1971).

Application of magnesium oxide at the rate of 0.4 and 0.8 kg increased the yield and oil to bunch ratio in oil palm by 1 and 1.8 per cent respectively (Tayeb, 2005). Khan *et al.* (1990) reported an increase in oil content and seed yield in sunflower by application of $MgSO_4$ @ 10 kg ha^{-1}. Chapagain and Wiesman (2004) conducted a greenhouse experiment for one year in order to study the effect of different nutrient solutions in tomato plants *via* fertigation. They replaced KCl solution with KCl + $MgCl_2$. Results revealed that application of KCl improved fruit appearance and quality but application of both potassium and magnesium through fertigation enhanced the quality of fruits by increasing glucose content.

Hao and Papadopoulos (2004) reported that application of magnesium to tomato crop decreased the incidence of blossom end rot, increased the firmness of fruits and lowered fruit russeting. Nitrogen application beyond the optimum dose in combination with magnesium maximized the yield and increased the baking quality of wheat (Mckenzie *et al.*, 2006).

In vegetables, more nitrogen input increased the vitamin B level and carotenoid contents (Mozafar, 1993). Marschner (2012) and Grzebisz (2013) reported that magnesium application to cereals increased thousand grain weight and carbohydrate translocation. Starch content of rye (*Secale cereale* L.) was increased by magnesium addition (Magnitskii *et al.*, 1970).

2.6 Impact of magnesium deficiency in soil and plants

Inhibition of photosynthesis by magnesium deficiency resulted in a misallocation of electrons to oxygen molecules, thereby producing reactive oxygen, which cause oxidative stress (Cakmak, 2005). Similarly Gong *et al.*, 1997; Dash and Mohanty, 2002 observed that anti-oxidative defense enzymes and heat stress were enhanced due to magnesium deficiency.

Romheld and Kirkby (2010) reported that high heat stress could be controlled by application of magnesium with adequate supply of other major nutrients which also increased fertilizer use efficiency. Carminati and Vetterlein (2013) reported that plant produced mucilage, a gelatinous secretion by enlarging its root hairs in magnesium deficient Ultisols. They ascribed that this would reduce sucrose accumulation in photo-synthetically active tissues and hence less energy supply to roots. Tonoi and Kobayashi (2015) reported that application of magnesium increased the yield of tomato crop and deficiency of this nutrient led to chlorosis, drooping and necrotic spots on leaves.

Materials and methods

3. MATERIALS AND METHODS

The present study entitled "Soil test based fertilizer prescription for tomato (*Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala" was carried out at STCR plot, College of Horticulture, Vellanikkara during August to December 2016 with the following objectives

1. To validate the formulated fertilizer prescription equations for tomato
2. To identify optimum rate of magnesium to be applied along with recommended fertilizer package for maximizing the yield.

The materials used and methods adopted for undertaking the study are described in this chapter.

3.1 General details

3.1.1 Experimental site

The field experiment was conducted at the STCR plot, College of Horticulture, Vellanikkara, Thrissur, Kerala. Geographically the field is situated at 13° 32' N latitude and 76° 26' E longitude, at an altitude of 40 m above mean sea level.

3.1.2 Climate and weather conditions

The experimental site had a humid tropical climate. The mean weekly average values of important meteorological observations during the experimental period are presented in Appendix 1.

3.1.3 Initial properties of soil

Soil samples were collected from 0-15 cm depth before the start of experiment. The soil samples were air dried, powdered and then sieved through 0.5mm sieve for organic carbon analysis and 2 mm sieve for analysis of other physico-chemical properties of soil. The analytical techniques followed for the estimation of physical and chemical properties of soil and the values obtained from the initial soil analysis are presented in Table 1.

Soil of the experimental site was sandy clay loam in texture and slightly acidic (pH, 5.10). Electrical conductivity was 0.023 dS m^{-1}, and organic carbon content was 0.618 per cent. Available nitrogen content and phosphorus content were low (212.65 kg N ha^{-1} and 11.20 kg P ha^{-1} respectively) and potassium content was in medium range (247.83 kg K ha^{-1}).

Table 1: Initial physico-chemical characteristics of soil in the experimental site

Particulars	Value	Method of analysis
I Physical properties		
Coarse sand (%)	31.89	Robinson international pipette method (Robinson, 1922)
Fine sand (%)	27.28	
Silt (%)	18.60	
Clay (%)	22.23	
Texture	Sandy clay loam	
Bulk density (Mg m^{-3})	1.34	Keen Raczkowski box method (Piper, 1966)
Porosity (%)	42.34	
Particle density (Mg m^{-3})	2.46	
Maximum water holding capacity (%)	38.99	
II Chemical properties		
pH (1:2.5)	5.10	1: 2.5 soil water ratio (Jackson, 1973)
Electrical conductivity (dS m^{-1})	0.023	Conductometry (Jackson, 1973)
Organic carbon (%)	0.61	Walkley and Black method (Walkely and Black, 1934)

Available nitrogen (kg ha^{-1})	212.65	Alkaline permanganate method (Subbiah and Asija, 1956)
Available phosphorus (kg ha^{-1})	11.20	Bray's method (Jackson, 1973)
Available potassium (kg ha^{-1})	247.83	Flame photometry method (Page *et al.*, 1982)
Available sulfur (mg kg^{-1})	12.77	Turbidimetry method (Jackson, 1973)
Available calcium (mg kg^{-1})	87.89	Neutral normal ammonium acetate extraction followed by ICP reading (Jackson, 1973)
Available magnesium (mg kg^{-1})	23.26	
Available boron (mg kg^{-1})	0.41	Hot water extraction and estimation by colorimetry (Tandon, 1993)
Available iron (mg kg^{-1})	6.80	0.1M HCl extraction followed by ICP reading (Sims and Johnson,1991)
Available manganese (mg kg^{-1})	18.43	
Available zinc (mg kg^{-1})	4.82	
Available copper (mg kg^{-1})	8.60	

3.1.4 Cropping Season

The experiment was conducted from August to December, 2016.

3.1.5 Cropping history of the experimental site

The field experiment for developing fertilizer prescription equation for cowpea was laid out in the plot before the experiment was started in August 2016.

3.1.6 Crop variety

The tomato variety, Anagha was used for the experiment. The variety is long duration, bacterial wilt resistant, open pollinated and is more susceptible to lower and higher temperature. It is branching type, yellow flowered with shiny, dark red, small and fleshy fruits.

Plate 1. Collection of soil samples for analysis

3.2 Experimental details

The experimental details are furnished below

Treatments	:	12
Replications	:	03
Design	:	RBD (Randomized Block Design)
No. of plots	:	36
Plot size	:	9 m^2
Spacing	:	60 cm x 60 cm
No. of plants per plot	:	25

The planting materials (seeds) were collected from Department of Olericulture, College of Horticulture, Vellanikkara.

The equations developed for tomato by the soil test crop response correlation studies centre, Vellanikkara, suited for laterite soils of Kerala were used for test verification studies of experiment.

For achieving the yield targets of 25 and 30 t ha^{-1}, the amount of fertilizer nutrients required were calculated by using the following equations.

$FN = 8.21T - 0.246SN - 0.25ON$

$FP_2O_5 = 4.92T - 8.437SP - 0.46OP$

$FK_2O = 10.07T - 0.439SK - 0.23OK$ (Bastin *et al.*, 2012)

where,

T	=	Targeted yield of tomato *i.e.* 25 t ha^{-1} and 30 t ha^{-1}
FN	=	Nitrogen to be supplied through fertilizer (kg ha^{-1})
FP_2O_5	=	Phosphorus to be supplied through fertilizer (kg ha^{-1})
FK_2O	=	Potassium to be supplied through fertilizer (kg ha^{-1})
SN	=	Soil available nitrogen in kg ha^{-1}
SP	=	Soil available phosphorus in kg ha^{-1}
SK	=	Soil available potassium in kg ha^{-1}

ON = Nitrogen from organic sources

OP = Phosphorus from organic sources

OK = Potassium from organic sources

3.2.1 Details of treatments

Details of treatments in the experiment are as follows

Table 2: Treatment details of the experiment

Treatment	
T_1	Absolute control
T_2	Soil test based POP of KAU
T_3	STCR + IPNS for target 25 t ha^{-1}
T_4	STCR + IPNS for target 30 t ha^{-1}
T_5	T_3 + $MgSO_4$ at 40 kg ha^{-1}
T_6	T_3 + $MgSO_4$ at 60 kg ha^{-1}
T_7	T_3 + $MgSO_4$ at 80 kg ha^{-1}
T_8	T_3 + $MgSO_4$ at 120 kg ha^{-1}
T_9	T_4 + $MgSO_4$ at 40 kg ha^{-1}
T_{10}	T_4 + $MgSO_4$ at 60 kg ha^{-1}
T_{11}	T_4 + $MgSO_4$ at 80 kg ha^{-1}
T_{12}	T_4 + $MgSO_4$ at 120 kg ha^{-1}

STCR – Soil test crop response correlation studies

IPNS – Integrated plant nutrient system

POP – Package of Practices recommendations of KAU

Table 3: Quantity of nutrients applied in different treatments

Treatment	N	P_2O_5	K_2O	$MgSO_4$
	kg ha^{-1}			
T_1	0.00	0.00	0.00	0.00
T_2	75.00	40.00	25.00	0.00
T_3	152.59	28.05	142.43	0.00
T_4	193.64	52.89	192.78	0.00
T_5	152.59	28.05	142.43	40.00
T_6	152.59	28.05	142.43	60.00
T_7	152.59	28.05	142.43	80.00
T_8	152.59	28.05	142.43	120.00
T_9	193.64	52.89	193.78	40.00
T_{10}	193.64	52.89	193.78	60.00
T_{11}	193.64	52.89	193.78	80.00
T_{12}	193.64	52.89	193.78	120.00

Table 4: Nutrient contents in fertilizers and manures used in the experiment

Sl. No.	Fertilizer	Nutrient content (%)				
		N	P_2O_5	K_2O	Mg	S
1	Urea	46.00	-	-	-	-
2	Diammonium phosphate	18.00	46.00	-	-	-
3	Muriate of potash	-	-	60.00	-	-
4	Magnesium sulphate	-	-	-	19.80	27.20
	Organic manure	N	P	K		
5	Farm yard manure	1.45	0.46	1.70		

3.2.2 Design and layout of field experiment

R-I	R-II	R-III
T_{12}	T_{10}	T_5
T_4	T_2	T_8
T_{10}	T_4	T_{12}
T_2	T_3	T_6
T_6	T_7	T_1
T_3	T_1	T_9
T_9	T_8	T_4
T_1	T_{11}	T_3
T_5	T_{12}	T_{11}
T_{11}	T_9	T_{10}
T_7	T_5	T_2
T_8	T_6	T_7

N

T_1 : Absolute control

T_2 : Soil test based POP of KAU

T_3 : STCR+IPNS for target 25t ha^{-1}

T_4 : STCR+IPNS for target 30t ha^{-1}

T_5 : T_3+$MgSO_4$ @ 40 kg ha^{-1}

T_6 : T_3+$MgSO_4$ @ 60 kg ha^{-1}

T_7 : T_3+$MgSO_4$ @ 80 kg ha^{-1}

T_8 : T_3+$MgSO_4$ @ 120 kg ha^{-1}

T_9 : T_4+$MgSO_4$ @ 40 kg ha^{-1}

T_{10} : T_4+$MgSO_4$ @ 60 kg ha^{-1}

T_{11} : T_4+$MgSO_4$ @ 80 kg ha^{-1}

T_{12} : T_4+$MgSO_4$ @ 120 kg ha^{-1}

3.3 Crop husbandry

3.3.1 Land preparation

Land was ploughed thoroughly with disc plough and worked with cultivator to produce good tilth and stubbles were removed from the field. Gross plot size was 10 cents and net plot size was 8.1 cents. Raised beds and furrows were taken and planting was done at a spacing of 0.5m.

3.3.2 Nursery preparation

Seedlings were sown in portrays. The potting mixture consisted of coir pith and perlite in the ratio of 3:1. Seedlings were kept in the nursery upto 30 days after sowing.

3.3.3 Transplanting

Seedlings were planted at a spacing of 60 cm × 60 cm. Twenty five seedlings were planted in each plot.

3.3.4 Gap filling

Gap filling was done with healthy seedlings, wherever is necessary.

3.3.5 Manures and fertilizers

Half of nitrogen, full dose phosphorus and half dose of the potash were applied as basal dose at the time of transplanting and remaining nitrogen and potash were applied one month after the application of basal dose. The quantity of fertilizers applied in each treatment is given based on target equations (Table 3). Lime was applied by considering initial soil pH (5.10).

3.3.6 Irrigation

Hose irrigation at 10mm depth once in two days interval was given.

Plate 2. Filling of potting mixture for planting tomato seeds

Plate 3. Sowing of seeds in seed trays

Plate 4. Germination of tomato seedlings

Plate 5. Tomato seedlings at ten days after sowing

Plate 6. Tomato seedlings ready for transplanting

3.3.7 Weed management

Hand weeding was done at monthly intervals after transplanting tomato seedlings in main field.

3.3.8 Plant protection

Incidence of fruit and shoot borer was noticed in the crop and ekalux spray @ 2 ml L^{-1} of water was done to control pest. Copper hydroxide (Kocide) @ 0.2 per cent was sprayed to control bacterial wilt. Mosaic and leaf curl infected plants were rouged off and disposed far away from field and soil was drenched with *Pseudomonas fluorescence* @ 10 g L^{-1} twice at 10 days interval to control the spread of the disease.

3.3.9 Harvesting

Harvesting was done by hand picking fruits on alternate days when the fruits were ready for harvest. The first harvest was done at 61 days after transplanting (DAT).

3.4 Observations

Observations on the following characteristics were done during the field experiment.

3.4.1 Analysis of soil

Soil samples were collected on January 16th, from a depth of 0-15 cm and analyzed for pH, EC, OC, major nutrients (N, P and K), secondary nutrients (Ca, Mg and S) and micronutrients (Fe, Mn, Zn, Cu and B). The methods followed are detailed below in Table 5.

Table 5: Methods of soil and FYM analysis

Parameter	**Method**	**Reference**
pH and electrical conductivity	1:2.5 soil water suspension-pH meter and conductivity meter	Jackson (1973)
Organic carbon	Walkley and Black method	Walkley and Black (1934)
Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Available phosphorus	Ascorbic acid reduced molybdo phosphoric blue colour method	Jackson (1973)
Available potassium	Neutral normal ammonium acetate extraction followed by flame photometry	
Available calcium and magnesium	Neutral normal ammonium acetate extraction followed by ICP reading	
Available sulfur	$BaCl_2$ extraction followed by spectrophotometry	
Available boron	Hot water extraction followed by colorimetry	Tandon (1993)
Available micronutrients	HCl extraction followed by ICP reading	Sims and Johnson (1991)
FYM		
Nitrogen	Micro kjeldahl distillation	Jackson, 1973
Phosphorus	Vanado – molybdo – phosphoric (Bartons reagent) yellow colour	
Potassium	Flame photometer method	

3.4.2 Biometric observations

Four plants were selected randomly from each plot and tagged. The following observations were recorded from these sample plants and the mean values were worked out.

3.4.2.1 Number of fruits/ plant

Number of fruits per plant was recorded from selected plants and mean value was computed.

3.4.2.2 Yield/ plant (kg)

Fruits were harvested from the sample plants and yield was noted, mean value was computed and expressed in kg/plant.

3.4.2.3 Plant height (cm)

Plant height was recorded at 30, 60 and 90DAT from the ground portion upto nodal base of fully opened leaf and mean plant height was noted and expressed in centimeter.

3.4.2.4 Days to flowering

Number of days required for flowering in randomly selected plants was noted and mean value was computed.

3.4.2.5 Deficiency symptoms, if any

Deficiency symptoms noticed in tomato crop are listed in Table. 6

Table 6: Deficiency symptoms noticed during field experiment

Deficiency symptoms	Reason
Fruit cracking	Boron deficiency
Blossom end rot	Calcium deficiency

Plate 7. Flowering stage of tomato crop

Plate 8. Fruiting stage of tomato crop

Plate 9. General view of experimental field during final harvest

3.4.3 Plant analysis

3.4.3.1 Collection of samples

At the time of harvesting, randomly selected four plants were uprooted carefully, and the plant samples were first washed with tap water in order to remove dirt and other adhering soil particles. The plants were again washed with single and double distilled water, and shade dried for a week. The shoot and root portions were separated by using sharp scissors. In the same way, fruits were collected and cut into small pieces and samples were kept in an oven @ 60 ^{0}C. Later these samples were powdered and stored in polythene covers. From these samples, major nutrients (N, P and K), secondary nutrients (Ca, Mg and S) and micronutrients (Fe, Mn, Zn, Cu and B) were analyzed. The methodology followed to determine the above parameters are detailed in Table 7.

Table 7: Methods of plant analysis

Parameter	**Method**	**Reference**
Nitrogen	Micro kjeldahl distillation	
Phosphorus	Vanado – molybdo – phosphoric (Bartons reagent) yellow colour	Jackson, 1973
Potassium	Flame photometer method	
Calcium and magnesium	Nitric acid digested in microwave and estimated by ICP-OES	Piper, 1966
Sulfur	Turbidimetry	Black, 1965
Micronutrients (Fe, Mn, Zn and Cu)	Digested in microwave and estimated in ICP-OES	Piper, 1966
Boron	Azomethane - H yellow colour development method	Page *et al.*, 1982

3.4.4 Uptake of Nutrients

Nutrient uptake for major, secondary and micronutrients were calculated by using the formula mentioned below.

$$\text{Uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%) x Biomass (kg ha}^{-1}\text{)}}{100}$$

3.4.5 Nutrient use efficiency (NUE) parameters

$AE = (Y-Y_0)/F$

$PE = (Y-Y_0)/ (U-U_0)$

$RE = (U-U_0)/F$

$PFP = Y/F$

where

Y	:	Yield of harvested portion of crop with nutrients applied
Y_0	:	Yield of harvested portion of crop without nutrients applied
U	:	Total nutrient uptake in fertilizer applied plot
U_0	:	Total nutrient uptake in control plot
F	:	Amount of nutrients applied
AE	:	Agronomic efficiency
PE	:	Physiological efficiency
RE	:	Recovery efficiency
PFP	:	Partial factor productivity

3.4.6 Biochemical parameters of tomato

3.4.6.1 Chlorophyll content of tomato leaves

Chlorophyll is extracted by 80 per cent acetone and the absorption at 663 nm and 645 nm was read in spectrophotometer. Using the absorption co-efficient, the amount of chlorophyll was calculated (Sadasivam and Manickam, 1992).

$$\text{Chl. a} = 12.7\ (A_{663nm}) - 2.69 \times A_{645nm} \times \frac{\text{volume}}{\text{weight} \times 1000}$$

$$\text{Chl. b} = 22.9\ (A_{645nm}) - 4.68 \times A_{663nm} \times \frac{\text{volume}}{\text{weight} \times 1000}$$

3.4.6.2 Total soluble solids

Total soluble solids of fruit samples was estimated by using refractometer (Sadasivam and Manickam, 1992).

3.4.6.3 Titratable acidity

Five gram of fruit pulp was taken and grinded with 10 ml of distilled water in mortar and pestle, and later subjected to centrifugation at 3000 rpm for 5 min. It was diluted to 100 ml. From this diluted sample, 10 ml aliquot was pipetted into a 250 ml conical flask and titrated against 0.1N NaOH until the end point is reached (colorless to light pink). Titratable acidity was calculated by using the formula (Sadasivam and Manickam, 1992).

$$\text{Titratable acidity} = \frac{\text{Titre value} \times \text{normality of acid} \times \text{vol. made up} \times \text{eq. wt of acid} \times 100}{\text{Vol. of sample taken for estimation} \times \frac{\text{wt. of sample}}{\text{Vol. of sample taken}} \times 1000}$$

3.4.6.4 Ascorbic acid content

Ascorbic acid in fruits was estimated by using 2, 6 dichloro indophenol dye. 10 ml of clarified tomato juice was taken and made upto 100 ml with 2 per cent oxalic acid. This sample was diluted again. 10 ml was pipetted into conical flask and titrated against 2, 6 dichloro indophenol dye until the solution changes its colour from colourless to light pink. The ascorbic acid content was calculated by using the formula given below (Sadasivam and Manickam, 1992).

$$\text{mg of ascorbic acid } 100\ g^{-1} = \frac{\text{Titre value}}{\text{Aliquot of extract taken for estimation}} \times \frac{\text{dye factor}}{\text{vol. of sample taken for estimation}} \times 100$$

3.5 Economics of cultivation

The economics of cultivation was worked out based on the cost of cultivation and prevailing price of the crop produce in the market.

Net income (Rs ha^{-1}) = Gross income – Total expenditure

The Benefit: Cost ratio (BCR) was worked out according to the formula given below.

$$BCR = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.6 Statistical analysis

Experimental data obtained was subjected to statistical analysis adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984). The level of significance used in 'F' test was given at 5 per cent. Critical difference (CD) values are given in the table at 5 per cent level of significance, wherever the 'F' test was found significant at 5 per cent level. Response curve was fitted to predict the response at different levels of magnesium by using Mini tab software.

Results

4. RESULTS

The results of the experiment conducted during *rabi* 2016 on "Soil test based fertilizer prescription for tomato (*Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala" at STCR plot, College of Horticulture, Vellanikkara, are presented in this chapter.

4.1 Effect of different levels of fertilizers on growth and yield parameters of tomato

The growth and yield parameters of tomato *viz.*, plant height, number of fruits per plant, yield per plant, days to flowering and deficiency symptoms noticed at different dosages of fertilizer application are given in Table 8, 9 and 10.

4.1.1 Growth parameters

4.1.1.1 Plant height

At 30 days after transplanting: The plant height of tomato was significantly influenced by various treatments (Table 8). The plant height varied from 23.76 to 33.86 cm. Significantly highest plant height (33.86 cm) was noticed in the treatment, STCR+ IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (T_7) followed by treatment, STCR+ IPNS for target 30t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{10}) (33.67 cm). Lowest plant height (23.76 cm) was noticed in absolute control (T_1).

At 60 days after transplanting: The plant height was significantly influenced by different treatments imposed (Table 8). Significantly highest plant height (60.80 cm) was obtained in treatment, STCR+ IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (T_7) followed by treatment STCR+ IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{10}) (59.90 cm). Lowest significant plant height (45.80 cm) was noticed in absolute control (T_1).

At 90 days after transplanting: There was significant difference between treatments with respect to plant height at 90 DAT (Table 8). Highest plant height (75.26 cm) was noticed in treatment, STCR+ IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}) followed by treatment that received STCR+ IPNS for target 30 t ha^{-1}

+ $MgSO_4$ @ 80 kg ha^{-1} (T_{11}) which was on par with STCR+ IPNS for target 30 t ha^{-1}+ $MgSO_4$ @ 60 kg ha^{-1} (T_{10}) with plant height of 74.78 cm and 74.26 cm respectively. Lowest significant plant height (59.80 cm) was noticed in absolute control (T_1).

4.1.1.2 Days to flowering

Perusal of the data in Table 9 indicated that there was significant difference in number of days to flowering of tomato due to different rates of fertilizer application. Maximum number of days to flowering (31.86) was noticed in STCR+ IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{10}) and significantly lowest number of days to flowering (26.93) was observed in absolute control (T_1).

4.1.1.3 Deficiency symptoms

Less than 2 per cent tomato fruits showed fruit cracking and blossom end rot at the final stage of harvesting.

4.1.2 Yield and yield parameters

4.1.2.1 Number of fruits per plant

From results of Table 10, it can be inferred that the number of fruits per plant was found to be significantly different due to various fertilizer applications. Highest number of fruits per plant (79.66) was noticed in STCR+ IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8) followed by treatment, STCR+ IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}) (77.03). However lowest significant number of fruits per plant (32.00) was obtained in absolute control (T_1).

4.1.2.2 Yield

Perusal of the data in Table 10 indicated that there was significant difference in fruit yield of tomato due to different fertilizer treatments. Highest yield of tomato (1.88 kg/plant, 37.75 t ha^{-1}) was obtained in STCR+ IPNS for target, 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8) followed by T_{12} (STCR+ IPNS for target, 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}) (1.83 kg/plant, 36.63 t ha^{-1}) and T_{11} (STCR+ IPNS for target

Fruit cracking

Blossom end rot

Plate 10. Deficiency symptoms noticed during field experiment

Table 8: Influence of different treatments on plant height (cm) of tomato

Treatment	Plant height (cm)		
	30DAT	60DAT	90DAT
T_1: Absolute control	23.76^{e}	45.80^{f}	59.80^{e}
T_2: Soil test based POP of KAU	26.93^{e}	48.90^{e}	69.50^{d}
T_3: STCR + IPNS for target 25 t ha^{-1}	27.10^{d}	54.53^{cd}	69.86^{cd}
T_4: STCR + IPNS for target 30 t ha^{-1}	33.40^{ab}	53.13^{d}	71.75^{abcd}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	30.71^{bc}	55.40^{cd}	72.50^{abcd}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	28.53^{cd}	54.03^{d}	73.13^{abcd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	33.86^{a}	60.80^{a}	70.86^{bcd}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	30.80^{abc}	58.23^{ab}	74.03^{abc}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	32.16^{ab}	58.26^{ab}	72.36^{abcd}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	33.60^{ab}	59.50^{ab}	74.26^{ab}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	33.66^{ab}	56.86^{bc}	74.78^{ab}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	33.66^{ab}	58.86^{ab}	75.26^{a}

DAT - Days after transplanting, STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

Table 9: Influence of different treatments on days to flowering

Treatment	No. of days to flowering
T_1: Absolute control	26.93[e]
T_2: Soil test based POP of KAU	31.00[ab]
T_3: STCR + IPNS for target 25 t ha^{-1}	29.53[cd]
T_4: STCR + IPNS for target 30 t ha^{-1}	28.80[cd]
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	29.23[cd]
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	29.23[cd]
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	28.16[de]
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	30.00[bc]
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	29.16[cd]
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	31.86[a]
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	30.03[bc]
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	29.16[cd]

DAT - Days after transplanting, STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

Table 10: Influence of different treatments on number of fruits and yield in tomato

Treatment	No. of fruits per plant	Yield ($t\ ha^{-1}$)
T_1: Absolute control	32.00^{f}	17.54^{h}
T_2: Soil test based POP of KAU	53.60^{e}	23.57^{g}
T_3: STCR + IPNS for target 25 $t\ ha^{-1}$	66.40^{d}	32.63^{f}
T_4: STCR + IPNS for target 30 $t\ ha^{-1}$	66.50^{d}	32.73^{f}
T_5: T_3 + $MgSO_4$ at 40 $kg\ ha^{-1}$	68.56^{d}	33.75^{e}
T_6: T_3 + $MgSO_4$ at 60 $kg\ ha^{-1}$	73.96^{abc}	34.63^{d}
T_7: T_3 + $MgSO_4$ at 80 $kg\ ha^{-1}$	72.03^{bcd}	34.70^{d}
T_8: T_3 + $MgSO_4$ at 120 $kg\ ha^{-1}$	79.66^{a}	37.75^{a}
T_9: T_4 + $MgSO_4$ at 40 $kg\ ha^{-1}$	72.83^{bc}	34.74^{d}
T_{10}: T_4 + $MgSO_4$ at 60 $kg\ ha^{-1}$	74.63^{ab}	35.23^{c}
T_{11}: T_4 + $MgSO_4$ at 80 $kg\ ha^{-1}$	72.26^{bcd}	36.55^{b}
T_{12}: T_4 + $MgSO_4$ at 120 $kg\ ha^{-1}$	77.03^{ab}	36.63^{b}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –Package of Practices recommendations

30 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1}) (1.82 kg/plant, 36.55 t ha^{-1}). Lowest yield (0.89 kg/plant, 17.54 t ha^{-1}) was obtained in absolute control (T_1).

4.2 Physico-chemical parameters of soil

4.2.1 Soil pH

From Table 11, it is clear that, no significant difference was noticed in soil pH in soils collected after harvest of tomato crop. The pH varied from 4.36 (STCR+ IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1}) to 4.89 (absolute control).

4.2.2 Electrical conductivity

The electrical conductivity of the soil samples after harvest of tomato crop significantly differed among the various treatments imposed (Table 11). Electrical conductivity of the soil was maximum (0.235 dS m^{-1}) in STCR + IPNS for target, 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1} (T_9) followed by the treatment which received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (T_{11}, 0.205 dS m^{-1}). Lowest electrical conductivity was observed in absolute control (T_1, 0.058 dS m^{-1}).

4.2.3 Organic carbon

The data on organic carbon analysis showed that there was no significant effect concerning organic carbon content of soil after harvest of tomato among various treatments (Table 11). The organic carbon content (0.93 %) in soil after harvest of tomato crop was highest in treatment receiving STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}). The organic carbon content was found to be increased in all the treatments after the harvest of crop compared to initial organic carbon content (0.61 %). The lowest organic carbon content of 0.83 per cent was noticed in absolute control (T_1).

4.3 Nutrient status of the soil

The nutrient status *viz.*, available N, P_2O_5, K_2O, Ca, Mg, S and micronutrients *viz.*, Fe, Mn, Zn Cu and B content of the soil after harvest of tomato crop was analyzed and the results are depicted in Tables 12, 13 and 14.

Table 11: Influence of different treatments on physico-chemical properties of soil after harvest of tomato

Treatments	pH	EC (dS m^{-1})	OC (%)
T_1: Absolute control	4.89	0.058^{d}	0.83
T_2: Soil test based POP of KAU	4.73	0.073^{cd}	0.84
T_3: STCR + IPNS for target 25t ha^{-1}	4.50	0.205^{ab}	0.91
T_4: STCR + IPNS for target 30t ha^{-1}	4.46	0.177^{ab}	0.90
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	4.36	0.156^{abc}	0.83
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	4.63	0.191^{ab}	0.85
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	4.72	0.156^{ab}	0.90
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	4.74	0.131^{bcd}	0.87
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	4.58	0.235^{a}	0.92
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	4.75	0.178^{ab}	0.85
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	4.66	0.205^{ab}	0.86
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	4.70	0.167^{ab}	0.93
Initial	5.10	0.023	0.61

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –Package of Practices recommendations

4.3.1 Available nitrogen

The available nitrogen content of the soil after the harvest of tomato crop did not vary significantly among the treatments (Table 12). Nitrogen content varied from 132.21 to 180.71 kg ha^{-1}. However nitrogen content was found to be lowest (132.21 kg ha^{-1}) in treatment with absolute control (T_1) and highest (180.71 kg ha^{-1}) in treatment with STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{10}).

4.3.2 Available phosphorus

Available phosphorus content in soil increased significantly due to different levels of fertilizer application (Table 12). Available phosphorus content of the soil was highest (53.05 kg ha^{-1}) in the treatment, STCR + IPNS for target 25 t ha^{-1} (T_3). Significantly lowest available phosphorus was found in absolute control (33.91 kg ha^{-1}) (T_1).

4.3.3 Available potassium

Available potassium content in soil increased significantly due to different levels of fertilizer application (Table 12). The potassium content varied from 186.66 to 379.33 kg ha^{-1}. Application of STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{10}) significantly recorded highest available potassium (379.33 kg ha^{-1}) followed by STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_6, 326.50 kg ha^{-1}) which was on par with STCR + IPNS for yield target of 30 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (333.66 kg ha^{-1}, T_{11}) and lowest available potassium content was recorded in treatment where no potassium was applied (T_1, 186.66 kg ha^{-1}).

4.3.4 Available calcium

From the data in Table 13, it can be concluded that, there was slight increase in calcium content in all the treatments as compared to initial value (87.89 mg kg^{-1}). However there was no significant difference in the calcium content of soil among various treatments after the harvest of tomato crop. Available calcium content after the harvest of tomato crop varied from 118.40 to 173.60 mg kg^{-1}.

Table 12: Effect of different treatments on available major nutrient status in soil after harvest of tomato

Treatment	N	P	K
	(kg ha^{-1})		
T_1: Absolute control	132.21	33.91^{f}	186.66^{e}
T_2: Soil test based POP of KAU	151.25	38.09^{de}	191.66^{e}
T_3: STCR + IPNS for target 25 t ha^{-1}	155.27	53.05^{a}	204.00^{de}
T_4: STCR + IPNS for target 30 t ha^{-1}	155.42	36.04^{ef}	225.50^{cde}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	140.74	44.76^{b}	296.73^{abcd}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	163.82	40.75^{cd}	326.50^{abc}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	153.33	38.26^{de}	233.50^{bcde}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	142.96	35.34^{ef}	203.83^{de}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	163.84	44.27^{bc}	244.50^{bcde}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	180.71	34.10^{f}	379.33^{a}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	141.72	43.99^{bc}	333.66^{ab}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	149.55	45.44^{b}	203.83^{de}
Initial	212.6	11.20	247.83

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

Table 13: Influence of different treatments on available secondary nutrients status of soil after harvest of tomato

Treatment	Ca	Mg	S
	(mg kg^{-1})		
T_1: Absolute control	118.40	20.40^{d}	16.14^{d}
T_2: Soil test based POP of KAU	152.01	25.68^{cd}	27.84^{c}
T_3: STCR + IPNS for target 25 t ha^{-1}	135.60	24.72^{cd}	23.71^{c}
T_4: STCR + IPNS for target 30 t ha^{-1}	150.40	24.00^{cd}	25.16^{c}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	170.07	27.12^{bc}	28.64^{c}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	165.20	29.28^{abc}	28.57^{c}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	144.80	32.64^{a}	29.25^{bc}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	137.62	31.20^{ab}	34.62^{ab}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	143.20	26.64^{bc}	26.04^{c}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	147.23	28.32^{abc}	27.88^{c}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	152.80	29.76^{abc}	35.30^{a}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	173.60	32.64^{a}	34.83^{ab}
Initial	87.89	23.26	12.77

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP — Package of Practices recommendations

4.3.5 Available magnesium

Significant difference was noticed among different treatments with respect to available magnesium content of soil, collected after the harvest of tomato crop (Table 14). Significantly highest magnesium content (32.64 mg kg^{-1}) was recorded with the application of STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}). Significantly lowest magnesium content (20.40 mg kg^{-1}) was noticed in absolute control (T_1).

4.3.6 Available sulfur

Available sulfur content was found to be differing significantly among different treatments in soil (Table 13). Highest value of available sulfur was noted in T_{11} (35.30 mg kg^{-1}) which received STCR + IPNS for target 30 t ha^{-1} + 120 kg $MgSO_4$ kg ha^{-1} which was on par with the treatment, STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8, 34.62 mg kg^{-1}) and treatment, STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} recorded S content of 34.83 mg kg^{-1} and lowest sulfur content (16.14 mg kg^{-1}) was recorded in absolute control (T_1).

4.3.7 Available iron

It is inferred from Table 14 that iron content of soil after harvest did not vary significantly because of various treatments given. Highest amount of Fe (16.47 mg kg^{-1}) was recorded in STCR + IPNS for target 30 t ha^{-1} (T_4) followed by (T_{11}) where STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (15.52 mg kg^{-1}). The lowest iron content (11.16 mg kg^{-1}) was noticed in absolute control (T_1).

4.3.8 Available manganese

Manganese status of post-harvest soil differed significantly by different levels of fertilizer application (Table 14). The manganese content varied from 42.37 to 76.37 mg kg^{-1}. The highest manganese content (76.37 mg kg^{-1}) was found in STCR + IPNS for yield target 25 t ha^{-1} (T_3) which was on par with STCR + IPNS for the target 25 t ha^{-1} + MgSO4 @ 60 kg ha^{-1} (T_6). Lowest manganese content (42.37 mg kg^{-1}) was found in absolute control (T_1).

4.3.9 Available zinc

From the information on micronutrient status of soil, it is revealed that the zinc content was found to be significantly different among the different treatments in soils after harvest of tomato crop (Table 14). The zinc content was highest (8.32 mg kg^{-1}) in treatment that received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}). Lowest zinc content (4.57 mg kg^{-1}) was found in absolute control (T_1).

4.3.10 Available copper

The copper content in soil did not vary significantly due to the application of different levels of fertilizers (Table 14). Available copper content varied from 7.83 mg kg^{-1} (STCR + IPNS for target 30 t ha^{-1}, T_4) to 13.19 mg kg^{-1} (absolute control, T_1).

4.3.11 Water soluble boron

The hot water extracted boron content in soil samples, collected after the harvest of tomato crop did not vary significantly due to different levels of fertilizer application (Table 14). The highest boron content (0.54 mg kg^{-1}) was found in the treatment which received STCR + IPNS for target, 30 t ha^{-1} (T_4) followed by T_5 which received STCR + IPNS for target, 25 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1} (0.49 mg kg^{-1}). The lowest content of boron (0.42 mg kg^{-1}) was noticed in absolute control (T_1).

4.4 Analysis of tomato plant samples

4.4.1 Macronutrient content in tomato plant

4.4.1.1 Nitrogen content

The nitrogen content in tomato plant differed significantly among different treatments (Table 15). The content of nitrogen varied from 2.62 to 3.91 per cent. Highest nitrogen concentration (3.91 per cent) was noticed in T_4 (STCR + IPNS for yield target, 30 t ha^{-1}). Lowest nitrogen content (2.62 per cent) was observed in T_1 (absolute control).

Table 14: Influence of different treatments on available micronutrient status (Fe, Mn, Zn, Cu and B) of soil after harvest of tomato

Treatment	Fe	Mn	Zn	Cu	B
	(mg kg^{-1})				
T_1: Absolute control	11.16	42.37^{c}	4.57^{d}	7.83	0.42
T_2: Soil test based POP of KAU	15.87	45.48^{c}	7.00^{abc}	12.15	0.43
T_3: STCR + IPNS for target 25 t ha^{-1}	13.79	76.37^{a}	6.31^{bcd}	11.83	0.48
T_4: STCR + IPNS for target 30 t ha^{-1}	16.47	58.96^{abc}	7.45^{ab}	13.19	0.54
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	13.93	47.98^{c}	6.89^{abc}	9.78	0.49
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	13.11	72.86^{ab}	5.40^{cd}	10.86	0.46
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	12.74	68.43^{ab}	6.09^{bcd}	10.81	0.48
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	13.42	56.58^{bc}	5.71^{cd}	11.62	0.45
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	12.89	68.26^{ab}	7.06^{abc}	9.68	0.44
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	12.67	69.27^{ab}	8.06^{a}	10.82	0.43
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	15.52	66.56^{ab}	7.12^{abc}	9.29	0.46
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	14.09	57.19^{bc}	8.32^{a}	10.80	0.46
Initial	6.80	18.43	4.82	8.60	0.41

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.4.1.2 Phosphorus content

The concentration of phosphorus in tomato plant differed significantly among various treatments (Table 15). Significantly highest phosphorus content of 0.33 per cent was noticed in treatment T_2, which received soil test based POP of KAU. However, significantly lowest phosphorus concentration was observed in treatment T_1 (0.22 per cent) which is absolute control.

4.4.1.3 Potassium content

The potassium content in tomato plant did not vary significantly due to different treatments (Table 15). The potassium content in plant varied from 1.71 to 2.19 per cent.

4.4.1.4 Calcium content

The calcium content in tomato plant differed significantly among the treatments (Table 16). Highest significant calcium content was found in T_3 (2.92 %) which received STCR + IPNS for target 25 t ha^{-1}. However lowest significant content of calcium (1.63 %) was noticed in T_1 (absolute control) which was on par with soil test based POP of KAU (T_2), where the value was 1.80 per cent.

4.4.1.5 Magnesium content

The magnesium content in tomato plant differed significantly among different treatments (Table 16). The magnesium content of tomato plant varied from 0.60 to 0.85 per cent. Significantly highest magnesium content (0.85%) was noticed in treatment which received STCR + IPNS for target 25 t ha^{-1} +$MgSO_4$ @ 120 kg ha^{-1} (T_8). Lowest magnesium content (0.60 %) was noticed in absolute control (T_1).

4.4.1.6 Sulfur content

The sulfur content in tomato plant did not vary significantly among the different treatments (Table 16). Sulfur content varied from 0.71 per cent (absolute control, T_1) to 0.92 per cent (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}, T_8).

Table 15: Influence of different treatments on content of major nutrients in tomato plant

Treatment	N	P	K
	(%)		
T_1: Absolute control	2.62[d]	0.22[e]	1.71
T_2: Soil test based POP of KAU	3.54[bc]	0.33[a]	1.99
T_3: STCR + IPNS for target 25 t ha^{-1}	3.39[bc]	0.29[abcd]	2.04
T_4: STCR + IPNS for target 30 t ha^{-1}	3.91[a]	0.31[ab]	1.73
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	3.76[bc]	0.29[abcd]	2.15
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	3.57[bc]	0.27[bcde]	1.62
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	3.13[cd]	0.24[de]	2.19
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	3.29[cd]	0.32[ab]	2.04
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	3.39[bc]	0.30[abc]	1.97
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	3.73[bc]	0.31[ab]	1.86
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	3.18[cd]	0.29[abcd]	2.11
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	3.90[ab]	0.25[cde]	2.03

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –– Package of Practices recommendations

Table 16: Influence of different treatments on content of secondary nutrient in tomato plant

Treatment	Ca	Mg	S
	(%)		
T_1: Absolute control	1.63[d]	0.60[c]	0.71
T_2: Soil test based POP of KAU	1.80[d]	0.61[bc]	0.82
T_3: STCR + IPNS for target 25 t ha^{-1}	2.92[a]	0.68[bc]	0.83
T_4: STCR + IPNS for target 30 t ha^{-1}	2.32[bcd]	0.70[ab]	0.86
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	2.32[bcd]	0.75[ab]	0.88
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	2.77[bc]	0.80[a]	0.84
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	2.29[bcd]	0.80[a]	0.74
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	2.42[bcd]	0.85[a]	0.92
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	2.82[ab]	0.73[ab]	0.83
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	2.69[bc]	0.76[a]	0.85
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	2.41[bcd]	0.84[a]	0.84
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	1.99[cd]	0.83[a]	0.84

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –Package of Practices recommendations

4.4.2 Micronutrient content in tomato plant

Micronutrient content of tomato plants content did not vary significantly among the different treatments except for copper and boron (Table 17). The iron content of plant varied from 0.077 to 0.138 per cent. Highest iron concentration (0.138 %) was noticed in treatment, STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (T_{11}). However lowest iron content (0.077 %) was found in absolute control (T_1). The content of manganese in tomato plant varied from 0.023 per cent (Soil test based POP of KAU, T_2) to 0.048 per cent (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1}, T_9). Zinc content varied from 0.008 % (absolute control, T_1) to 0.018 % (STCR + IPNS for target 25 t ha^{-1} $MgSO_4$ @ 40 kg ha^{-1}, T_5). Significantly highest copper content (30.33 mg kg^{-1}) was seen in treatment STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{10}). However significantly lowest copper content (15.33 mg kg^{-1}) was found in absolute control (T_1). Significantly highest boron content (13.68 mg kg^{-1}) was seen in treatment that received STCR + IPNS for target 30 t ha^{-1} (T_4). However significantly lowest boron content (12.65 mg kg^{-1}) was found in absolute control (T_1).

4.5 Analysis of tomato root samples

4.5.1 Macro nutrient content in tomato root

4.5.1.1 Nitrogen content

The nitrogen concentration in tomato roots differed significantly due to different levels of fertilizer application (Table 18). Significantly highest nitrogen concentration (2.78 %) was noticed in T_2 (Soil test based POP of KAU) which was on par with treatment, STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}) which recorded 2.65 per cent. Lowest nitrogen concentration (1.41 per cent) was found in T_1 (absolute control).

4.5.1.2 Phosphorus content

The concentration of phosphorus in tomato root did not differ significantly (Table 18). The phosphorus content of root varied from 0.21 per cent (absolute control, T_1) to 0.32 per cent (STCR + IPNS for target 25 t ha^{-1}, T_3).

4.5.1.3 Potassium content

The potassium concentration in tomato roots varied significantly due to different treatment applications (Table 18). Significantly highest potassium concentration (1.98 %) was noticed in T_4 which received STCR + IPNS for target 30 t ha^{-1} and lowest significant potassium content (1.36 %) was noted in absolute control (T_1).

4.5.1.4 Calcium content

The calcium concentration in tomato root differed significantly among the different treatments (Table 19). Highest significant calcium content was found in T_4 (1.62 %) which received STCR + IPNS for tàrget 30 t ha^{-1} however lowest significant content of calcium (1.11 %) was noticed in T_1 (absolute control).

4.5.1.5 Magnesium content

The magnesium content in plant root differed significantly among treatments (Table 19). Maximum content of magnesium (0.39 %) was noticed in the treatment that received STCR + IPNS for target 30 t ha^{-1} +$MgSO_4$ @ 80 kg ha^{-1} (T_{11}). The lowest significant magnesium content (0.23 %) was recorded in absolute control (T_1).

Table 17: Influence of different treatments on micronutrient content of tomato plant

Treatment	Fe (%)	Mn (%)	Zn (%)	Cu (mg kg^{-1})	B (mg kg^{-1})
T_1: Absolute control	0.077	0.031	0.008	15.33^{e}	12.65^{d}
T_2: Soil test based POP of KAU	0.088	0.023	0.015	28.76^{ab}	12.89^{cd}
T_3: STCR + IPNS for target 25 t ha^{-1}	0.093	0.039	0.012	24.00^{bcd}	13.00^{bcd}
T_4: STCR + IPNS for target 30 t ha^{-1}	0.088	0.037	0.012	26.90^{abc}	13.68^{a}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	0.082	0.036	0.018	27.83^{ab}	13.37^{ab}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	0.101	0.029	0.014	18.63^{de}	13.08^{bcd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	0.092	0.033	0.013	21.66^{cd}	12.94^{bcd}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	0.127	0.039	0.012	26.66^{abc}	13.06^{bcd}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	0.087	0.048	0.017	26.26^{abc}	13.20^{bc}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	0.094	0.041	0.014	30.33^{a}	13.02^{bcd}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	0.138	0.047	0.017	23.66^{bcd}	12.84^{cd}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	0.087	0.033	0.010	25.50^{ab}	12.86^{cd}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.5.1.6 Sulfur content

The sulfur concentration in tomato root differed significantly (Table 18). Highest sulfur content (0.99 %) was seen in treatment that received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}). Lowest significant sulfur content (0.64 %) was observed in absolute control (T_1).

4.5.2 Micronutrient content in root

The micronutrients concentration of tomato root did not vary significantly due to different levels of fertilizers application (Table 20). The iron content varied from 0.237 to 0.837 per cent. Manganese content ranged from 0.018 to 0.044 per cent. Zinc content in root varied from 0.011 to 0.022 per cent among different treatments. Copper content varied from 28.40 mg kg^{-1} to 35.60 mg kg^{-1}. Boron content was varied between 13.26 mg kg^{-1} and 13.70 mg kg^{-1}.

Table 18: Influence of different treatments on content of major nutrient in tomato root

Treatment	N	P	K
	(%)		
T_1: Absolute control	1.41^{d}	0.21	1.36^{c}
T_2: Soil test based POP of KAU	2.78^{a}	0.30	1.77^{ab}
T_3: STCR + IPNS for target 25 t ha^{-1}	1.79^{cd}	0.32	1.95^{a}
T_4: STCR + IPNS for target 30 t ha^{-1}	2.04^{bc}	0.31	1.98^{a}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	1.96^{bcd}	0.25	1.47^{bc}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	1.99^{bc}	0.31	1.39^{bc}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	1.75^{cd}	0.29	1.76^{abc}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	1.72^{cd}	0.25	1.47^{bc}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	2.49^{ab}	0.30	1.65^{abc}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	2.00^{bc}	0.30	1.42^{bc}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	1.98^{bc}	0.29	1.38^{bc}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	2.65^{a}	0.29	1.59^{abc}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

Table 19: Influence of different treatments on content of secondary nutrients in tomato root

Treatment	Ca	Mg	S
	(%)		
T_1: Absolute control	1.11^{e}	0.23^{g}	0.64^{f}
T_2: Soil test based POP of KAU	1.30^{bcde}	0.27^{efg}	0.74^{e}
T_3: STCR + IPNS for target 25 t ha^{-1}	1.23^{cde}	0.25^{fg}	0.73^{e}
T_4: STCR + IPNS for target 30 t ha^{-1}	1.62^{a}	0.28^{cdefg}	0.84^{d}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	1.27^{bcde}	0.31^{bcde}	0.78^{e}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	1.36^{bcde}	0.34^{abc}	0.88^{cd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	1.47^{bc}	0.37^{ab}	0.92^{bc}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	1.38^{bcd}	0.33^{abc}	0.89^{cd}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	1.19^{de}	0.27^{defg}	0.88^{cd}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	1.52^{ab}	0.29^{cdef}	0.95^{ab}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	1.17^{de}	0.39^{a}	0.90^{bc}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	1.16^{de}	0.33^{abcd}	0.99^{a}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

Table 20: Influence of different treatments on micronutrient content of tomato root

Treatment	Fe (%)	Mn(%)	Zn (%)	Cu (mg kg^{-1})	B (mg kg^{-1})
T_1: Absolute control	0.237	0.018	0.011	28.40	13.26
T_2: Soil test based POP of KAU	0.392	0.030	0.017	35.60	13.45
T_3: STCR + IPNS for target 25 t ha^{-1}	0.266	0.021	0.014	29.33	13.37
T_4: STCR + IPNS for target 30 t ha^{-1}	0.295	0.036	0.022	30.66	13.69
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	0.506	0.036	0.019	30.66	13.57
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	0.427	0.035	0.014	33.00	13.39
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	0.408	0.037	0.018	30.33	13.36
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	0.429	0.030	0.013	29.50	13.26
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	0.367	0.044	0.015	31.66	13.32
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	0.680	0.030	0.016	34.16	13.70
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	0.365	0.039	0.014	29.00	13.28
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	0.837	0.033	0.015	32.66	13.44

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –Package of Practices recommendations

4.6 Analysis of tomato fruit

4.6.1 Macronutrient concentration in tomato fruit

4.6.1.1 Nitrogen content in fruit

The nitrogen concentration in tomato fruit did not vary significantly among the treatments (Table 21). Nitrogen content of tomato fruit varied from 1.93 to 2.50 per cent.

4.6.1.2 Phosphorus content in fruit

The phosphorus content in fruits did not show significant difference among the treatments (Table 21). Phosphorus content in fruit varied from 0.33 to 0.50 per cent.

4.6.1.3 Potassium content in fruit

The potassium content in tomato fruit was significantly different among different treatments (Table 21). The potassium content in tomato fruit varied from 2.3 to 2.80 per cent. The significantly highest potassium concentration (2.80 per cent) was recorded in treatment, STCR + IPNS for yield target 25 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} which was on par with the treatment that received STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (T_7) (2.72 per cent). Lowest significant K content (2.30 per cent) was recorded in absolute control (T_1).

4.6.1.4 Calcium content in fruit

The calcium content in tomato fruit differed significantly among various treatments (Table 22). The significantly highest calcium content (0.18 %) was recorded in treatments that received STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8). The lowest calcium concentration (0.09 %) was recorded in treatment that received absolute control (T_1).

Table 21: Influence of different treatments on content of major nutrients in tomato fruit

Treatment	N	P	K
	(%)		
T_1: Absolute control	1.93	0.33	2.30^{d}
T_2: Soil test based POP of KAU	2.25	0.36	2.37^{d}
T_3: STCR + IPNS for target 25 t ha^{-1}	2.32	0.47	2.30^{d}
T_4: STCR + IPNS for target 30 t ha^{-1}	2.07	0.45	2.64^{abc}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	2.08	0.45	2.49^{bcd}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	2.50	0.44	2.80^{a}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	2.25	0.49	2.72^{ab}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	2.27	0.45	2.69^{ab}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	2.31	0.50	2.49^{bcd}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	2.27	0.43	2.37^{d}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	2.05	0.40	2.65^{abc}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	2.31	0.456	2.45^{cd}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.6.1.5 Magnesium content in fruit

The magnesium content in tomato fruit was significantly different among various treatments (Table 22). The highest magnesium content (0.17 %) was recorded in the treatment that received STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_6), STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8), STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}) and STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1} (T_9). The lowest magnesium content (0.12 %) was recorded in absolute control (T_1).

4.6.1.6 Sulfur content in fruit

The sulfur concentration in tomato fruit did not differ significantly among various treatments imposed (Table 22). Sulfur concentration in fruit varied from 0.69 to 1.00 per cent.

4.6.2 Micronutrient concentration in tomato fruit (Fe, Mn, Zn, Cu and B)

4.6.2.1 Iron content in tomato fruit

Iron content in fruit differed significantly among various treatments (Table 23). Significantly highest content of iron (96.63 mg kg^{-1}) was received in STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8) followed by treatment that received STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{12}, 96.10 mg kg^{-1}). The lowest content of iron (60.46 mg kg^{-1}) was observed in treatment that received soil test based POP of KAU (T_2).

4.6.2.2 Manganese content in tomato fruit

The manganese content in fruit differed significantly among different treatments (Table 23). Significantly highest manganese content (32.93 mg kg^{-1}) was recorded in treatment that received STCR + IPNS for target, 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8) and lowest manganese content (15.90 mg kg^{-1}) was observed in treatment that received absolute control (T_1).

Table 22: Influence of different treatments on content of secondary nutrients in tomato fruit

Treatment	Ca	Mg	S
	(%)		
T_1: Absolute control	0.09^{f}	0.12^{bc}	0.69
T_2: Soil test based POP of KAU	0.13^{de}	0.13^{b}	0.75
T_3: STCR + IPNS for target 25 t ha^{-1}	0.12^{e}	0.14^{b}	0.83
T_4: STCR + IPNS for target 30 t ha^{-1}	0.10^{f}	0.13^{b}	0.83
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	0.10^{f}	0.13^{b}	0.88
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	0.13^{cde}	0.17^{a}	0.85
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	0.15^{b}	0.16^{a}	0.82
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	0.18^{a}	0.17^{a}	0.83
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	0.14^{bc}	0.17^{a}	1.00
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	0.14^{bcd}	0.16^{a}	0.91
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	0.15^{b}	0.16^{a}	0.70
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	0.13^{de}	0.17^{a}	0.84

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.6.2.3 Zinc content in tomato fruit

The zinc content in fruit differed significantly among various treatments (Table 23). Significantly highest zinc content (48.83 mg kg^{-1}) was noticed in treatment that received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1} (T_9) and lowest zinc concentration (33.60 mg kg^{-1}) was noted in absolute control (T_1).

4.6.2.4 Copper content in fruit

The copper content in fruit differed significantly among various treatments (Table 23). Significantly highest copper content (12.83 mg kg^{-1}) was observed in treatment which received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1} (T_9) and lowest significant zinc concentration (10.86 mg kg^{-1}) was noticed in absolute control (T_1).

4.6.2.5 Boron content in fruit

The boron content in fruit differed significantly among different treatments (Table 23). Significantly highest boron content (13.54 mg kg^{-1}) was observed in treatment that received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1} (T_9) and lowest boron concentration (12.82 mg kg^{-1}) was noticed in absolute control (T_1).

4.7 Uptake of nutrients by tomato

4.7.1 Uptake of N, P and K by tomato

The total uptake of N, P and K by tomato crop is presented in Table 24, 25 and 26.

4.7.1.1 Uptake of nitrogen by tomato plant

The perusal of the data in Table 24 showed that nitrogen uptake by tomato plant differed significantly due to different levels of fertilizer application. Significantly highest nitrogen uptake (24.29 kg ha^{-1}) by tomato plant was noticed in treatment that received STCR + IPNS for yield target of 30 t ha^{-1} (T_4). The lowest uptake of nitrogen by tomato (11.80 kg ha^{-1}) was noted in absolute control (T_1).

Table 23: Effect of different treatments on micronutrient content of tomato fruit

Treatment	Fe (mg kg^{-1})	Mn(mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})
T_1: Absolute control	60.46^{d}	15.90^{f}	33.60^{e}	10.86^{f}	12.82^{e}
T_2: Soil test based POP of KAU	64.23^{d}	21.86^{cd}	35.16^{de}	10.93^{ef}	13.29^{abc}
T_3: STCR + IPNS for target 25 t ha^{-1}	81.56^{bc}	17.20^{ef}	34.46^{de}	11.06^{ef}	13.21^{bc}
T_4: STCR + IPNS for target 30 t ha^{-1}	94.16^{a}	19.53^{cde}	36.93^{cde}	11.06^{ef}	12.88^{de}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	89.63^{ab}	18.03^{def}	42.23^{abc}	11.46^{def}	13.06^{bcde}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	96.10^{a}	27.20^{b}	45.20^{ab}	12.36^{abc}	13.01^{cde}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	94.26^{a}	20.06^{cdef}	40.06^{bcd}	11.30^{ef}	13.16^{bcd}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	96.63^{a}	32.93^{a}	40.40^{bcd}	11.46^{def}	13.21^{bc}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	76.60^{c}	32.36^{a}	48.23^{a}	12.83^{a}	13.54^{a}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	85.26^{abc}	26.23^{b}	35.86^{de}	12.07^{bcd}	13.37^{ab}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	79.50^{bc}	23.40^{bc}	44.33^{ab}	12.50^{ab}	13.06^{bcde}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	88.63^{abc}	23.41^{bc}	45.73^{ab}	11.64^{cde}	12.83^{e}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.7.1.2 Uptake of nitrogen by root

The uptake of nitrogen by root varied significantly due to different levels of fertilizer application. Significantly highest nitrogen uptake by root (5.63 kg ha^{-1}) was noticed in STCR + IPNS for target yield 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_{12}). However lowest uptake (1.58 kg ha^{-1}) was observed in absolute control (T_1).

4.7.1.3 Uptake of nitrogen by fruit

The uptake of nitrogen by tomato fruit differed significantly among the treatments. Significantly highest uptake of nitrogen by fruit (162.60 kg ha^{-1}) was observed in treatment that received STCR + IPNS for target yield 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). However significantly lowest uptake (63.28 kg ha^{-1}) was noticed in absolute control (T_1).

4.7.1.4 Total uptake of nitrogen by tomato crop

Total uptake of nitrogen by tomato varied significantly among treatments. Significantly highest nitrogen uptake (185.19 kg ha^{-1}) was observed in treatment that received STCR + IPNS for target yield of 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). Significantly lowest uptake (76.66 kg ha^{-1}) was seen in absolute control (T_1).

4.7.1.5 Uptake of phosphorus by tomato plant

The perusal of the data in Table 25 showed that phosphorus uptake by tomato plant did not differ significantly due to different levels of fertilizers application. Highest phosphorus uptake (1.96 kg ha^{-1}) by tomato plant was noticed in treatment that received STCR + IPNS for target yield of 30 t ha^{-1} + $MgSO_4$ at 60 kg ha^{-1} (T_{10}) and STCR + IPNS for target yield of 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8) . Lowest uptake of phosphorus by tomato plant (1.33 kg ha^{-1}) was noticed in absolute control (T_1).

4.7.1.6 Uptake of phosphorus by root

The uptake of phosphorus by root did not differ significantly because of different treatment applications. Highest phosphorus uptake by root (0.66 kg ha^{-1}) was

Table 24: Uptake of nitrogen by tomato at different levels of fertilizer application

Treatment	Nitrogen (kg ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	11.80^{e}	1.58^{d}	63.28^{c}	76.66^{d}
T_2: Soil test based POP of KAU	16.46^{de}	3.81^{abc}	83.91^{c}	104.19^{c}
T_3: STCR + IPNS for target 25 t ha^{-1}	17.80^{cd}	2.15^{cd}	121.98^{b}	141.95^{b}
T_4: STCR + IPNS for target 30 t ha^{-1}	24.29^{a}	3.32^{bcd}	121.16^{b}	148.78^{b}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	20.73^{abcd}	2.87^{bcd}	112.81^{b}	136.41^{b}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	22.44^{abc}	3.22^{bcd}	134.13^{b}	159.79^{ab}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	17.16^{cde}	2.55^{cd}	127.69^{b}	147.42^{b}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	19.81^{abcd}	2.77^{bcd}	162.60^{a}	185.19^{a}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	19.25^{abcd}	4.70^{ab}	133.01^{b}	156.98^{b}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	23.32^{ab}	3.87^{abc}	133.43^{b}	160.64^{ab}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	18.45^{bcd}	3.95^{abc}	124.24^{b}	146.64^{b}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	23.30^{ab}	5.63^{a}	131.61^{b}	160.59^{ab}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

noticed in STCR + IPNS for target yield 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_{12}). However lowest uptake (0.22 kg ha^{-1}) was noticed in absolute control (T_1).

4.7.1.7 Uptake of phosphorus by fruit

The uptake of phosphorus by tomato fruit differed significantly among different treatment. Significantly highest uptake of phosphorus by fruit (28.24 kg ha^{-1}) was found in treatment that received STCR + IPNS for target yield of 25 t ha^{-1} + $MgSO_4$ at 80 kg ha^{-1} (T_7). However significantly lowest uptake (11.85 kg ha^{-1}) was noticed in absolute control (T_1).

4.7.1.8 Total uptake of phosphorus by tomato crop

Total uptake of phosphorus by tomato crop differed significantly among treatments. Significantly highest phosphorus uptake (30.47 kg ha^{-1}) was noticed in treatment that received STCR + IPNS for yield target 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} (T_9). Significantly lowest uptake (13.40 kg ha^{-1}) was seen in absolute control (T_1).

4.7.1.9 Uptake of potassium by plant

The data on potassium uptake by tomato plant did not show significant difference due to various treatments imposed (Table 26). The uptake of potassium by plant varied from 8.42 to 12.34 kg ha^{-1}.

4.7.1.10 Uptake of potassium by root

Examination of the potassium uptake information in Table 26 revealed that there was no significant difference among different treatments in K uptake by root because of various levels of fertilizer application. The uptake of potassium by tomato root varied from 1.44 to 3.45 kg ha^{-1}.

4.7.1.11 Uptake of potassium by fruit

Significant difference was noticed in uptake of potassium by tomato fruit. Significantly highest potassium uptake by fruit (167.52 kg ha^{-1}) was noticed in STCR

Table 25: Uptake of phosphorus by tomato at different levels of fertilizer application

Treatment	Phosphorus (kg ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	1.33	0.22	11.85^c	13.40^c
T_2: Soil test based POP of KAU	1.54	0.43	17.08^b	19.06^b
T_3: STCR + IPNS for target 25 t ha^{-1}	1.57	0.39	24.99^a	26.95^a
T_4: STCR + IPNS for target 30 t ha^{-1}	1.72	0.50	26.58^a	28.81^a
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	1.63	0.38	24.76^a	26.77^a
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	1.70	0.50	24.01^a	26.30^a
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	1.36	0.42	28.24^a	30.03^a
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	1.96	0.41	28.03^a	30.42^a
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	1.73	0.56	28.18^a	30.47^a
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	1.96	0.59	25.53^a	28.09^a
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	1.34	0.39	24.61^a	26.34^a
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	1.43	0.66	25.95^a	28.05^a

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

+ IPNS for yield target, 25 t ha^{-1} + $MgSO_4$ at 120kg ha^{-1} (T_8). Significantly lowest uptake (76.51 kg ha^{-1}) was noticed in absolute control (T_1).

4.7.1.12 Total uptake of potassium by tomato crop

The data on potassium uptake in Table 26 revealed that there was significant difference among treatments due to various levels of fertilizer application. Significantly highest uptake (182.22 kg ha^{-1}) was noticed in STCR + IPNS for target yield, 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). Significantly lowest uptake (86.38 kg ha^{-1}) of potassium was found in absolute control (T_1).

4.7.2 Uptake of secondary nutrients (Ca, Mg and S) by tomato crop

4.7.2.1 Uptake of calcium by tomato plant

The data on calcium uptake by tomato plant showed significant difference among treatments (Table 27). Significantly highest calcium uptake by plant (18.88 kg ha^{-1}) was noticed in STCR + IPNS for target yield, 25 t ha^{-1} (T_3). However significantly lowest uptake (7.61 kg ha^{-1}) was noted in absolute control (T_1).

4.7.2.2 Uptake of calcium by root

The uptake of calcium by tomato root did not differ significantly among different treatments imposed. The calcium uptake by root varied from 1.36 to 2.89 kg ha^{-1}.

4.7.2.3 Uptake of calcium by fruit

The information on uptake of calcium by tomato fruit was found to be significantly different because of the application of various levels of fertilizers. Significantly highest uptake of calcium (11.59 kg ha^{-1}) by fruit was noticed in STCR + IPNS for target yield, 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). However significantly lowest uptake of calcium (3.11 kg ha^{-1}) was noted in absolute control (T_1).

Table 26: Uptake of potassium by tomato at different levels of fertilizer application

Treatment	Potassium (kg ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	8.42	1.44	76.51^{f}	86.38^{f}
T_2: Soil test based POP of KAU	9.27	2.44	89.02^{f}	100.74^{f}
T_3: STCR + IPNS for target 25 t ha^{-1}	10.72	2.35	120.64^{e}	133.73^{e}
T_4: STCR + IPNS for target 30 t ha^{-1}	9.48	3.19	153.95^{abc}	166.63^{abcd}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	11.83	2.18	136.28^{de}	150.30^{de}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	10.06	2.23	149.84^{bcd}	162.14^{bcd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	12.04	2.61	154.04^{abc}	168.69^{abc}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	12.28	2.41	167.52^{a}	182.22^{a}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	11.24	3.03	143.42^{cd}	157.70^{cd}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	10.32	2.64	137.32^{d}	150.29^{de}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	12.34	2.68	160.51^{abc}	175.54^{ad}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	11.58	3.45	140.24^{cd}	155.28^{cd}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.7.2.4 Total uptake of calcium by tomato crop

The total uptake of calcium by tomato crop differed significantly among different treatments imposed. Significantly highest uptake of calcium by tomato crop (28.68 kg ha^{-1}) was noticed in STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 60 kg ha^{-1} (T_{10}). Significantly lowest uptake of calcium by tomato crop (12.66 kg ha^{-1}) was noticed in absolute control (T_1).

4.7.2.5 Uptake of magnesium by tomato plant

The perusal of the data in Table 28 showed that magnesium uptake by tomato plant differed significantly due to different levels of fertilizer application. Significantly highest magnesium uptake (4.82 kg ha^{-1}) by tomato plant was noticed in treatment that received STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 60 kg ha^{-1} (T_{10}). Significantly lowest uptake of magnesium by tomato (2.97 kg ha^{-1}) was noted in absolute control (T_1).

4.7.2.6 Uptake of magnesium by root

The uptake of magnesium by root differed significantly because of different levels of fertilizer application. Significantly highest magnesium uptake by root (0.734 kg ha^{-1}) was noticed in STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_{12}). However lowest significant uptake (0.240 kg ha^{-1}) was seen in absolute control (T_1).

4.7.2.7 Uptake of magnesium by fruit

The uptake of magnesium by tomato fruit differed significantly among the treatments. Significantly highest uptake of magnesium by fruit (10.50 kg ha^{-1}) was noted in treatment that received STCR + IPNS for target yield 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). However, significantly lowest uptake (4.44 kg ha^{-1}) was noticed in absolute control (T_1).

Table 27: Uptake of calcium by tomato at different levels of fertilizer application

Treatment	Calcium (kg ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	7.61^{e}	1.36	3.11^{f}	12.63^{e}
T_2: Soil test based POP of KAU	8.18^{de}	1.81	4.83^{e}	14.82^{e}
T_3: STCR + IPNS for target 25 t ha^{-1}	18.88^{a}	1.49	6.53^{cd}	26.90^{ab}
T_4: STCR + IPNS for target 30 t ha^{-1}	12.4^{cd}	2.89	6.30^{d}	21.60^{cd}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	15.30^{abc}	1.89	5.84^{d}	23.04^{bcd}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	14.42^{abc}	2.11	7.28^{c}	23.82^{abcd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	12.75^{bcd}	2.20	8.89^{b}	23.86^{abcd}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	14.42^{abc}	2.25	11.59^{a}	28.27^{a}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	15.85^{abc}	2.20	8.43^{b}	26.49^{abc}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	17.21^{ab}	2.90	8.56^{b}	28.68^{a}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	13.97^{bc}	2.30	9.19^{b}	25.48^{abcd}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	15.67^{abc}	2.40	7.41^{c}	25.48^{abcd}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.7.2.8 Total uptake of magnesium by tomato crop

Total uptake of magnesium by tomato crop differed significantly among treatments. Significantly highest magnesium uptake (15.81 kg ha^{-1}) was noted in treatment that received STCR + IPNS for target yield, 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). Significantly lowest uptake (7.65 kg ha^{-1}) was seen in absolute control (T_1).

4.7.2.9 Uptake of sulfur by plant

The data on sulfur uptake by tomato plant did not show a significant difference among treatments due to different treatments imposed (Table 29). The uptake of sulfur by plant varied from 3.84 to 5.37 kg ha^{-1}.

4.7.2.10 Uptake of sulfur by root

Persual of the data on sulfur uptake in Table 29 revealed significant difference among treatments because of various levels of fertilizer application. Significantly highest sulfur uptake by root (2.16 kg ha^{-1}) was noticed in STCR + IPNS for target yield 30 t ha^{-1} + $MgSO_4$ at 120kg ha^{-1} (T_{12}). Lowest uptake (0.65 kg ha^{-1}) was noted in absolute control (T_1).

4.7.2.11 Uptake of sulfur by fruit

Significant difference was noticed in uptake of sulfur by tomato fruit. Significantly highest sulfur uptake by fruit (58.04 kg ha^{-1}) was noticed in STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 60 kg ha^{-1} (T_9). Significantly lowest uptake (22.69 kg ha^{-1}) was noted in absolute control (T_1).

4.7.2.12 Total uptake of sulfur by tomato crop

Examination of the sulfur uptake information in Table 29 indicated that there is significant difference among treatments due to various levels of fertilizer application. Significantly highest uptake (64.94 kg ha^{-1}) was noticed in STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} (T_9). Significantly lowest uptake (27.19 kg ha^{-1}) of sulfur was observed in absolute control (T_1).

Table 28: Uptake of magnesium by tomato at different levels of fertilizer application

Treatment	Magnesium (kg ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	2.97^{f}	0.240^{d}	4.44^{d}	7.65^{f}
T_2: Soil test based POP of KAU	3.30^{ef}	0.379^{cd}	5.10^{d}	8.76^{f}
T_3: STCR + IPNS for target 25 t ha^{-1}	4.48^{abcd}	0.381^{cd}	7.31^{c}	12.18^{de}
T_4: STCR + IPNS for target 30 t ha^{-1}	3.60^{def}	0.651^{ab}	7.83^{c}	12.09^{e}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	4.42^{abcd}	0.376^{cd}	7.39^{c}	12.18^{de}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	4.68^{abc}	0.552^{abc}	9.34^{b}	14.57^{abc}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	3.68^{cdef}	0.552^{abc}	9.37^{b}	13.61^{cd}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	4.87^{ab}	0.443^{bcd}	10.50^{a}	15.81^{a}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	4.73^{ab}	0.629^{abc}	9.90^{ab}	15.27^{ab}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	4.82^{a}	0.540^{abc}	9.81^{ab}	15.17^{ab}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	4.30^{abcde}	0.546^{abc}	10.22^{ab}	15.07^{ab}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	4.25^{bcdef}	0.734^{a}	9.67^{ab}	14.65^{abc}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

Table 29: Uptake of sulfur by tomato at different levels of fertilizer application

Treatment	Sulfur (kg ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	3.84	0.65^{e}	22.69^{e}	27.19^{d}
T_2: Soil test based POP of KAU	3.94	1.03^{cde}	28.26^{e}	33.24^{d}
T_3: STCR + IPNS for target 25 t ha^{-1}	4.40	0.91^{de}	44.93^{cd}	50.25^{c}
T_4: STCR + IPNS for target 30 t ha^{-1}	4.68	1.36^{bcd}	48.70^{bcd}	54.75^{bc}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	4.85	1.16^{bcde}	48.16^{bcd}	54.18^{c}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	5.24	1.42^{bcd}	42.89^{d}	49.56^{c}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	4.14	1.36^{bcd}	46.66^{bcd}	52.18^{c}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	5.05	1.44^{bcd}	51.80^{abc}	58.29^{abc}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	5.25	1.64^{abc}	58.04^{a}	64.94^{a}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	5.37	1.79^{ab}	54.18^{ab}	61.35^{ab}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	4.10	1.77^{ab}	50.51^{abcd}	56.39^{abc}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	4.77	2.16^{a}	47.72^{bcd}	54.66^{bc}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.7.3 Uptake of micronutrients (Fe, Mn, Zn, Cu and B) by tomato

4.7.3.1 Uptake of iron by tomato plant

The data on iron uptake by tomato plant did not show significant difference among treatments due to different treatments imposed (Table 30). The uptake of iron by tomato plant varied from 360.13 to 786.76 g ha^{-1}.

4.7.3.2 Uptake of iron by root

The uptake of iron by tomato root differed significantly among different treatments imposed. Significantly highest iron uptake (1511.54 g ha^{-1}) was noticed in treatment that received STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_{12}). Lowest uptake of iron by root (301.79 g ha^{-1}) was noticed in absolute control (T_1).

4.7.3.3 Uptake of iron by fruit

The information on uptake of iron by tomato fruit was found to be significantly different due to application of different fertilizers. Significantly highest uptake of iron (602.00 g ha^{-1}) by fruit was noticed in STCR + IPNS for target yield 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). However significantly lowest uptake of iron (240.00 g ha^{-1}) was noted in soil test based POP of KAU (T_2).

4.7.3.4 Total uptake of iron

The total uptake of iron by tomato crop differed significantly among different treatments imposed. Significantly highest uptake of iron by tomato crop (2468.55 g ha^{-1}) was noticed in STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_{12}). Significantly lowest uptake of iron by tomato crop (990.51 g ha^{-1}) was observed in absolute control (T_1).

4.7.3.5 Uptake of manganese by plant

The data on manganese uptake by tomato plant showed significant difference among different treatments (Table 31). Significantly highest manganese uptake (270.07 g ha^{-1}) was noted in STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 80

Table 30: Uptake of iron by tomato at different levels of fertilizer application

Treatment	Iron (g ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	394.72	301.79^{c}	294.00^{ef}	990.51^{f}
T_2: Soil test based POP of KAU	360.13	585.64^{c}	240.00^{f}	1185.72^{ef}
T_3: STCR + IPNS for target 25 t ha^{-1}	487.21	321.32^{c}	428.00^{d}	1236.51^{def}
T_4: STCR + IPNS for target 30 t ha^{-1}	467.44	484.76^{c}	549.00^{ab}	1501.22^{cdef}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	454.45	744.87^{bc}	330.00^{e}	1529.41^{cdef}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	622.62	696.50^{c}	514.00^{bc}	1833.52^{bcd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	517.91	611.08^{c}	534.00^{ab}	1662.92^{cde}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	761.50	692.85^{c}	602.00^{a}	2056.35^{abc}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	460.22	751.66^{bc}	440.00^{cd}	1651.92^{cde}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	602.82	1302.98^{ab}	501.00^{bcd}	2406.93^{ab}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	786.76	740.15^{bc}	480.00^{bcd}	2007.21^{abc}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	450.52	1511.54^{a}	506.00^{bc}	2468.55^{a}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

kg ha^{-1} (T_{11}). Lowest uptake of manganese (105.90 g ha^{-1}) by tomato plant was noticed in soil test based POP of KAU (T_2).

4.7.3.6 Uptake of manganese by root

From the manganese uptake information from Table 31, it is revealed that manganese uptake by root did not vary significantly among different treatments. The uptake of manganese by root varied from 16.67 to 83.33 g ha^{-1}.

4.7.3.7 Uptake of manganese by fruit

Significant difference was noticed in the uptake of manganese by tomato fruit. Significantly highest manganese uptake by fruit (205.00 g ha^{-1}) was noticed in STCR + IPNS for target yield, 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). Significantly lowest uptake (56.00 g ha^{-1}) was observed in absolute control (T_1).

4.7.3.8 Total uptake of manganese by tomato

From Table 31, it is revealed that different levels of fertilizer application have significant effect on manganese uptake. Significantly highest uptake (540.65 g ha^{-1}) was noticed in STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} (T_9). Lowest uptake (214.08 g ha^{-1}) of manganese was observed in absolute control (T_1).

4.7.3.9 Uptake of zinc by tomato plant

The perusal of the data in Table 32 did not show significant difference in zinc uptake by tomato plant due to different levels of fertilizer application. Zinc uptake ranged from 59.20 g ha^{-1} to 100.20 g ha^{-1}.

4.7.3.10 Uptake of zinc by root

The uptake of zinc by root did not vary significantly because of different levels of fertilizer application. Zinc uptake by root varied from 16.60 to 36.80 g ha^{-1}.

Table 31: Uptake of manganese by tomato at different levels of fertilizer application

Treatment	Manganese (g ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	141.27^{cd}	16.67	56.00^{g}	214.08^{d}
T_2: Soil test based POP of KAU	105.90^{d}	39.00	82.00^{f}	226.55^{d}
T_3: STCR + IPNS for target 25 t ha^{-1}	204.06^{abc}	25.26	83.00^{f}	312.38^{cd}
T_4: STCR + IPNS for target 30 t ha^{-1}	197.42^{abcd}	59.56	120.00^{cde}	376.67^{bc}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	196.38^{abcd}	52.53	98.00^{ef}	347.31^{c}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	175.94^{bcd}	60.31	146.00^{b}	382.01^{bc}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	183.38^{abcd}	55.29	114.00^{de}	352.44^{c}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	232.91^{abc}	48.13	205.00^{a}	486.13^{ab}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	271.11^{a}	83.33	186.00^{a}	540.65^{a}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	261.27^{ab}	58.71	154.00^{b}	473.90^{ab}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	270.07^{ab}	78.61	141.00^{bc}	490.23^{ab}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	189.07^{abcd}	72.00	133.00^{bcd}	394.10^{bc}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.7.3.11 Uptake of zinc by fruit

The uptake of zinc by tomato fruit varied significantly among different treatments. Significantly highest uptake of zinc by fruit (278.00 g ha^{-1}) was observed in treatment, STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} (T_9). However significantly lowest uptake (117.00 g ha^{-1}) was noticed in absolute control (T_1).

4.7.3.12 Total uptake of zinc by tomato

Total uptake of zinc by tomato crop differed significantly among various treatments. Significantly highest zinc uptake (397.90 g ha^{-1}) was noticed in STCR + IPNS for target yield 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} (T_9). Significantly lowest uptake of Zn (192.80 g ha^{-1}) was noted in absolute control (T_1).

4.7.3.13 Uptake of copper by tomato plant

The perusal of the data in Table 33 showed that copper uptake by tomato plant did not vary significantly due to different levels of fertilizers application. The uptake of copper by tomato plant ranged from 1.64 to 2.33 g ha^{-1}.

4.7.3.14 Uptake of copper by root

The uptake of copper by root did not differ significantly because of different levels of fertilizer application. Copper content of root varied from 3.37 to 7.00 g ha^{-1}.

4.7.3.15 Uptake of copper by fruit

The uptake of copper by tomato fruit differed significantly among different treatments. Significantly highest uptake of copper by fruit (75.51 g ha^{-1}) was noted in STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 80 kg ha^{-1} (T_{11}). The lowest uptake (37.42 g ha^{-1}) was noticed in absolute control (T_1).

4.7.3.16 Total uptake of copper by tomato

Total uptake of copper by tomato crop varied significantly among treatments. Significantly highest copper uptake (83.12 g ha^{-1}) was noticed in STCR + IPNS for

Table 32: Uptake of zinc by tomato at different levels of fertilizer application

Treatment	Zinc (g ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	59.20	16.60	117.00^{f}	192.80^{f}
T_2: Soil test based POP of KAU	70.60	23.00	131.00^{f}	224.60^{ef}
T_3: STCR + IPNS for target 25 t ha^{-1}	62.20	17.80	181.00^{e}	261.00^{de}
T_4: STCR + IPNS for target 30 t ha^{-1}	63.40	36.80	215.00^{cde}	315.20^{bc}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	100.10	27.10	230.00^{bcd}	357.10^{abc}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	51.20	20.45	242.00^{abc}	313.60^{bc}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	71.10	25.91	227.00^{bcd}	324.00^{abc}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	71.20	17.72	252.00^{abc}	340.90^{abc}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	94.10	25.87	278.00^{a}	397.90^{a}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	84.10	31.92	197.00^{de}	313.00^{bc}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	100.2	26.51	268.00^{ab}	394.70^{ab}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	62.30	34.32	262.00^{ab}	358.60^{ab}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

Table 33: Uptake of copper by tomato at different levels of fertilizer application

Treatment	Cu (g ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	1.64	3.37	37.42^{f}	42.43^{f}
T_2: Soil test based POP of KAU	1.93	4.89	40.62^{f}	47.44^{f}
T_3: STCR + IPNS for target 25 t ha^{-1}	1.78	3.50	58.01^{e}	63.29^{e}
T_4: STCR + IPNS for target 30 t ha^{-1}	2.42	5.11	64.30^{d}	71.84^{cd}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	2.07	4.25	62.50^{de}	68.91^{de}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	2.24	5.36	66.20^{cd}	73.89^{cd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	1.71	4.54	63.90^{de}	70.25^{de}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	1.98	4.77	67.65^{bcd}	74.41^{bcd}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	1.92	5.98	73.80^{ab}	81.75^{ab}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	2.33	6.39	70.97^{abc}	79.70^{abc}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	1.84	5.76	75.51^{a}	83.12^{a}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	2.33	7.00	66.56^{cd}	75.90^{abcd}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

target yield 30 t ha^{-1} + $MgSO_4$ at 80 kg ha^{-1} (T_{11}). Significantly lowest uptake (42.43 g ha^{-1}) was recorded in absolute control (T_1).

4.7.3.17 Uptake of boron by plant

The perusal of the data in Table 34, showed that boron uptake by tomato plant was found to be significant due to different levels of fertilizer application. Highest boron uptake (9.20 g ha^{-1}) was noticed in STCR + IPNS for target yield 30 t ha^{-1} (T_4). Lowest boron uptake (6.63 g ha^{-1}) by tomato plant was noticed in absolute control (T_1).

4.7.3.18 Uptake of boron by root

Boron uptake by root did not vary significantly among the treatments due to application of different levels of fertilizers. The boron uptake varied from 7.16 to 9.32 g ha^{-1} by different levels of fertilizer application.

4.7.3.19 Uptake of boron by fruit

The perusal of the data in Table 34 showed that the uptake of boron by tomato fruit differed significantly among different treatments. Significantly highest boron uptake (18.86 g ha^{-1}) was observed in treatment that received STCR + IPNS for target yield, 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} (T_9). Significantly lowest boron uptake (15.03 g ha^{-1}) was noticed in absolute control (T_1).

4.7.3.20 Total uptake of boron by tomato crop

Uptake of boron by tomato showed significant difference due to different treatments imposed. Highest boron uptake (35.72 g ha^{-1}) was noticed in treatment that received STCR + IPNS for target yield 30 t ha^{-1} (T_4). Significantly lowest uptake of boron (28.82 g ha^{-1}) was seen in absolute control (T_1).

Table 34: Uptake of boron by tomato at different levels of fertilizer application

Treatment	B (g ha^{-1})			
	Plant	Root	Fruit	Total uptake
T_1: Absolute control	6.63^{d}	7.16	15.03^{e}	28.82^{f}
T_2: Soil test based POP of KAU	7.23^{cd}	8.63	17.06^{de}	32.92^{e}
T_3: STCR + IPNS for target 25 t ha^{-1}	7.50^{bcd}	8.43	18.03^{bc}	33.97^{d}
T_4: STCR + IPNS for target 30 t ha^{-1}	9.20^{a}	9.32	17.20^{de}	35.72^{a}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	8.43^{ab}	8.93	17.66^{bcde}	35.02^{b}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	7.70^{bcd}	8.48	17.53^{cde}	33.74^{d}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	7.36^{bcd}	8.40	17.90^{bcd}	33.77^{d}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	7.66^{bcd}	8.16	18.23^{abc}	34.33^{c}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	8.00^{bc}	8.30	18.86^{a}	35.17^{b}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	7.56^{bcd}	9.27	18.43^{ab}	35.27^{b}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	7.10^{cd}	8.20	17.66^{bcde}	32.97^{e}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	7.16^{cd}	8.60	18.03^{bc}	33.86^{d}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.8 Nutrient use efficiency parameters

4.8.1 Agronomic efficiency (AE)

Highest agronomic nutrient use efficiency for nitrogen (0.13 t kg^{-1}) was recorded in T_8 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}) and lowest AE_N (0.07 t kg^{-1}) was noted in T_4 (STCR + IPNS for target 30 t ha^{-1}) (Table 35). Maximum AE_P (0.72 t kg^{-1}) was seen in T_8 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}) and minimum AE_P (0.15 t kg^{-1}) was recorded in T_2 (soil test based POP of KAU). Maximum (0.24 t kg^{-1}) and minimum (0.07 t kg^{-1}) AE_K was noticed in T_2 (soil test based POP of KAU) and T_4 (STCR + IPNS for target 30 t ha^{-1}) respectively. Highest AE_{Mg} (0.40 t kg^{-1}) was recorded in T_{10} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1}) whereas lowest AE_{Mg} (0.15 t kg^{-1}) was seen in T_{12} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}).

4.8.2 Physiological efficiency (PE)

Highest physiological efficiency for nitrogen (0.27 t kg^{-1}) was noted in T_{11} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1}) and lowest PE_N (0.18 t kg^{-1}) was recorded in T_8 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}) (Table 36). Highest PEP (1.46 t kg^{-1}), PE_K (0.41 t kg^{-1}) and PE_{Mg} (3.57 t kg^{-1}) were recorded in T_{11} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1}), T_2 (soil test based POP of KAU) and T_5 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1}) respectively. Lowest PE_P (0.98 t kg^{-1}) and PE_K (0.18 t kg^{-1}) was noted in T_4 (STCR + IPNS for target 30 t ha^{-1}), whereas lowest PE_{Mg} (2.25 t kg^{-1}) was observed in T_5 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1}).

4.8.3 Recovery efficiency (RE)

Highest recovery efficiency for nitrogen (0.71 kg kg^{-1}) and potassium (0.67 kg kg^{-1}) was observed in T_8 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}) (Table 37). Whereas lowest RE_N (0.36 kg kg^{-1}) and RE_K (0.32 kg kg^{-1}) was found in T_{11} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1}) and T_{10} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1}) respectively. Highest RE_P

(0.60 kg kg^{-1}) was noted in T_7 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1}) and it was lowest (0.14 kg kg^{-1}) in T_2 (soil test based POP of KAU). Maximum RE_{Mg} (0.12 kg kg^{-1}) was noticed in T_{10} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1}) and minimum RE_{Mg} (0.05 kg kg^{-1}) was recorded in T_{12} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}).

4.8.4 Partial factor productivity (PFP)

Highest PFP_N (0.31 t kg^{-1}) and PFP_K (0.94 t kg^{-1}) were noticed in T_2 (soil test based POP of KAU), whereas both PFP_N (0.16 t kg^{-1}) and PFP_K (0.16 t kg^{-1}) found to be low in T_4 (STCR + IPNS for target 25 t ha^{-1}) (Table 38). Highest PFP_P (1.34 t kg^{-1}) was recorded in T_8 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}) and lowest PFP_P (0.58 t kg^{-1}) was observed in T_2 (soil test based POP of KAU). Maximum (0.86 t kg^{-1}) and minimum (0.30 t kg^{-1}) PFP_{Mg} was noticed in T_9 (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1}) and T_{12} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1}) respectively.

Table 35: Influence of different treatments on agronomic efficiency

Treatments	Agronomic efficiency (t kg^{-1})			
	AE_N	AE_P	AE_K	AE_{Mg}
T_1: Absolute control	-	-	-	-
T_2: Soil test based POP of KAU	0.08	0.15	0.24	-
T_3: STCR + IPNS for target 25t ha^{-1}	0.09	0.53	0.10	-
T_4: STCR + IPNS for target 30t ha^{-1}	0.07	0.28	0.07	-
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	0.10	0.57	0.11	0.40
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	0.11	0.60	0.11	0.28
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	0.11	0.61	0.12	0.21
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	0.13	0.72	0.14	0.16
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	0.08	0.32	0.08	0.43
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	0.09	0.33	0.09	0.29
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	0.09	0.35	0.09	0.23
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	0.09	0.36	0.09	0.15

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –Package of Practices recommendations , AE_N – AE for N , AE_P – AE for P, AE_K- AE for K, AE_{Mg} – AE for Mg

Table 36: Influence of different treatments on physiological efficiency

Treatments	Physiological efficiency (t kg^{-1})			
	PE_N	PE_P	PE_K	PE_{Mg}
T_1: Absolute control	-	-	-	-
T_2: Soil test based POP of KAU	0.21	1.06	0.41	-
T_3: STCR + IPNS for target 25t ha^{-1}	0.23	1.11	0.31	-
T_4: STCR + IPNS for target 30t ha^{-1}	0.21	0.98	0.18	-
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	0.27	1.21	0.25	3.57
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	0.20	1.32	0.22	2.46
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	0.24	1.03	0.20	2.87
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	0.18	1.18	0.21	2.47
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	0.21	1.00	0.24	2.25
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	0.21	1.20	0.27	2.35
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	0.27	1.46	0.21	2.56
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	0.22	1.30	0.27	2.72

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –Package of Practices recommendations , PE_N – PE for N, PE_P – PE for P, PE_K – PE for K, PE_{Mg} – PE for Mg

Table 37: Influence of different treatments on recovery efficiency

Treatments	Recovery efficiency (kg kg^{-1})			
	RE_N	RE_P	RE_K	RE_{Mg}
T_1: Absolute control	-	-	-	-
T_2: Soil test based POP of KAU	0.36	0.14	0.57	-
T_3: STCR + IPNS for target 25t ha^{-1}	0.42	0.48	0.33	-
T_4: STCR + IPNS for target 30t ha^{-1}	0.37	0.29	0.41	-
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	0.39	0.47	0.44	0.11
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	0.54	0.45	0.53	0.11
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	0.46	0.59	0.57	0.07
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	0.71	0.60	0.67	0.06
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	0.41	0.32	0.36	0.19
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	0.43	0.27	0.32	0.12
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	0.36	0.24	0.46	0.09
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	0.43	0.27	0.35	0.05

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –Package of Practices recommendations, RE_N – RE for N, RE_P – RE for P, RE_K– RE for K, RE_{Mg} – RE for Mg

Table 38: Influence of different treatments on partial factor productivity

Treatments	Partial factor productivity (t kg^{-1})			
	PFP_N	PFP_P	PFP_K	PFP_{Mg}
T_1: Absolute control	-	-	-	-
T_2: Soil test based POP of KAU	0.31	0.58	0.94	-
T_3: STCR + IPNS for target 25t ha^{-1}	0.21	1.16	0.22	-
T_4: STCR + IPNS for target 30t ha^{-1}	0.16	0.61	0.16	-
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	0.22	1.20	0.23	0.84
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	0.22	1.23	0.24	0.57
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	0.22	1.23	0.24	0.43
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	0.24	1.34	0.26	0.31
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	0.17	0.65	0.17	0.86
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	0.18	0.66	0.18	0.58
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	0.18	0.69	0.18	0.45
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	0.18	0.69	0.18	0.30

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP –Package of Practices recommendations , PFP_N – PFP for N, PFP_P – PFP for P, PFP_K– PFP for K, PFP_{Mg} – PFP for Mg

4.9 Quality of tomato crop

4.9.1 Chlorophyll content

Analysis of the information in Table 39 depicted that there was significant difference in chlorophyll content of tomato leaves due to various levels of fertilizer application.

At vegetative stage, significantly highest chlorophyll a content (1.21 mg g^{-1}) was noticed in STCR + IPNS for target, 25 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (T_7) and lowest chlorophyll content (0.84 mg g^{-1}) was observed in absolute control (T_1). Significantly highest chlorophyll b content (0.39 mg g^{-1}) was noticed in STCR + IPNS for target, 25 t ha^{-1} + $MgSO_4$ @ 80 kg ha^{-1} (T_7) followed by STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1} (T_9, 0.38 mg g^{-1}) and lowest significant chlorophyll b content (0.28 mg g^{-1}) was noticed in absolute control (T_1).

At flowering stage, chlorophyll a content of tomato leaves differed significantly. The chlorophyll a content varied from 0.552 to 0.882 mg g^{-1}. Maximum chlorophyll a content (0.88 mg g^{-1}) was noticed in STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8) which was on par with STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 40 kg ha^{-1} (T_9). Lowest chlorophyll a content (0.55 mg g^{-1}) was noticed in absolute control (T_1). Significantly highest chlorophyll b content (0.38 mg g^{-1}) was noticed in soil test based POP of KAU (T_2) followed by STCR + IPNS for target 25 t ha^{-1} (T_3) Lowest chlorophyll b content (0.23 mg g^{-1}) was noticed in absolute control (T_1).

At fruiting stage, significantly highest chlorophyll a content (0.62 mg g^{-1}) was noticed in STCR + IPNS for target, 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{10}) and lowest significant value (0.34 mg g^{-1}) was noticed in absolute control (T_1). Highest chlorophyll b content (0.22 mg g^{-1}) was noticed in STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8) and lowest significant value (0.14 mg g^{-1}) was observed in absolute control (T_1).

Table 39: Influence of different treatments on chlorophyll content (mg g^{-1}) of tomato at different stages

Treatment	Vegetative stage (mg g^{-1})		Flowering stage (mg g^{-1})		Fruiting stage (mg g^{-1})	
	Chl.a	Chl.b	Chl.a	Chl.b	Chl.a	Chl.b
T_1: Absolute control	0.84^{c}	0.28^{e}	0.55^{e}	0.23^{c}	0.34^{f}	0.14^{d}
T_2: Soil test based POP of KAU	0.86^{c}	0.35^{abcd}	0.60^{d}	0.36^{ab}	0.36^{ef}	0.15^{cd}
T_3: STCR + IPNS for target 25 t ha^{-1}	0.89^{bc}	0.32^{cd}	0.83^{bc}	0.36^{ab}	0.43^{d}	0.17^{cd}
T_4: STCR + IPNS for target 30 t ha^{-1}	0.86^{c}	0.32^{cd}	0.80^{c}	0.31^{b}	0.41^{de}	0.16^{cd}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	1.02^{abc}	0.34^{bcd}	0.85^{ab}	0.36^{ab}	0.45^{cd}	0.19^{abc}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	1.02^{abc}	0.35^{abcd}	0.81^{bc}	0.30^{b}	0.48^{c}	0.17^{cd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	1.21^{a}	0.39^{a}	0.81^{bc}	0.32^{ab}	0.42^{d}	0.15^{cd}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	1.03^{abc}	0.35^{abcd}	0.88^{a}	0.38^{a}	0.56^{b}	0.22^{a}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	0.99^{bc}	0.38^{ab}	0.88^{a}	0.36^{ab}	0.47^{cd}	0.17^{bcd}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	0.93^{bc}	0.32^{cd}	0.80^{c}	0.33^{ab}	0.62^{a}	0.22^{a}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	1.08^{ab}	0.36^{abc}	0.80^{c}	0.34^{ab}	0.57^{ab}	0.21^{ab}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	0.95^{bc}	0.31^{de}	0.81^{bc}	0.31^{b}	0.59^{ab}	0.22^{a}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

4.9.2 Total soluble solids (TSS)

Perusal of the data in Table 40 showed that there was significant difference in total soluble sugars of tomato due to different treatment applications. Significantly highest TSS value (5.93 ^{0}B) was noticed in STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_{12}) and lowest significant TSS (4.20 ^{0}B) was noticed in T_1, absolute control.

4.9.3 Titratable acidity

From examining the data in Table 40, it is clear that there was significant difference in titratable acidity of tomato due to various levels of fertilizer application. Significantly highest titratable acidity (1.31 %) was noticed in STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (T_{10}) and significantly lowest titratable acidity (0.55 %) was observed in absolute control (T_1).

4.9.4 Ascorbic acid content

Persual of the data in Table 40 revealed that there was significant difference in ascorbic acid content of tomato due to different treatment application. Significantly highest ascorbic acid content (18.34 mg 100 g^{-1} fruit) was noticed in STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} (T_8) and significantly lowest ascorbic content (12.43 mg 100 g^{-1} fruit) was seen in absolute control (T_1).

4.10 Correlation studies

The correlation studies between yield contributing factors and fruit yield were done based on data obtained from the experiment.

4.10.1 Correlation between nutrient uptake and tomato fruit yield

Linear correlation was worked out and is presented in Table 41. Nitrogen and magnesium were significantly and positively correlated with fruit yield with $r = 0.621^*$ and $r = 0.736^{**}$ respectively.

Inter correlation was also studied among the uptake of soil nutrients. The inter correlation of nutrients *viz.*, nitrogen, phosphorus, sulfur, copper, boron and zinc were

Table 40: Influence of different treatments on total soluble solids (TSS ^{0}B), titratable acidity (%) and ascorbic acid content (mg 100g^{-1}) of tomato fruit

Treatment	TSS (^{0}B)	Titratable acidity (%)	Ascorbic acid (mg100g^{-1})
T_1: Absolute control	4.20^{g}	0.55^{f}	12.43^{f}
T_2: Soil test based POP of KAU	4.30^{g}	0.64^{e}	12.49^{f}
T_3: STCR + IPNS for target 25 t ha^{-1}	4.36^{fg}	0.81^{d}	15.21^{de}
T_4: STCR + IPNS for target 30 t ha^{-1}	4.80^{ef}	1.02^{c}	16.23^{bcd}
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	5.00^{cde}	1.02^{c}	16.79^{abc}
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	5.06^{cde}	1.02^{c}	16.62^{bcd}
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	5.35^{bcd}	1.22^{b}	16.62^{bcd}
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	5.60^{ab}	1.28^{ab}	18.34^{a}
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	4.90^{de}	1.02^{c}	16.27^{bcd}
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	5.45^{abc}	1.31^{a}	16.84^{abc}
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	5.63^{ab}	1.02^{c}	16.27^{bcd}
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	5.93^{a}	1.28^{ab}	17.73^{ab}

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

found to be positive and significant effect. Among the nutrients, nitrogen is positively correlated with sulfur (r = 0.609*), copper (r = 0.603*) and with boron (r = 0.792**). Phosphorus had significant and positive correlation with sulfur (r = 0.643*) and copper (r = 0.780**). The sulfur content was positively and significantly correlated with zinc (r = 0.645*), copper (r = 0.663*) and boron (r = 0.667*).

4.10.2 Correlation between soil nutrients and fruit yield

The correlation of various soil nutrients at harvest stage with fruit yield were worked out. The results are presented in Table 48. A positive and significant correlation was found with available magnesium (r = 0.715**) and available zinc (r = 0.606*).

A positive and significant inter correlation was noticed between nitrogen and manganese (r = 0.651*) and iron and copper (r = 0.624*). There was no correlation found among soil nutrients *viz*., P, K, Ca, Mg, S, Zn and B.

4.10.3 Correlation between plant nutrient content and fruit yield

Perusal of data given in Table 43 shows that nitrogen and magnesium content had significant and positive correlation with fruit yield. There was no significant correlation with other nutrients like phosphorus, potassium and micronutrients. Significantly positive correlation was noticed between nitrogen (r = 0.621*) and magnesium (r = 0.736**).

Inter correlation among different plant nutrients were also studied. Significant and positive correlation was found among N, P, S, Zn, Cu and B. Significantly highest inter correlation was found between nitrogen and boron (r = 0.792**). The other positive and significant correlations noticed were between N and S (r = 0.609*) N and Cu (r = 0.603*), P and S (r = 0.643*), P and Cu (r = 0.780**), S and Cu (r = 0.663*), S and Zn (r = 0.645*) and S and B (r = 0.667*).

Table 41: Correlation coefficient of uptake of nutrients with yield

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Yield
N		0.427	-0.13	0.041	0.205	0.609*	-0.184	-0.023	0.123	0.603*	0.792**	0.621*
P			0.085	0.213	-0.091	0.643*	0.305	0.216	0.508	0.780**	0.529	0.256
K				0.024	0.441	0.092	0.248	0.268	0.394	0.386	-0.056	0.324
Ca					0.249	0.404	0.177	0.538	0.202	0.054	0.261	0.419
Mg						0.387	0.162	0.428	0.313	0.239	0.318	0.736**
S							0.13	0.523	0.645*	0.663*	0.667*	0.575
Fe								0.433	0.253	0.061	-0.112	0.36
Mn									0.379	0.249	0.222	0.48
Zn										0.474	0.369	0.238
Cu											0.519	0.493
B												0.572
Yield												

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 42: Correlation coefficient of soil nutrients with yield

	Yield	pH	EC	OC	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
Yield		-0.065	0.714**	0.552	0.372	0.293	0.32	0.555	0.715**	0.539	0.307	0.543	0.606*	0.424	0.535
pH			-0.148	-0.074	0.02	-0.317	0.162	-0.147	0.487	0.222	-0.049	0.098	0.027	-0.194	-0.614*
EC				0.555	0.521	0.564	0.461	0.328	0.377	0.525	0.135	0.829**	0.41	0.126	0.375
OC					0.23	0.434	-0.373	0.072	0.498	0.258	0.124	0.487	0.374	0.352	0.304
N						-0.039	0.523	0.18	0.283	0.117	-0.044	0.651*	0.444	0.38	-0.005
P							-0.043	0.311	-0.004	0.148	0.169	0.409	0.204	0.006	0.234
K								0.388	0.155	0.239	-0.01	0.419	0.296	-0.182	-0.006
Ca									0.444	0.335	0.435	0.065	0.57	0.228	0.314
Mg										0.566	0.168	0.453	0.364	0.332	0.104
S											0.397	0.319	0.27	0.196	0.116
Fe												-0.065	0.522	0.624*	0.505
Mn													0.144	0.223	0.208
Zn														0.347	0.197
Cu															0.531
B															

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 43: Correlation coefficient of plant nutrients with yield

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Yield
N		0.427	-0.13	0.041	0.205	0.609*	-0.184	-0.023	0.123	0.603*	0.792**	0.621*
P			0.085	0.213	-0.091	0.643*	0.305	0.216	0.508	0.780**	0.529	0.256
K				0.024	0.441	0.092	0.248	0.268	0.394	0.386	-0.056	0.324
Ca					0.249	0.404	0.177	0.538	0.202	0.054	0.261	0.419
Mg						0.387	0.162	0.428	0.313	0.239	0.318	0.736**
S							0.13	0.523	0.645*	0.663*	0.667*	0.575
Fe								0.433	0.253	0.061	-0.112	0.36
Mn									0.379	0.249	0.222	0.48
Zn										0.474	0.369	0.238
Cu											0.519	0.493
B												0.572
Yield												

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.10.4 Correlation between nutrient content in fruit and fruit yield

The correlation between nutrient content of fruit and yield was studied and perusal data is presented in Table 44. Significant and positive correlation was noticed only in total phosphorus content ($r = 0.745^{**}$).

Correlation among nutrient contents in fruit was studied by using the data on different treatments. Correlation was found to be positive and significant among various nutrients. Highest significant and positive correlation was noticed between Zn and Cu ($r = 0.790^{**}$) followed by Mg and Cu ($r = 0.786^{**}$). Other correlations recorded are between N and Mg ($r = 0.625^{*}$), P and S ($r = 0.753^{**}$), Ca and Mg ($r = 0.758^{**}$), Ca and Mn ($r = 0.732^{**}$), Mg and Mn ($r = 0.778^{**}$), Mg and Zn ($r = 0.709^{**}$), Mn and Cu ($r = 0.674^{*}$) and between Mn and Zn ($r = 0.577^{*}$).

4.10.5 Correlation between uptake of nutrients and chlorophyll content

Simple correlation coefficients were worked out for uptake of nutrients and chlorophyll content (Table 45). Nitrogen and magnesium uptake were significantly and positively correlated with chlorophyll a content with $r = 0.873^{**}$ and $r = 0.937^{**}$ respectively. Chlorophyll b content was significantly and positively correlated with nitrogen ($r = 0.679^{*}$) and magnesium ($r = 0.633^{*}$).

4.10.6 Correlation between uptake of nutrients and titratable acidity

The correlation between nutrient uptake and titratable acidity was studied and perusal data is presented in Table 46. Significant and positive correlation was noticed only between titratable acidity and uptake of P ($r = 0.637^{*}$) and Mg ($r = 0.731^{**}$).

4.10.7 Correlation between uptake of nutrients and ascorbic acid content

Simple correlation coefficients were worked out for uptake of nutrients and ascorbic acid content (Table 47). The results revealed that ascorbic acid was positively and significantly correlated with nitrogen ($r = 0.813^{**}$), phosphorus ($r = 0.841^{**}$), potassium ($r = 0.915^{**}$), calcium ($r = 0.830^{**}$), magnesium ($r = 0.868^{**}$), sulfur ($r = 0.895^{**}$), iron ($r = 0.698^{*}$), manganese ($r = 0.803^{**}$), zinc ($r = 0.879^{**}$) and copper ($r = 0.946^{**}$).

Table 44: Correlation between nutrient content of fruit and yield

	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Yield
N		0.519	0.264	0.452	0.625*	0.531	-0.224	0.492	0.364	0.374	0.396	0.358
P			0.386	0.363	0.468	0.753**	0.163	0.265	0.494	0.357	0.33	0.745**
K				0.496	0.526	0.062	0.098	0.402	0.516	0.363	-0.122	0.443
Ca					0.758**	0.2	0.14	0.732**	0.32	0.429	0.549	0.403
Mg						0.392	0.066	0.778**	0.709**	0.786**	0.325	0.563
S							-0.104	0.478	0.442	0.476	0.56	0.498
Fe								0.01	-0.189	-0.274	-0.33	0.302
Mn									0.577*	0.674*	0.505	0.3
Zn										0.790**	0.108	0.468
Cu											0.408	0.381
B												0.049
Yield												

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 45: Correlation between uptake of N and Mg with chlorophyll content

	N	Mg	chl.a	chl.b
N	1	0.931**	0.873**	0.679*
Mg		1	0.937**	0.633*
chl.a			1	0.640*
chl.b				1

*. Correlation is significant at 0.05 level (2-tailed)

**. Correlation is significant at 0.01 level (2-tailed)

Table 46: Correlation between titratable acidity and macronutrients

	Titratable acidity	N	P	K	Mg
Titratable acidity	1	0.381	0.637*	0.487	0.731**
N		1	0.519	0.264	0.625*
P			1	0.386	0.468
K				1	0.526
Mg					1

*. Correlation is significant at 0.05 level (2-tailed)

**. Correlation is significant at 0.01 level (2-tailed)

4.10.8 Correlation between uptake of nutrient and TSS

There was positive and significant correlation noted between uptake of phosphorus and TSS of fruits ($r = 0.598^*$) (Table 48).

4.10.9 Correlation between plant nutrients and days to flowering

The correlation between plant nutrients and days to flowering was studied and data is presented in Table 49. Significant and positive correlation was noticed only between days to flowering and P content ($r = 0.748^{**}$).

4.11 Magnesium response curve

Response curve was fitted to determine the optimum level of magnesium to realize maximum yield response. Yield response from eight fertilizer treatments each comprising of different levels of magnesium was used to generate response curve. A total of 36 design points, utilizing replication wise yield data was used.

The true functional form that captures variability in yield as affected by application of different combinations of nutrients was made by fitting a suitable equation to the data. The model which explained profusely the variations in the yield as observed from the good R^2 value was considered as the best fit.

The best fit model is,

$$Y = 1.342 + 0.00967\ Mg - 0.000046\ Mg * Mg$$

$$R^2 = 0.5598$$

The optimal fertilizer dose was calculated by equating the partial derivative of yield and magnesium to zero.

$$dY/dMg = 0.00967 - 0.000046\ Mg = 0$$

Optimum dose of magnesium sulfate = 105.10 kg ha^{-1}.

4.12 Economics of cultivation

Analysis of Benefit: Cost ratio of different treatments is given in Table 46. This has been calculated to evaluate the economics of field experiment in tomato. The higher gross returns (Table 50) was recorded in treatment, T_8 *i.e.* STCR + IPNS for

Table 47: Correlation between ascorbic acid and nutrient content of fruit

	Ascorbic acid
Ascorbic acid	1
N	0.813**
P	0.841**
K	0.915**
Ca	0.830**
Mg	0.868**
S	0.895**
Fe	0.698*
Mn	0.803**
Zn	0.879**
Cu	0.946**
B	0.447

*. Correlation is significant at 0.05 level (2-tailed)

**. Correlation is significant at 0.01 level (2-tailed)

Table 48: Correlation between TSS and major nutrients

	TSS	N	P	K
TSS	1	0.598*	0.022	-0.039
N		1	0.427	-0.13
P			1	0.085
K				1

*. Correlation is significant at 0.05 level (2-tailed)

**. Correlation is significant at 0.01 level (2-tailed)

Table 49: Correlation between days to flowering and plant nutrients

	Days to flowering	N	P	K
Days to flowering	1	0.324	0.748**	0.17
N		1	0.427	-0.13
P			1	0.085
K				1

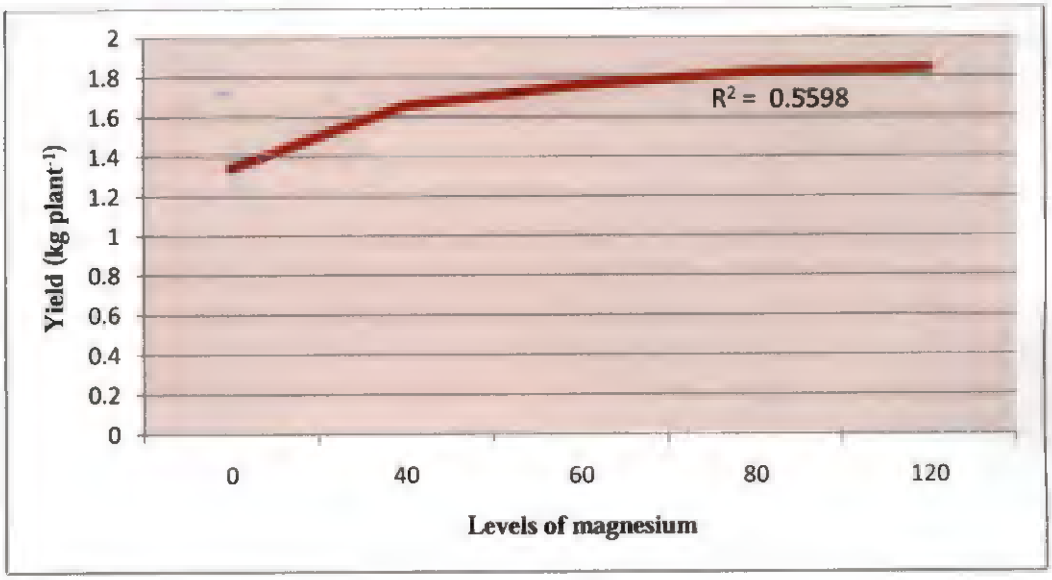
*. Correlation is significant at 0.05 level (2-tailed)

**. Correlation is significant at 0.01 level (2-tailed)

Fig 1: Magnesium response curve

$Y = 1.342 + 0.00967\ Mg - 0.000046\ Mg*Mg$

$R^2 = 0.5598$



target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} followed by T_{11}, STCR + IPNS for target 30 t ha^{-1}+ $MgSO_4$ @ 80 kg ha^{-1}. The lowest gross returns were recorded in T_1, absolute control.

The highest B: C ratio of 3.09 was recorded in treatment, T_8 which received STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ @ 120 kg ha^{-1} and it was followed by T_{11}, STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ @ 60 kg ha^{-1} (2.91). The lowest B: C (1.98) was observed in the treatment, absolute control (T_1).

Table 50: Effect of different treatments on Benefit: Cost ratio

Treatment	Total cost of cultivation (ha^{-1})	Gross returns (ha^{-1})	Net returns (ha^{-1})	B: C
	(Rs in lakhs)			
T_1: Absolute control	0.90	1.78	0.88	1.98
T_2: Soil test based POP of KAU	1.0	2.35	1.32	2.28
T_3: STCR + IPNS for target 25 t ha^{-1}	1.19	3.26	2.06	2.72
T_4: STCR + IPNS for target 30 t ha^{-1}	1.23	3.27	2.03	2.64
T_5: T_3 + $MgSO_4$ at 40 kg ha^{-1}	1.20	3.46	2.25	2.87
T_6: T_3 + $MgSO_4$ at 60 kg ha^{-1}	1.20	3.47	2.26	2.87
T_7: T_3 + $MgSO_4$ at 80 kg ha^{-1}	1.21	3.46	2.25	2.86
T_8: T_3 + $MgSO_4$ at 120 kg ha^{-1}	1.21	3.77	2.55	3.09
T_9: T_4 + $MgSO_4$ at 40 kg ha^{-1}	1.24	3.37	2.12	2.70
T_{10}: T_4 + $MgSO_4$ at 60 kg ha^{-1}	1.24	3.52	2.27	2.81
T_{11}: T_4 + $MgSO_4$ at 80 kg ha^{-1}	1.25	3.65	2.40	2.91
T_{12}: T_4 + $MgSO_4$ at 120 kg ha^{-1}	1.26	3.66	2.39	2.90

STCR – Soil test crop response correlation studies, IPNS – Integrated plant nutrient system, POP – Package of Practices recommendations

Discussion

5. DISCUSSION

Improving soil fertility for enhancing and sustaining agricultural production is of utmost importance for India's food and nutritional security. In order to meet the food requirement for growing population, India requires about 7 – 9 m t of additional food grains every year. Considering the need for enhanced productivity in order to attainfood security for the growing population, it is necessary to reconsider the fertilizer recommendations made earlier. This can be attained by adopting ecologically and economically sound management strategies like Soil Test Crop Response based Integrated Plant Nutrition System (STCR-IPNS) for ensuring balanced nutrition, soil health and sustained crop productivity.

The results of the research project entitled "Soil test based fertilizer prescription for tomato *(Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala", conducted in STCR plot at College of Horticulture, Vellanikkara presented in previous chapter are discussed here in the light of the studies conducted elsewhere based on the available literature.

5.1 Effect of different levels of fertilizers on growth and yield parameters of tomato

5.1.1 Growth parameters

5.1.1.1 Plant height

Significantly highest plant height was noticed at 30 DATand 60 DAT (33.86 and 60.80 cm respectively)in the treatment, STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 80 kg ha^{-1} (T_7). At 90 DAT, highest plant height (75.26 cm) was noticed in treatment that received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_{12}) (Fig. 2). Lowest plant height (59.80 cm) was seen in absolute control. The increased plant height might be due to increased fertilizer application of nitrogen,which in turn attributed to the increased physiological processes in crop plants and better utilization of nutrients which resulted in highest plant height. These results are in conformity with Patel *et al*. (2006); Kumar *et al*. (2007) and Santhosha (2013). The integrated use of organic and inorganic fertilizers helped in improving the crop growth and development because of better root development and translocation of photosynthates bringing about good plant development. The comparable works likewise were detailed by Khan *et al.* (2010) and Maurya *et al.* (2014) in wheat crop.

5.1.1.2 Days to flowering

Number of days taken for flowering in different treatments varied from 26.93 to 31.86 days (Fig. 3). The reason behind this isapplication of fertilizerspromoted vegetative growth hence the reproductive growth or flowering is delayed in tomato (Hozhbryan, 2013 and Taber, 2001). The significant and positive correlation between days to flowering and application of phosphorus ($r = 0.748^{**}$) further support the above conclusion.

5.1.2 Yield attributes of tomato crop

5.1.2.1 Number of fruits per plant

Number of fruits per plant was found to be significantly different among the different treatmentsimposed (Fig. 4). Significantly highest number of fruits per plant (79.66) was noticed in the treatment that received STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8). The nutrients supplied (N, P, K and Mg) through this treatment were adequate and balanced for optimum yield (Lamina, 2009). Magnesium is an important constituent of chlorophyll, cell wall and membrane integrity, activators of enzymes, enhancing pollen germination and growth, which in turn increases carbohydrate synthesis (Epstein, 1961 and Morarad *et al.,* 1999). Magnesium deficiency may cause abscission of flowers. The increase in number of fruits may be due to sufficient carbohydrate availability (Davis *et al.*, 2003). The lowest number of fruits (32.00) was noticed in absolute control (T_1).

5.1.2.2 Yield

Crop yield showed significant difference among different treatments (Fig. 5). Significantly highest yield (37.75 t ha^{-1}) was noticed in STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8) and lowest yield were noted in absolute control (T_1).

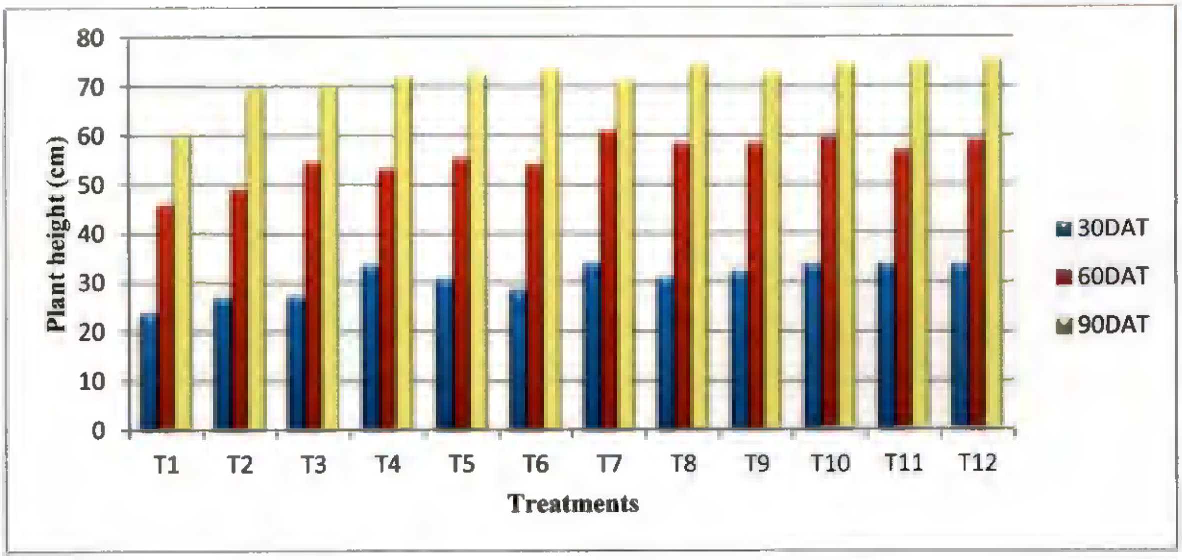


Fig. 2 Effect of different treatments on plant height at different intervals

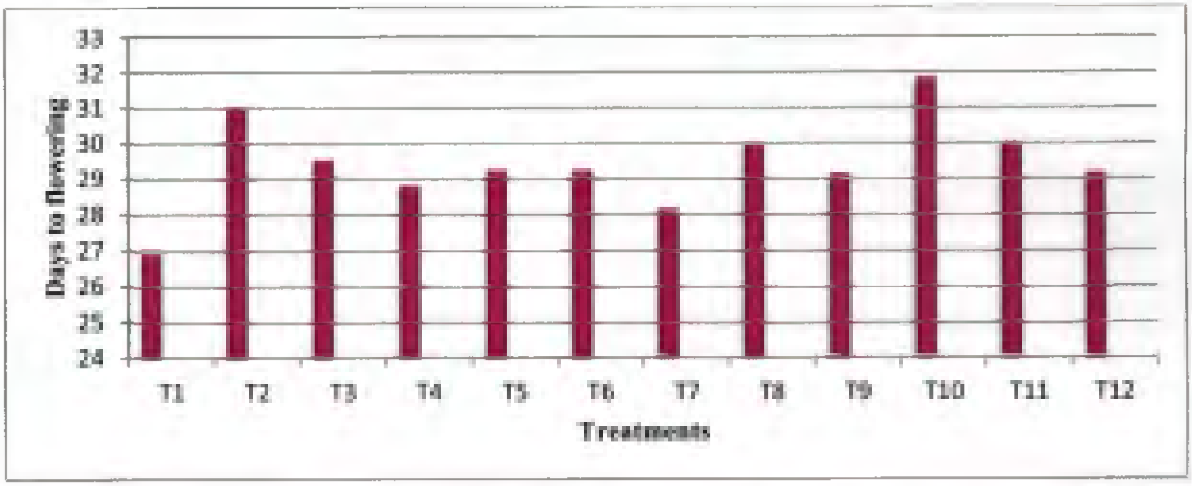


Fig. 3 Effect of different treatments on number of days to flowering

T_1	:	Absolute control
T_2	:	Soil test based POP of KAU
T_3	:	STCR+IPNS for target 25t ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}
T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

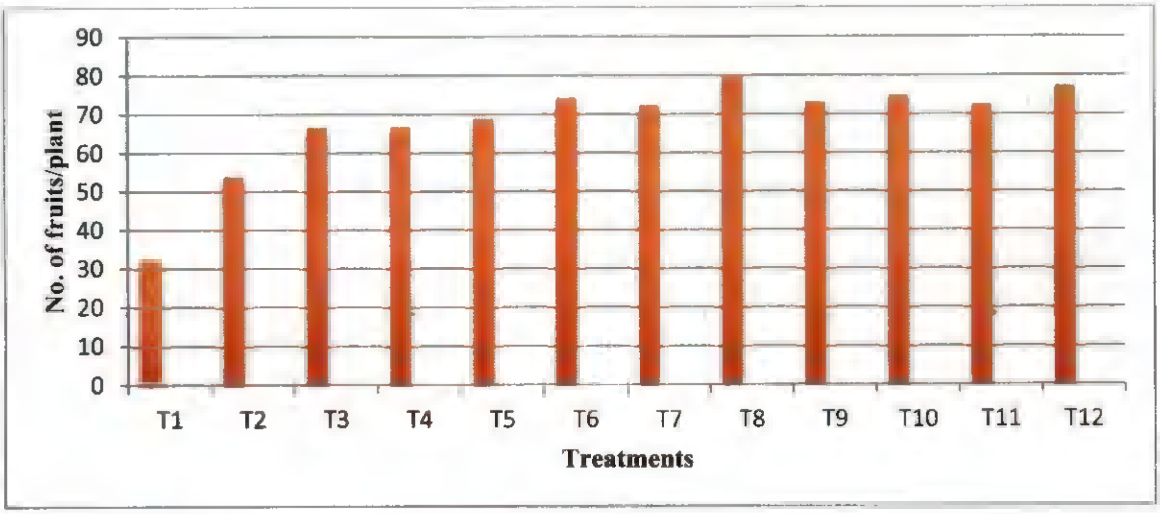


Fig. 4 Effect of different treatments on number of fruits per plant

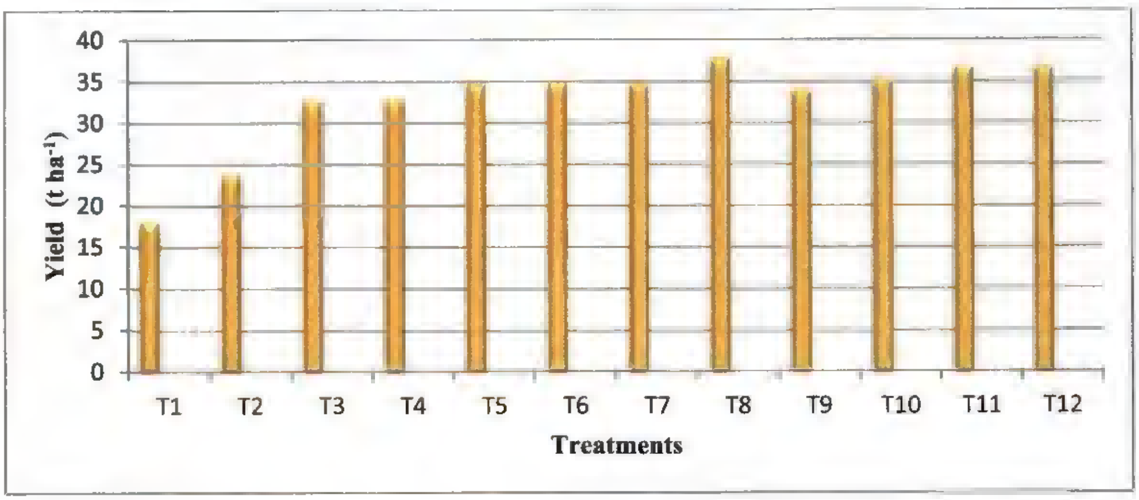


Fig. 5 Effect of different treatments on yield of tomato

T_1	:	Absolute control	T_7	:	T_3+MgSO_4 @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+MgSO_4 @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+MgSO_4 @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+MgSO_4 @ 60 kg ha^{-1}
T_5	:	T_3+MgSO_4 @ 40 kg ha^{-1}	T_{11}	:	T_4+MgSO_4 @ 80 kg ha^{-1}
T_6	:	T_3+MgSO_4 @ 60 kg ha^{-1}	T_{12}	:	T_4+MgSO_4 @ 120 kg ha^{-1}

Increased fruit yield associated with added nitrogen, phosphorus and potassium fertilizers along with magnesium sulfate had enhanced the cumulative effect of increased translocation of photosynthates to sink resulting in enhanced level of yield components. These results corroborated the findings of Rao *et al.* (2004). In general tomato yield was found to be significantly higherin plots treated with magnesium sulfate as compared to control plots. This is due to the fact that magnesium is the essential nutrient for growth and yield of the plants and activator of enzymes. It is also involved in the process of photosynthesis and therefore enhanced the production (Jones, 1999). Final yield depends on many factors *viz.*, nutrient uptake, number of fruits per plant and fruit weight. As magnesium application resulted in enhancementof all these parameters, yield also increased. This was in accordance with Kashinath *et al.* (2013) in tomato. The significant and positive relationship of fruit yield with magnesium ($r = 0.736^{**}$) and nitrogen (0.621^{*}) confirms the above conclusion.

5.2 Influence of different levels of fertilizers on soil properties

5.2.1 Effect of different levels of fertilizers on soil properties

The different levels of fertilizer application have resulted in the changes of properties of soil after harvest of tomato.

5.2.1.1 Soil pH, electrical conductivity and soil organic carbon

There was no significant difference noticed with respect to post harvest soil pH among different treatments. However the pH values were lower compared to initial soil test value. This is due to the fact that addition of nitrogenous fertilizers producedacidifying effect in soil (Chawla and Chhabra, 1991) and also the decomposition of organic matter has been known to release of organic and inorganic acids with concomitant increase in soil acidity (Agbede, 2009).

A significant difference in electrical conductivity of soil was noticed due to incorporation of various levels of organic manures. The plots which got STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} had generally higher EC values than control plot. This is because of the addition of muriate of potash (192.78 kg ha^{-1})

which increased the salt concentration in the soil. Comparable discoveries were accounted by Shaaban *et al.* (2011) in clay loam soil. And furthermore, release of solvent salts from FYM upon decomposition brought about higher EC values. These results were in conformity with the findings of Chawla and Chhabra (1991).

No significant difference was noted in the soil organic carbon content due to various treatments imposed. The addition of nitrogen, phosphorus and potassium along with magnesium and FYM increased the content of organic carbon in the soil compared to absolute control plots (T_1). Increase in organic carbon mightbe attributed to increased crop growth and addition of biomass to the soil by roots and crop residues and also due to incorporation of FYM into the soil. This is in similarity with the reports of Swarup and Yaduvanshi (2000). Nalatwadmath *et al.* (2006) noticed that organic carbon content of soil after four years increased significantly when sorghum + dolichos were incorporated into the soil as compared to sorghum interculture (3.6 g kg^{-1}) and increase in organic carbon was due to addition of organic materials and root biomass to soil.

5.2.1.2 Available nitrogen, phosphorus and potassium

Available nitrogen content of the soil did not show critical variance between the treatmentsdue to different levels of fertilizer application (Fig. 5). Highest available nitrogen content was observed in the treatment, STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 60 kg ha^{-1} (180.71 kg N ha^{-1}), followed by STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} and STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 60 kg ha^{-1}. In general, highest available nitrogen content was observed in treatment with IPNS at different targets. Lowestcontent(132.21 kg N ha^{-1}) of available nitrogen was recorded in absolute control (T_1). The reason behind this is increased organic matter content because of combined application of farm yard manure and nitrogenous fertilizers. Similar results were observed by Bandyopadhay and Puste (2002) and Prakash *et al.* (2002). In corroboration with the present study, Praveena *et al.* (2014)

and Santhosha (2013), reported that the treatmentsreceiving relatively higher doses of fertilizers at higher yield targets resulted in increasein available NPK status of soil.

Significantly highest available phosphorus was noticed in T_3 (53.05 kg ha^{-1}), STCR + IPNS for target 25 t ha^{-1} followed by T_{12} (45.44 kg ha^{-1}). Lowest available P content was noticed in absolute control (T_1, 33.91 kg ha^{-1}) (Fig. 6). In general phosphorus applied plots showed more amount of available phosphorus compared to initial P. However, lower availability of phosphorus was noticed wherephosphorus was not applied. This noteworthy variation in available phosphorus may be due to increased availabilityof P occurred due to fertilizer application in field.In addition to that, solubilization of soil P by organic acids which is produced during decomposition or mineralization of added farm yard manure. The synergetic effect of potassium also contributed to the availability of phosphorus in soils after harvest of tomato. Similar results were observed by Ramachandrappa *et al.* (2014).

The increase in the potassium content after harvest of tomato in plot with IPNS is due to immediate release of potassium to the available potassium pool in soil due to addition of farm yard manure and high dose of potassium (Apoorva, 2008). Rangaraj *et al.* (2007) had also confirmed that the addition of organics could result in increased availability of potassium.There is possible retention of the added potassium by the soil colloids in the exchangeable form (Subbarao and Brar, 2002). The higher status of potassium might be due to addition of FYM to soil which increased the nutrient availability to crop due to their direct addition particularly as soluble fertilizers and also due to chelation of these nutrients by FYM, thereby ensuring their availability for longer period. Similar results were observed by Shashi (2003); Manasa (2013) and Elayarajan *et al.* (2015).

5.2.1.3 Available calcium, magnesium and sulfur content of soil

The available calcium content in soil did not show any significant difference at different targets and different levels of fertilizer application (Fig. 7). The available calcium varied from 118.40 (absolute control) to 173.60 mg kg^{-1} (STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 120kg ha^{-1}) (Fig. 6). Highest calcium content is due to continuous application of NPK fertilizers with FYM. Comparative outcomes were noted by Santhosha (2013). Release of calcium during mineralization process and retention of calcium due to incorporation of organic matter might have additionally increased Ca concentration in soil (Shashi, 2003).

The available magnesium showed significant difference among treatments due to addition of different doses of magnesium fertilizers to soil (Fig. 7). The significantly highest soil available magnesium (32.64 mg kg^{-1}) was found in treatments that received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_{12}) and STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 80 kg ha^{-1} (T_7). However, there was slight increase in magnesium content in all the treatments compared to the initial value (23.26 mg kg^{-1}). Higher magnesium could be attributed to the application of $MgSO_4$ which contains 19.8 per cent of Mg resulting in increased soil magnesium and also due to incorporation of farm yard manure, which resulted in release of magnesium during mineralization process. These results were supported by the findings of Shashi (2003).

The available sulfur showed significant difference among the treatments. Significantly highest available sulfur (35.30 mg kg^{-1}) was recorded in the treatment, STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 80 kg ha^{-1} followed by STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1}. The increase in available sulfur content in soil after harvest of tomato was due to addition of S (27.2 %) through $MgSO_4$. Similar results were reported by Singh *et al.* (1999), Shashi (2003), Apoorva (2008), Sunitha (2008), and Santhosha (2013). In addition, the synergistic relationship between phosphorus and sulfur had also resulted in increased sulfur content with increased dose of phosphorus fertilizers (Thiyagarajan, 1998). The NPK fertilizers along with FYM recorded highest available sulfur, where FYM application directly added sulfur to the soil available pool. Similar type of results was confirmed by Intidia and Sahu (1999), Poongothai *et al.* (1999) and Trivedi *et al.* (2000)

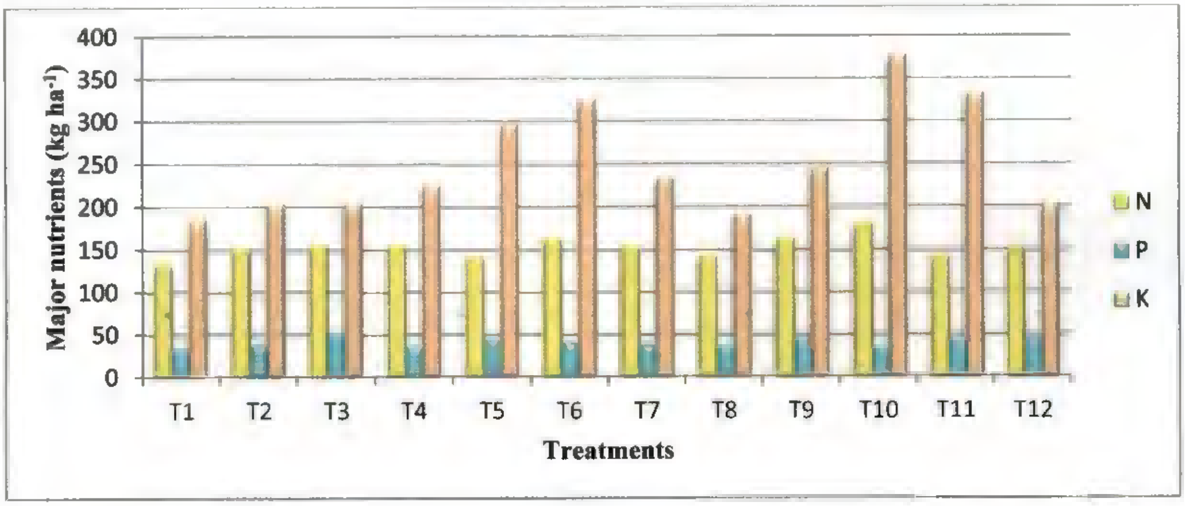


Fig. 6 Effect of different treatments on major nutrients in soil

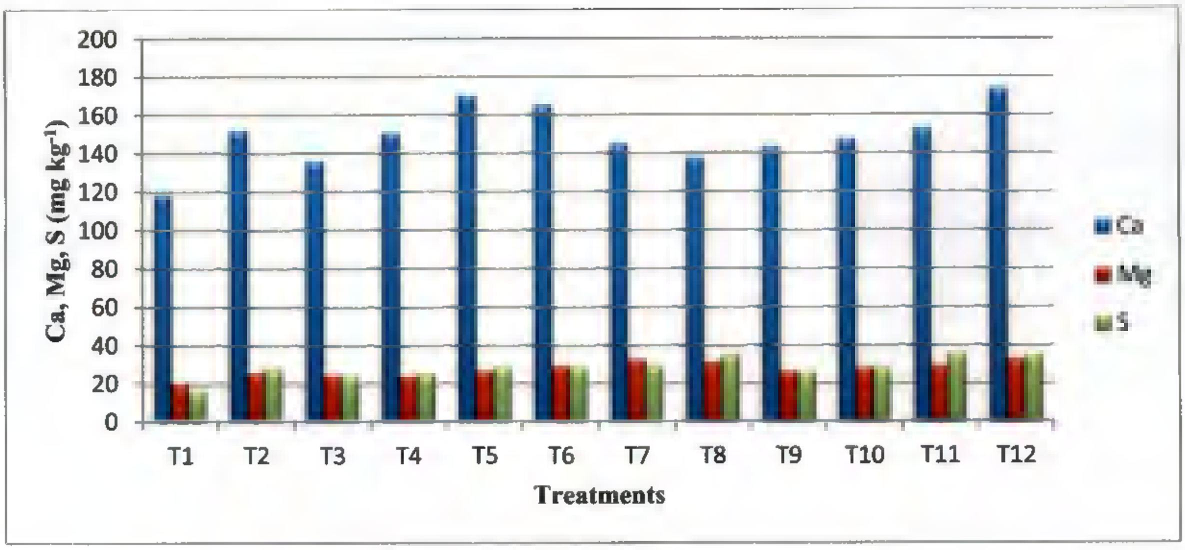


Fig. 7 Effect of different treatments on secondary nutrients in soil

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

5.2.1.4 Available micronutrients (Fe, Mn, Zn, Cu and B)

The content of micronutrients did not show significant difference among treatments by the application of different levels of fertilizers except for manganese and zinc. The micronutrient status of soil increased after the harvest of tomato crop compared to initial soil test values (Fig. 8). The micronutrients *i.e.* Fe, Mn, Zn, Cu and B ranged from 11.16 to 16.47 mg kg^{-1}, 42.37 to 76.37 mg kg^{-1}, 4.57 to 8.06 mg kg^{-1}, 7.83 to 13.19 mg kg^{-1} and 0.42 to 0.54 mg kg^{-1} respectively. The increased micronutrient status of soil after the harvest of tomato is due to incorporationof FYM, which releases micronutrients to soil during mineralization process. The available Fe was emphatically related with organic matter and available phosphorus (Xiaorong *et al.*, 2006 and Malhi *et al.*, 1998). Kumar and Babel (2011) detailed that the availability of micronutrients content increased significantly with increase in organic matter content of soil and reduced with increase in soil pH.

The increased boroncontent at higher doses of N, P or K is due to addition of boron through the incorporation of FYM as well as through root residues where highest plant growth and yield were recorded. Similar findings were reported by Saqueebulla (2014) who noticed highly significant positive correlation between organic matter and hot water soluble boron.

5.3 Effect of different levels of fertilizers on nutrient content and uptake

5.3.1 Nutrient concentration in tomato fruit

The content of nutrient in the fruit is considered to be an important quality criterion, since it ultimately determines the quantity of nutrients consumed by the human being. With the recent awareness about nutritional security, thisaspect gains much importance.

Nutrient content in tomato fruit differed significantly for all nutrients except nitrogen and phosphorus (Figs. 12, 13 and 14). Significantly highest potassium content (2.80 %) was noted in T_6. Significantly highest calcium (0.18 %) and manganese (32.93 mg kg^{-1}) was observed in T_8. The highest sulfur content (1.00 %), Mg (0.17 %), Zn (48.83 mg kg^{-1}), Cu (12.83 mg kg^{-1}) and Bcontent (13.54 mg kg^{-1}) was observed in T_9 and significantly highest iron content (96.63 mg kg^{-1}) wererecorded in T_8. The higher amount of nitrogen, phosphorus, potassium, sulfur along with magnesium is conducive for extensive root proliferation, to explore a greater volume of soil and absorb larger quantities of nutrients that often tend to correlate positively with dry matter production and concentration of nutrients in the plant under higher level of nutrient supply. Similar findings were recorded by Rao *et al.* (2014). Significant and positive correlation observed between N and Mg ($r = 0.625^{*}$), P and S ($r = 0.753^{**}$), Mg and Mn ($r = 0.778^{**}$), Mg and Zn ($r = 0.709^{**}$) and Mg and Cu ($r = 0.786^{**}$) content of fruit further supports the above conclusion.

Somani and Saxena (1971) had reviewed that the plant nutrient concentration depended on the root surface and high phytase and nucleosidase activity provided at the rhizosphere by the organic manure addition which resulted in better absorption of nutrients by crops and thus increased its concentration.

5.3.2 Effect of different fertilizers on uptake of nutrients by tomato

In the present investigation, it is clear that the uptake of nutrients was increased due to the addition of organic and inorganic fertilizers.

5.3.2.1 Uptake of N, P and K nutrients by tomato

Total uptake of nitrogen (185.19 kg ha^{-1}) by tomato was highest in the treatment, STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8) (Fig. 15). This is due to improved utilization of applied nitrogen in the presence of sufficient inorganic P and K fertilizers and FYM. Similar positive interaction between N and K was also reported by Thippeswamy (1995) who reported that the uptake of N and K was found to increase significantly with the increased levels of K application in finger millet. Similarly FYM enhanced available N, through mineralization process and also increased the efficiency of applied N. The mineralization process further builds up the efficiency of applied nitrogen. The higher uptake of nitrogen was noted at increased

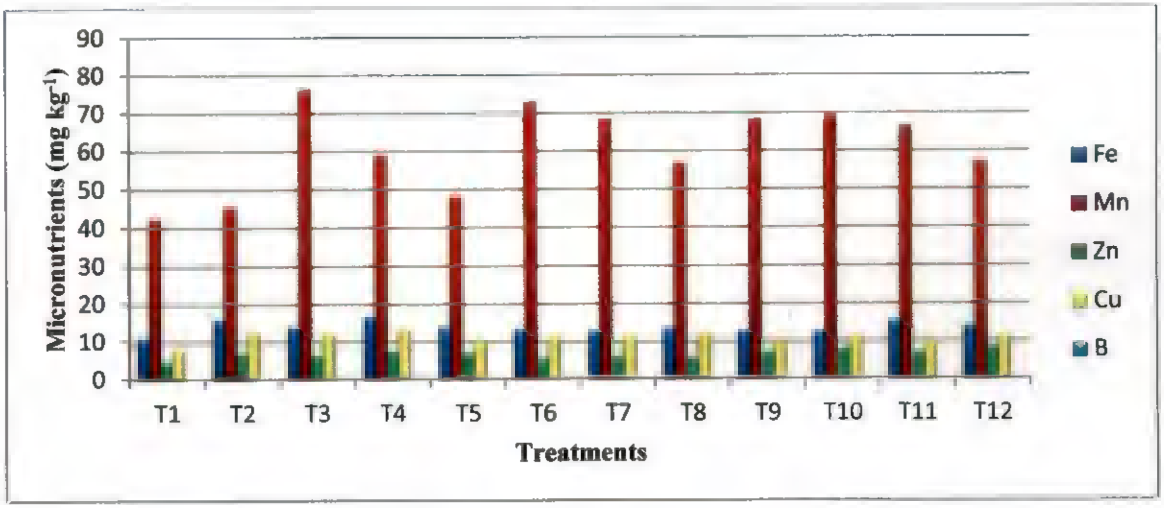


Fig. 8 Effect of different treatments on soil micronutrient status

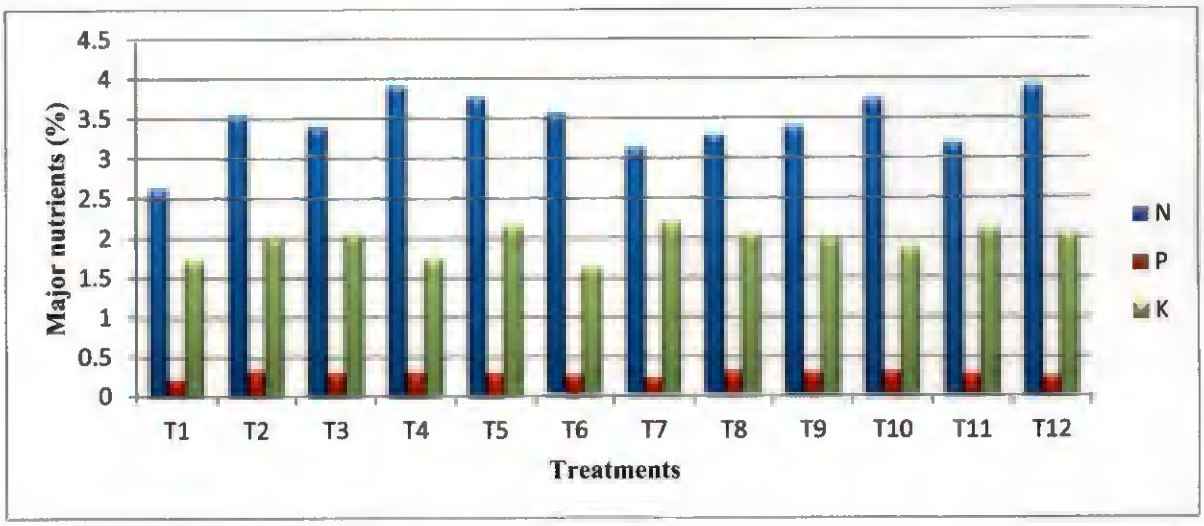


Fig. 9 Effect of different treatments on major nutrients in plant

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

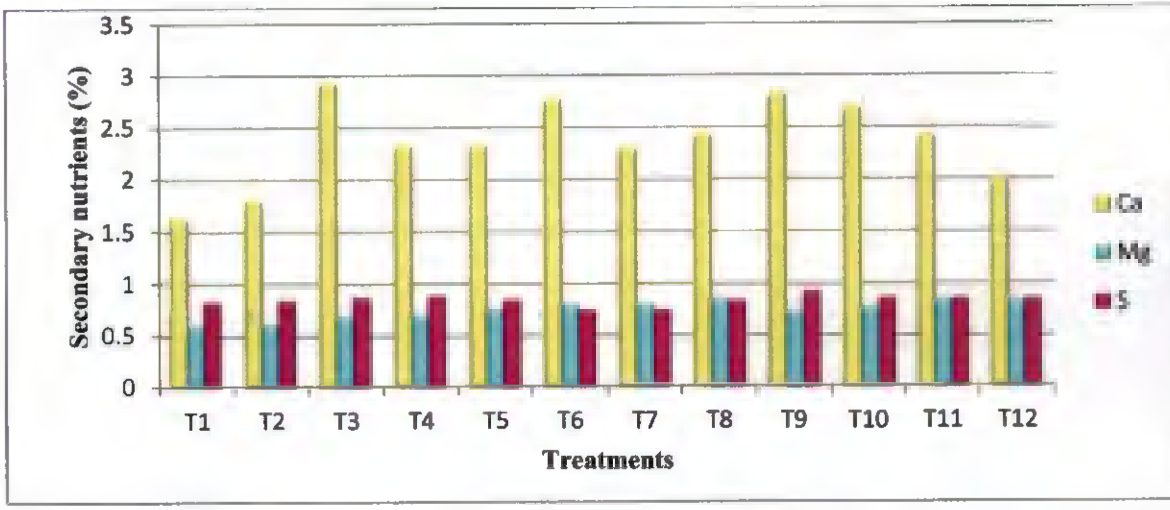


Fig. 10 Effect of different treatments on secondary nutrient in plant

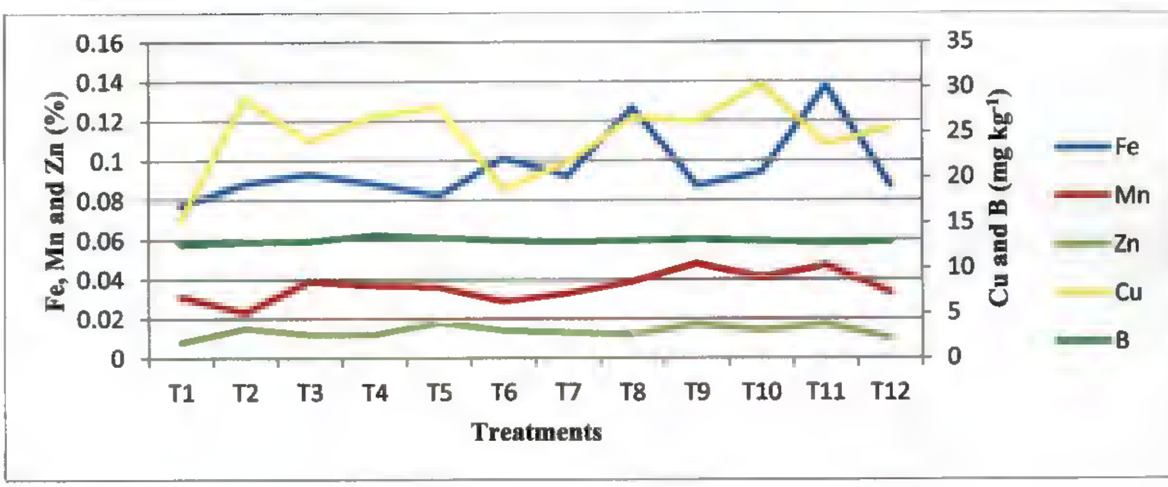


Fig.11 Effect of different treatments on micronutrient in plant

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

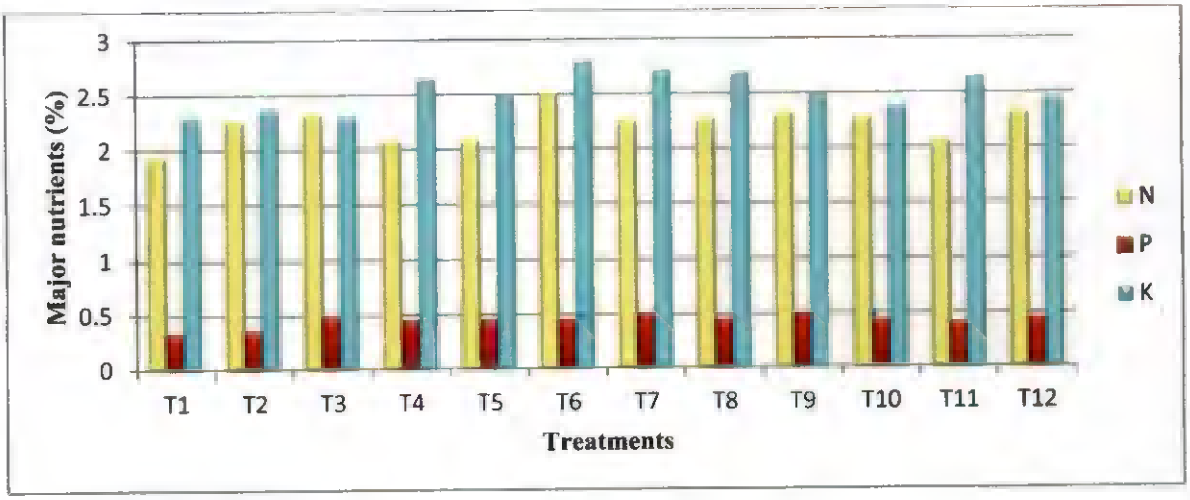


Fig. 12 Effect of different treatments on major nutrients in fruit

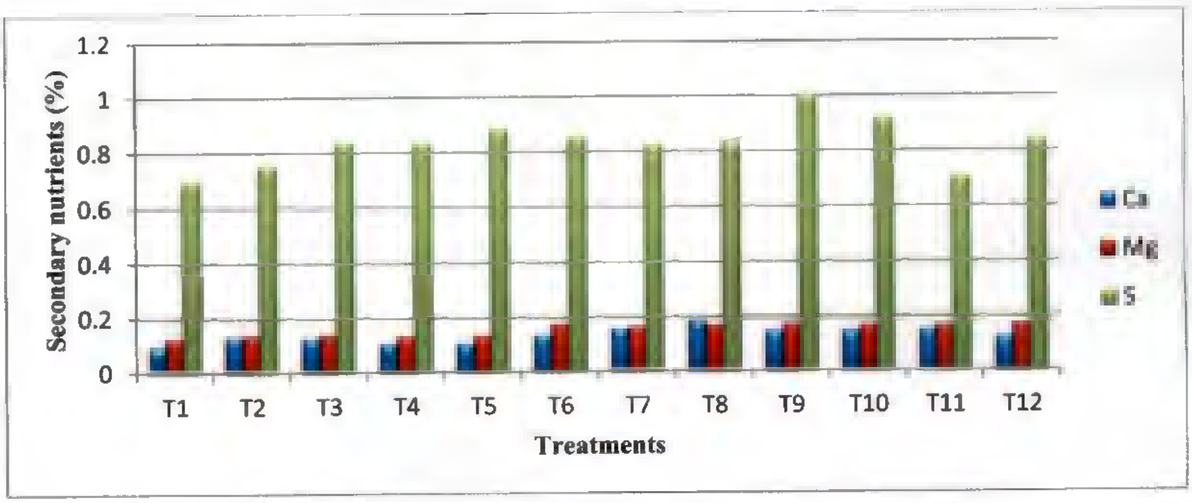


Fig. 13 Effect of different treatments on secondary nutrients in fruit

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

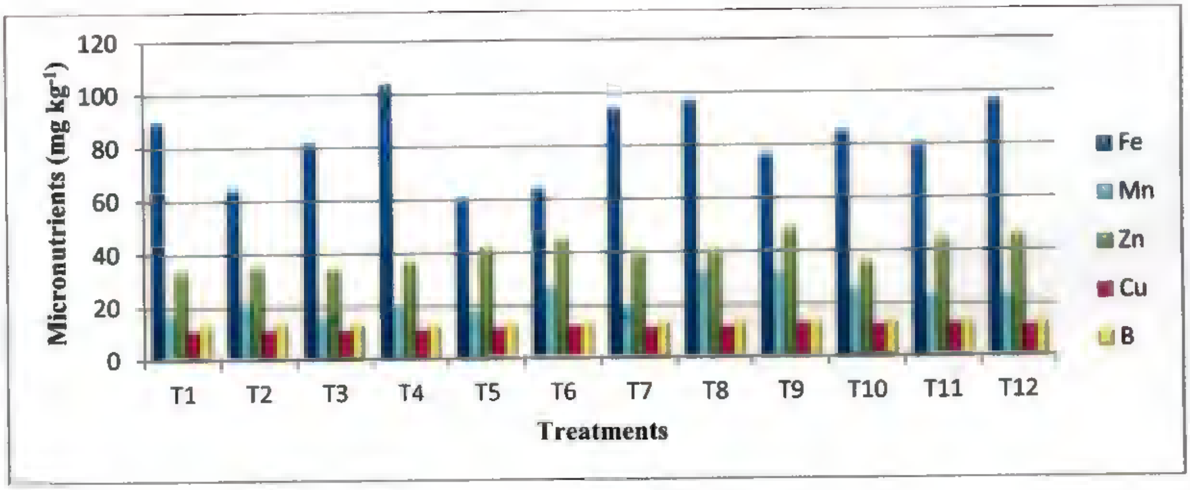


Fig. 14 Effect of different treatments on micronutrients in fruit

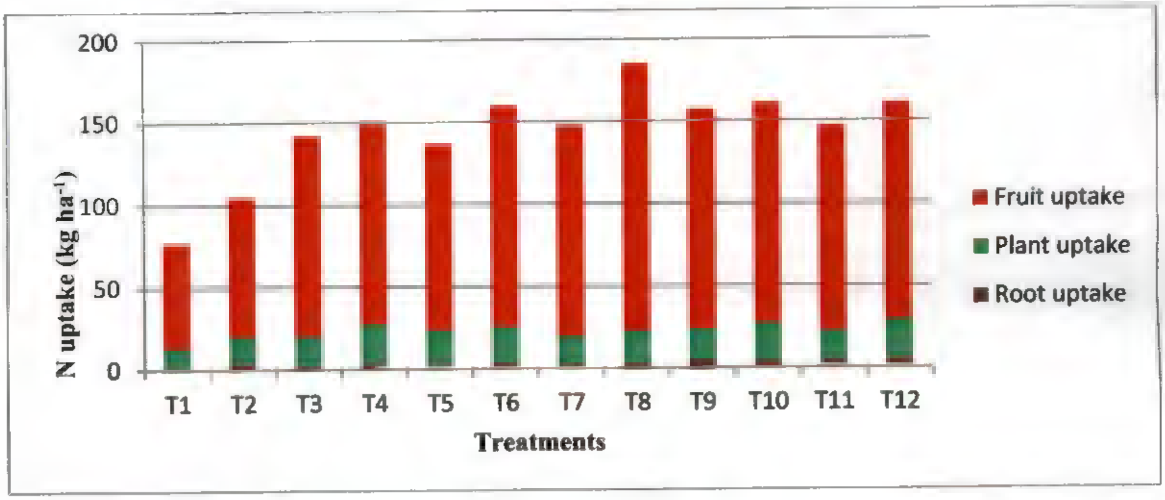


Fig. 15 Effect of different treatments on uptake of nitrogen

T_1	:	Absolute control
T_2	:	Soil test based POP of KAU
T_3	:	STCR+IPNS for target 25t ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}
T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

level of N application in STCR based approach. Comparable outcome was recorded by Santhosha (2013).

Uptake of phosphorus by tomato was significantly highest in STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 40kg ha^{-1} (T_9, 30.47 kg ha^{-1}) (Fig. 16). However the uptake of phosphorus was somewhat higher in every treatment where phosphorus was applied compared to control plots where no P was applied. In the present work higher phosphorus content was present due to utilization of phosphorus which enhanced higher phosphorus uptake. Highestuptake of phosphorus was due to higher dosages of phosphorus (79.91 kg ha^{-1}) in soil. The availability and solubility of fertilizers increased with increase in the dose of P fertilizers. This was in conformity with the findings of Chandrakanth (2015).

Higher uptake of potassium (182.22 kg ha^{-1}) was noticed in STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 120kg ha^{-1} (T_8) (Fig. 17). This is due to higher biomass production in this treatment. This is due to increased availability of potassium at various crop stages. This is in accordance with the discoveries of Thippeswamy (1995) who detailed that availability of potassium at critical stages of crop development which led to higher uptake of potassium.

The lower uptake of potassium was noted in absolute control where there was no addition of K. This infers that lack in the supply or absence of any one major nutrient to the crop would bring unevenness in the supply of nutrient components and subsequent decrease in yield, nutrient use efficiency and uptake. These outcomes are in similarity with the conclusions of Chandrakanth (2015).

5.3.2.2 Uptake of Ca, Mg and S by tomato

The total uptake of calcium (28.68 kg ha^{-1}) and magnesium (15.81 kg ha^{-1}) by tomato crop was highest in the treatment, STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 60 kg ha^{-1} (T_{10}) and STCR + IPNS for target 25 t ha^{-1}+ $MgSO_4$ at 120 kg ha^{-1} (T_8) respectively (Figs. 18 and 19). Increase in calcium uptake was mainly because of higher biomass production. These results are in accordance with Shaymaa *et al.*

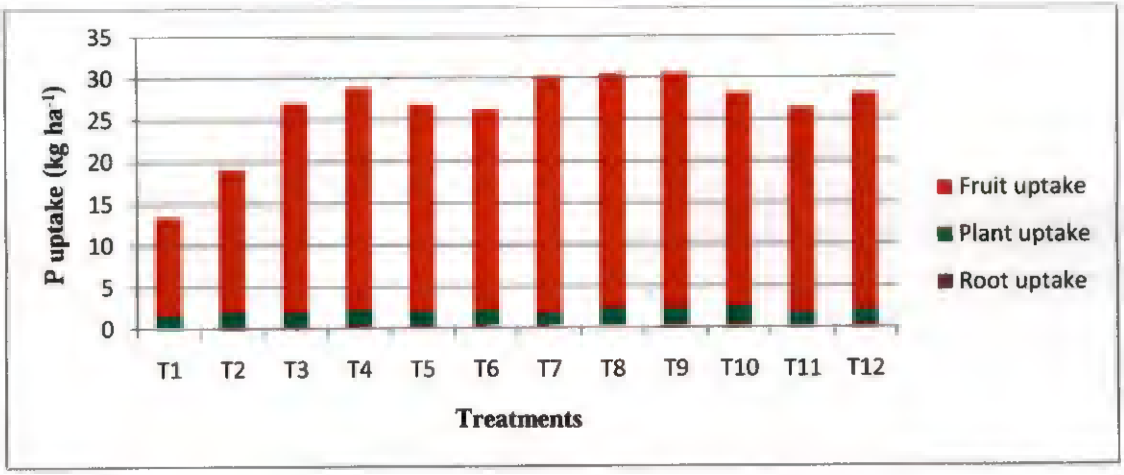


Fig. 16 Effect of different treatments on uptake of Phosphorus

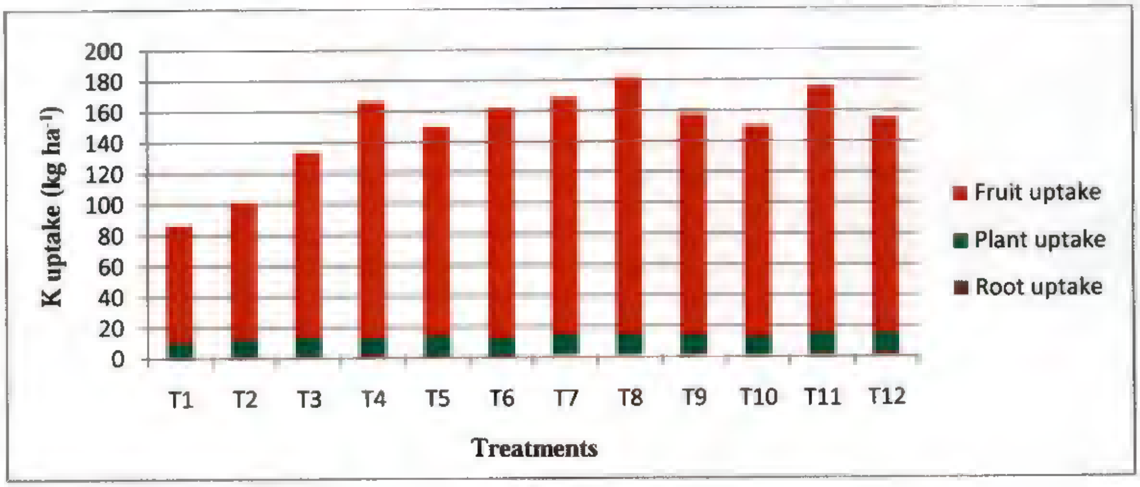


Fig. 17 Effect of different treatments on uptake of potassium

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

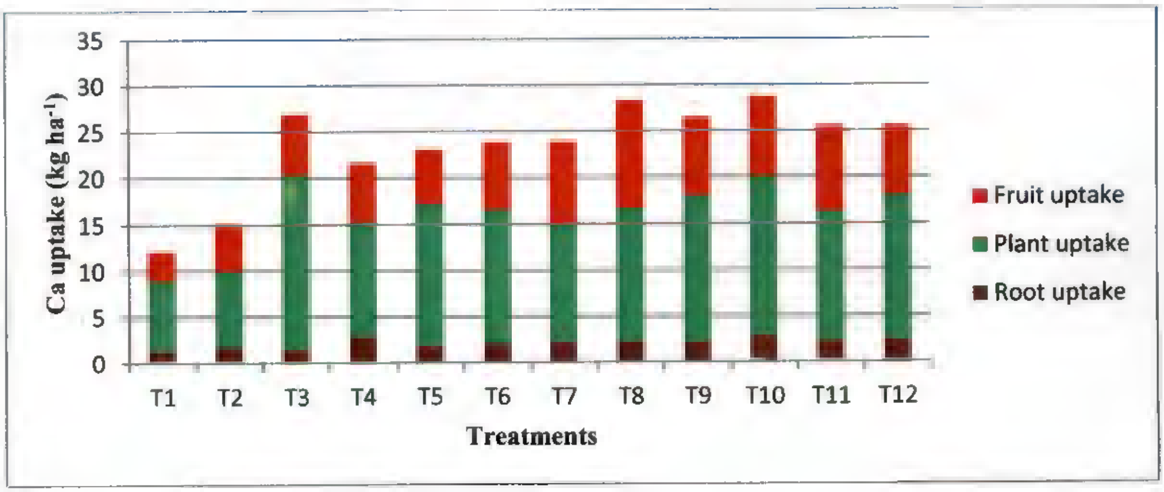


Fig. 18 Effect of different treatments on uptake of calcium

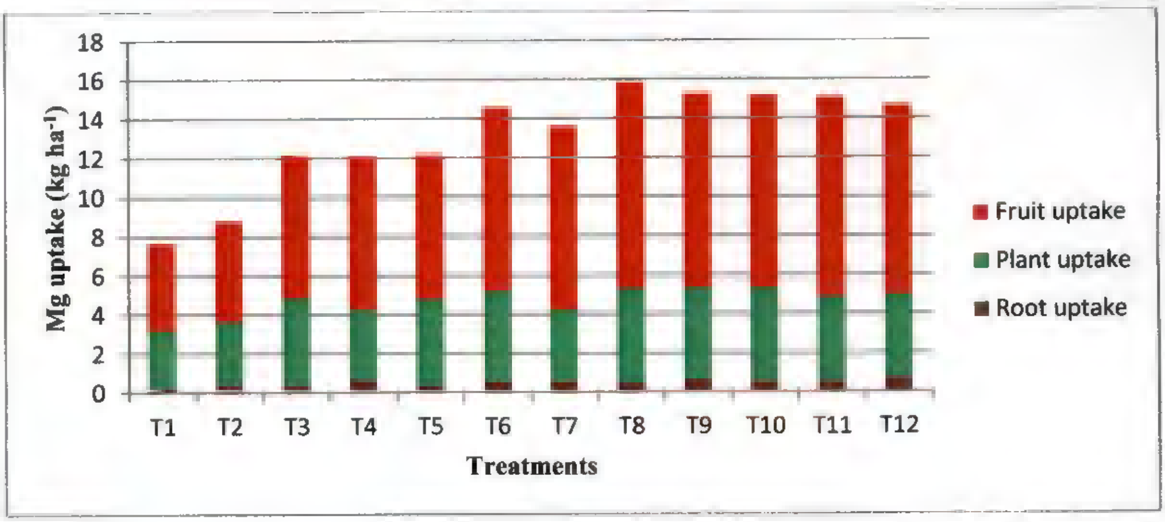


Fig. 19 Effect of different treatments on uptake of magnesium

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

(2009) and Santhosha (2013). Increase in the uptake of magnesium is due to application of $MgSO_4$and different levels of magnesium application was found to have significant and positive correlation with uptake of magnesium ($r = 0.739^{**}$). This further adds support to the above interpretation.

Highest uptake of sulfur was seen in the treatment that received STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} (T_9) (Fig. 20). This is due to application of $MgSO_4$ which contains 27.2 per cent sulfur. There is also synergistic interaction between sulfur and phosphorus (Thiyagarajan, 1998 and Bansal, 1991). Uptake of P having significant and positive correlation with uptake of S ($r = 0.643^{*}$) further confirms the above conclusion.

5.3.2.3 Uptake of micronutrients by tomato

The total uptake of micronutrients *viz.*, Fe, Mn, Zn, Cu and B by tomato varied significantly among different treatments (Figs. 21, 22, 23, 24 and 25). Highest uptake of Mn (540.65 g ha^{-1}) and Zn (397.90 g ha^{-1}) was recorded in STCR + IPNS for target, 30 t ha^{-1} + $MgSO_4$ at 40 kg ha^{-1} (T_9). The Cu (83.12 g ha^{-1}) uptake was maximum in treatment (T_{11}), STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 80 kg ha^{-1}, Fe uptake was highest (2468.50 g ha^{-1}) in STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_{12}) and total uptake of B (35.72 g ha^{-1}) was maximum in T_4 (STCR + IPNS for target 30 t ha^{-1}). The micronutrient uptake by plant is positively influenced by nitrogen and sulfur containing fertilizers. These outcomes are similar to that given by Malvi (2011). Significant and positive correlation was noted between uptake of N and Cu ($r = 0.603^{*}$), N and B ($r = 0.792^{**}$), S and Zn ($r = 0.645^{*}$), S and B ($r = 0.667^{*}$) and S and Cu ($r = 0.663^{*}$) which further confirms the above inference. The higher uptake of micronutrients due to incorporation of FYM along with chemical fertilizers was observed by a few researchers (Shashi, 2003; Manasa, 2013). Atheefa (2007) also revealed that FYM application enhanced the uptake of micronutrients through greater availability of micronutrients by forming soluble complexes.

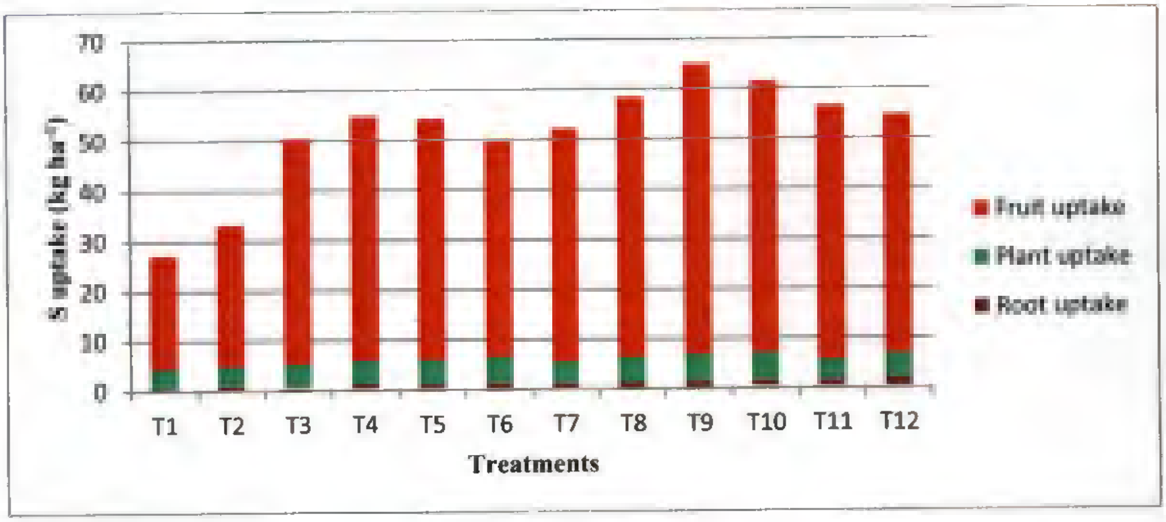


Fig. 20 Effect of different treatments on uptake of sulfur

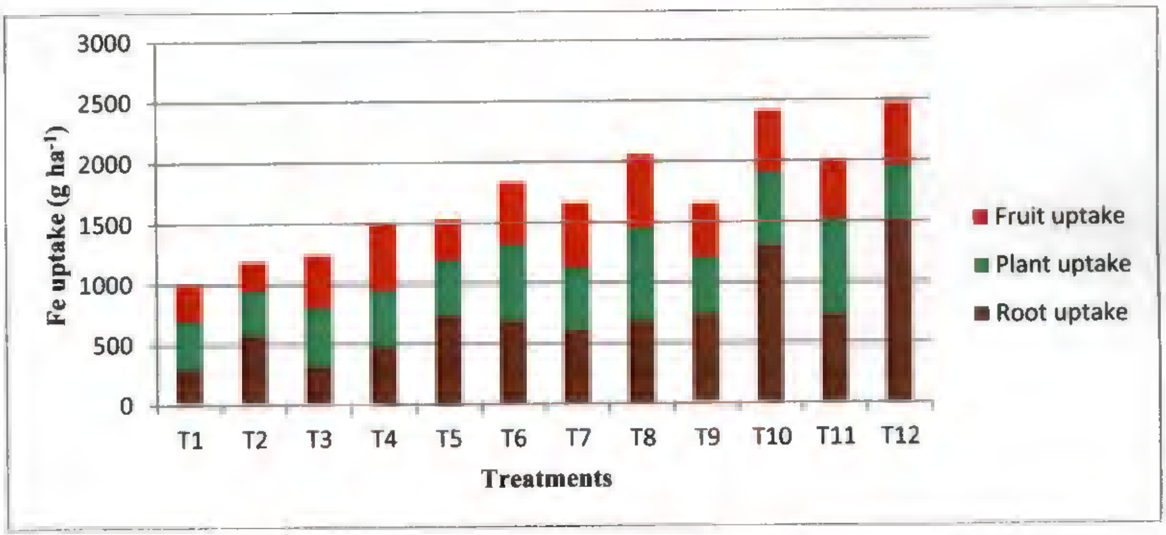


Fig. 21 Effect of different treatments on uptake of iron

T_1	:	Absolute control
T_2	:	Soil test based POP of KAU
T_3	:	STCR+IPNS for target 25t ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}
T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

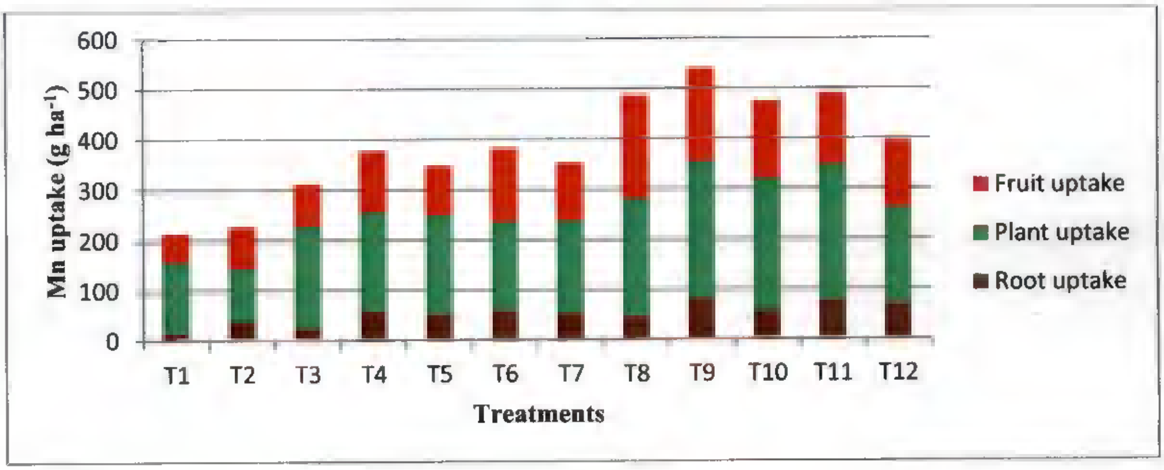


Fig. 22 Effect of different treatments on uptake of manganese

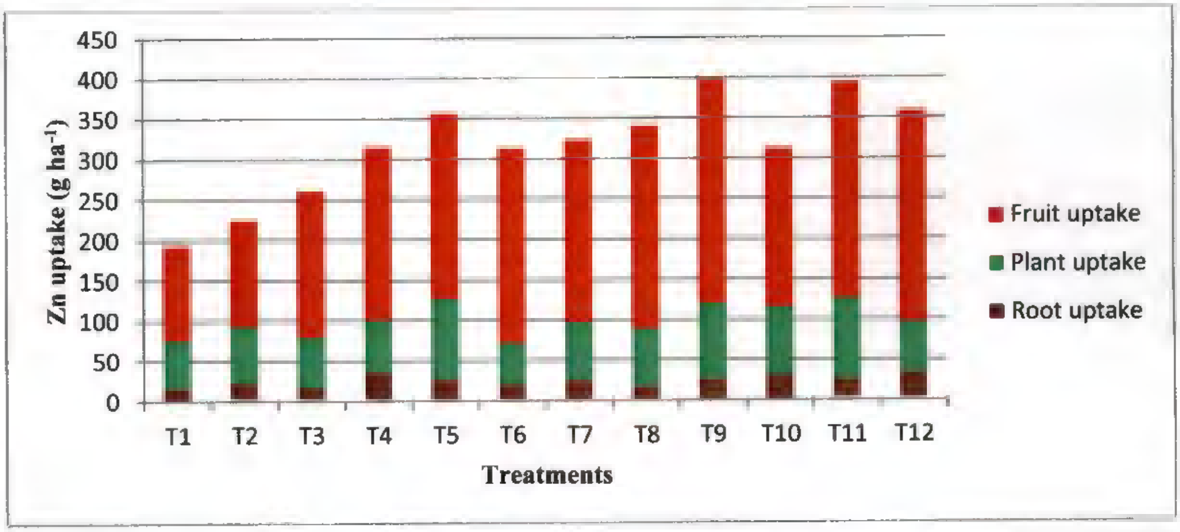


Fig. 23 Effect of different treatments on uptake of zinc

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

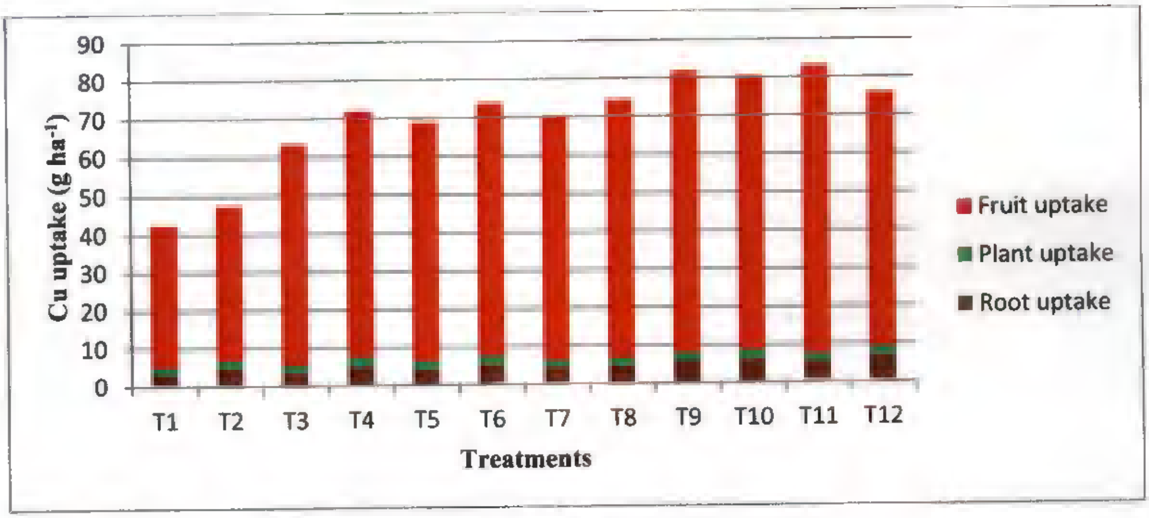


Fig. 24 Effect of different treatments on uptake of copper

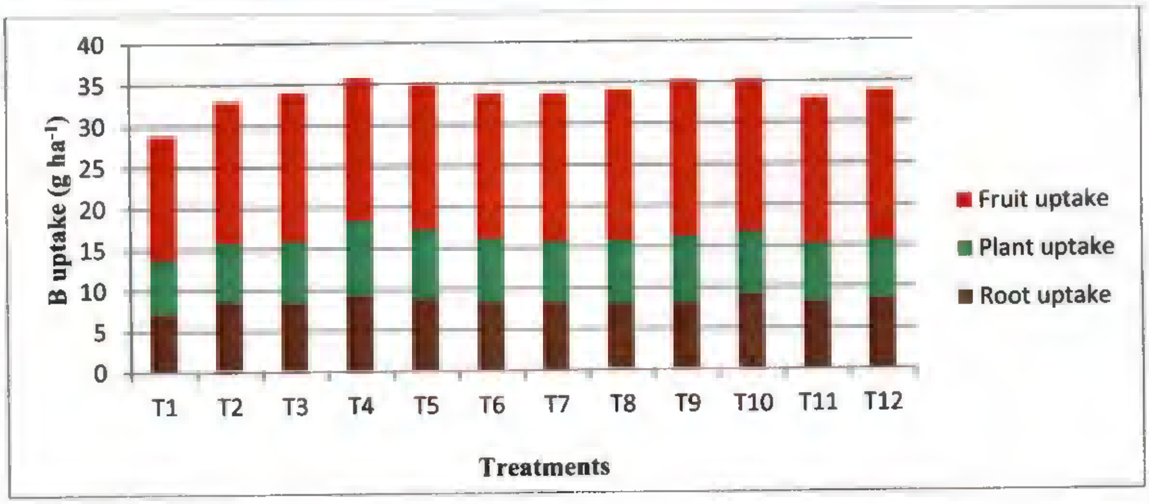


Fig. 25 Effect of different treatments on uptake of boron

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

Addition of FYM along with inorganic nutrients enhanced the microbial activity in the soil and consequent release of complex organic substances whichprevented micronutrients from precipitation, fixation, oxidation and leaching and thereby increased the uptake (Sushma, 2005).

5.4 Quality of tomato crop

In the present study, the fruit quality parameters *viz.,* content of chlorophyll in tomato leaves at different growth stages, ascorbic acid content, total soluble solids and titratable acidity were examined. Each one of the above parameters is considered to be an important criterion to evaluate the efficiency of the added treatments. It is also true that there are ample evidences to show that the addition of organic manure and fertilizers could improvethe quality of fruits.

5.4.1 Chlorophyll content

The chlorophyll content was found to be influenced by the addition of organic manures and NPK along with $MgSO_4$ fertilizers and the lowest chlorophyll content was observed in control plots (Figs. 26 and 27). This could be attributed to the supply of essential nutrients through the addition of organic manure, which might have improved the synthesis of chlorophyll. It is also worth mentioning that when organic manures are applied with inorganic fertilizers comprising N, P, K, Mg and S, it could serve as a major source of N, whereas when it was blended with FYM, the additional advantage of Mg and S was realized due to application of $MgSO_4$. In particular, the nutrients like N and Mg favorably influenced the chlorophyll synthesis. The positive and significant correlation of chlorophyll with that of nitrogen ($r = 0.873^{**}$) and magnesium ($r = 0.937^{**}$) uptake by tomato crop further substantiate the above inference. It was reported by Rajakumar (2014) that the chlorophyll content increased due to the addition of organic manures and magnesium.

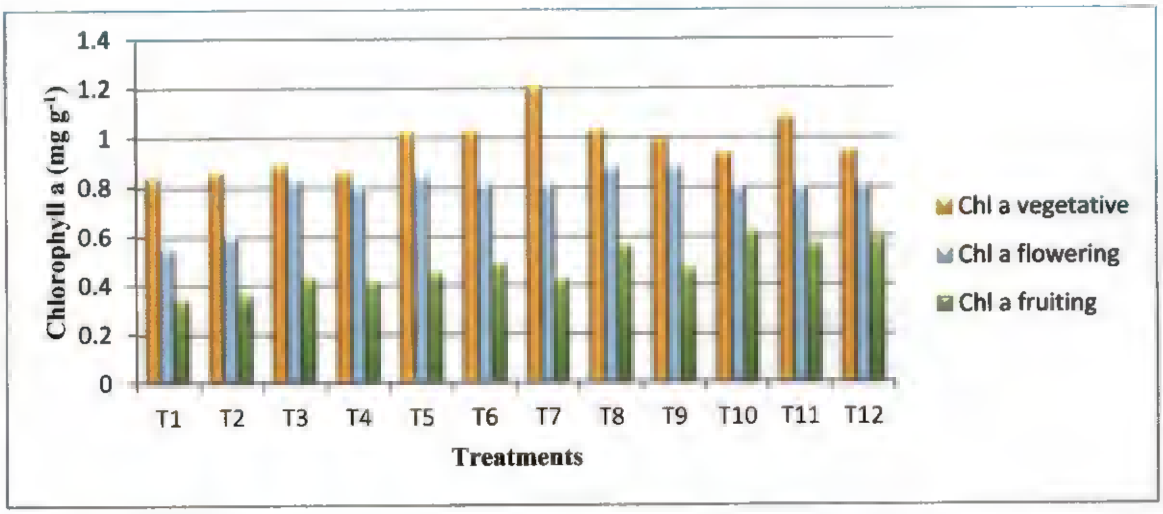


Fig. 26 Effect of treatments on chlorophyll a content at different growth stages

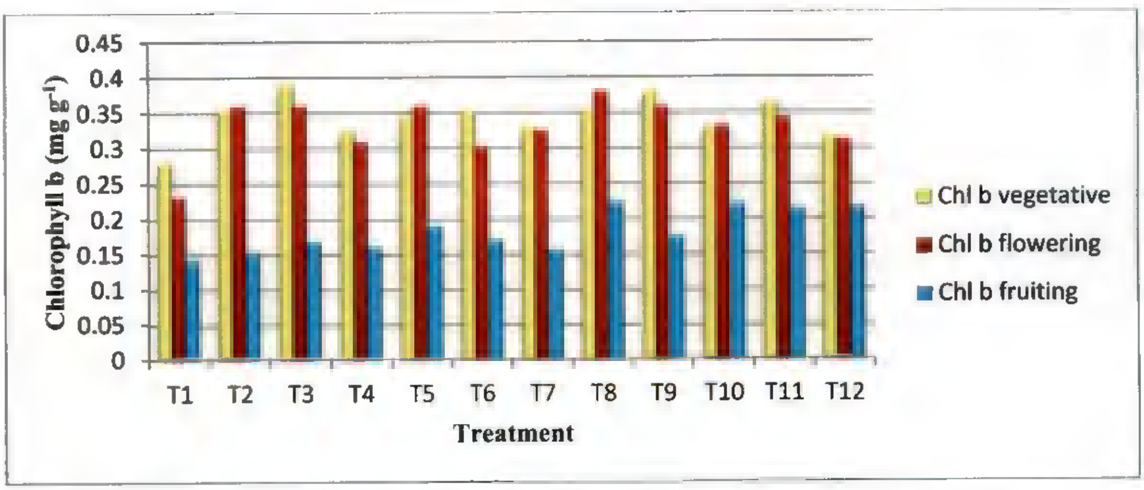


Fig. 27 Effect of treatments on chlorophyll b content at different growth stages

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

5.4.2 Total soluble solids

The results of the analysis for total soluble solids (TSS) revealed that the highesttotal soluble solids (5.93 °B) was noticed in STCR + IPNS for target 30 t ha^{-1}+ $MgSO_4$ at 120 kg ha^{-1} (T_{12}) (Fig. 28). Furthermore, the higher content of N, P K and Mg brought about more soluble solids compared to control plot. These outcomes are in concurrence with findings of Zekri and Obreza (2003) who observed that plant growth and development at high N, P, K and Mgproduce fruits with high dissolvable solid content. This maybe attributed to more efficient uptake of nutrient and efficient nutrient absorption consequently resulted in more luxuriant vegetativegrowth at the expense of translocation of metabolites tothe developing fruits.The results are in conformity with Badyal (1980) and Sharma and Bhargava (2003). Similar results were reported by Ritter (1961); Joon *et al.* (1990) and Jia *et al.* (1999) who opinedthat total soluble solids increased with the increased rate of N application in different stone fruits.The significant and positive correlation of TSS with nitrogen ($r = 0.598^{*}$) further adds support to the above interpretation.

In addition to this, potassium at higher doses adds up soluble solids of tomato. Imas (1999) and Sainju *et al.* (2003) found that high potassium concentrations increased TSS of tomato fruit. It can be concluded that the total soluble solids consists of cation component that are acidic. Factors which may influence the TSS content of tomato fruit include number of fruits, the rate of assimilates exported from leaves; rate of import of assimilates by fruits, and fruit carbon metabolism (Young *et al.*, 1993; Abdalla *et al.,* 1996 and Allahlam *et al.*, 2003). Hewitt *et al.* (1982) observed that high phosphorus content increased TSS content of tomato fruit. The reason behind this is Mg involvement in chlorophyll synthesis, carbohydrate synthesis and partitioning and activator of enzymes. It is also involved in the process of photosynthesis and therefore increases the production and helps in translocation of metabolites to growing fruits which in turn increased total soluble solids in tomato fruits (Jones, 1999).

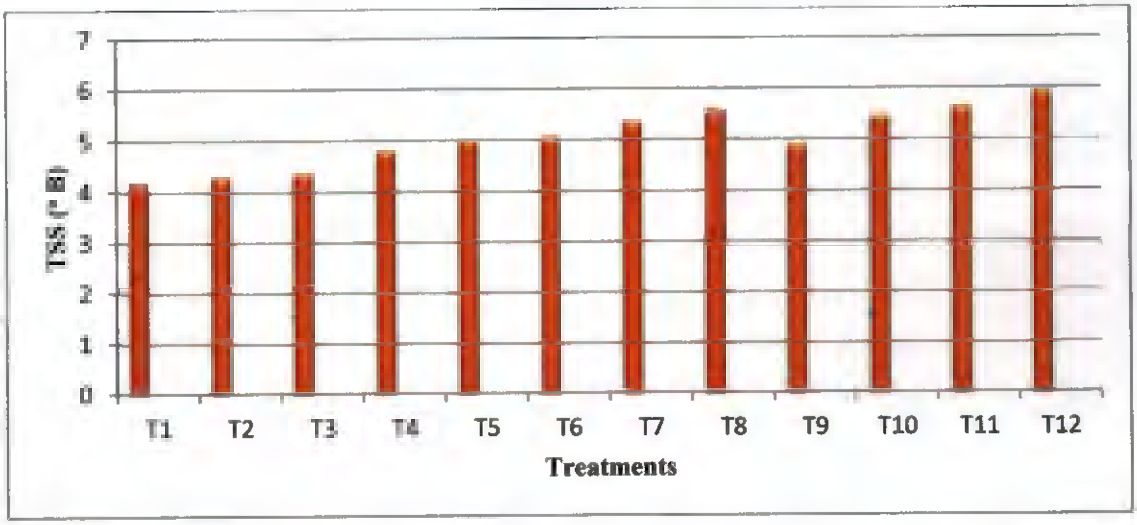


Fig. 28 Effect of different treatments on total soluble solids of tomato fruit

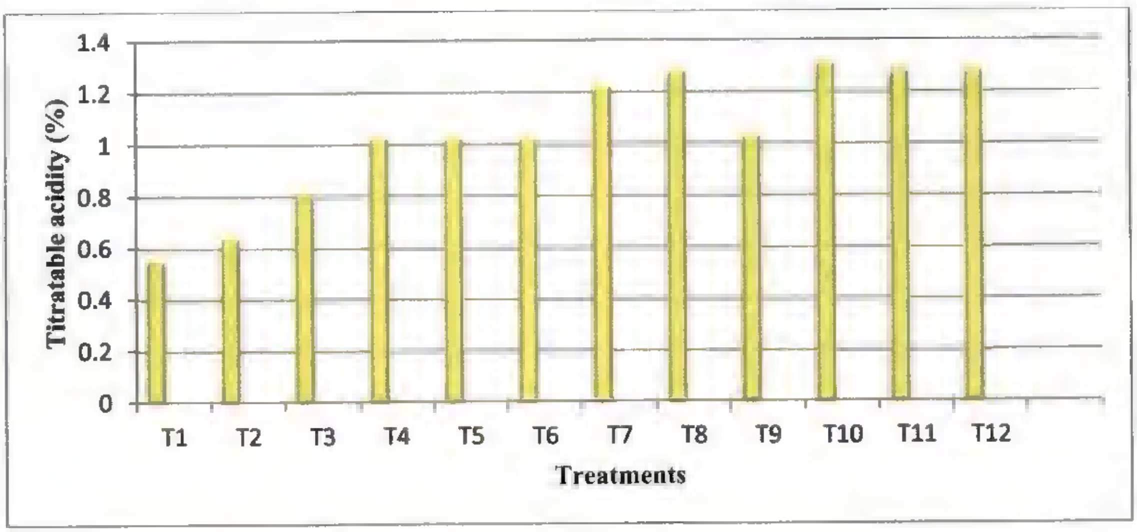


Fig. 29 Effect of different treatments on titratable acidity of tomato fruit

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

5.4.3 Titratable acidity

Titratable acidity was found to be significantly different among different treatments (Fig. 29). Significantly maximum titratable acidity (1.31 %) was noted in treatment, STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 60 kg ha^{-1} followed by STCR + IPNS for target 30 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} and STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1}. Reason behind this is application of nitrogen and magnesium will increase titratable acidity. (Shibli *et al.*, 1995). The increase in titratable acidity by nitrogen and magnesium application is due to increased synthesis of proteins, amino acids and other metabolites and their consequent translocation to the fruits. Similar findings were given by Chadha and Bajwa (1966); Nijjar *et al.* (1972) and Bhutani *et al.* (1983) and Chandel (1985). The significant and positive correlation of titratable acidity with magnesium ($r = 0.731^{**}$) and phosphorus ($r = 0.637^{*}$) further adds support to the above conclusion.

5.4.4 Ascorbic acid content

Ascorbic acid content of tomato fruit was found to be significantly different among treatments. Significantly highest ascorbic acid content (18.34 mg $100g^{-1}$) was noticed in treatment, STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1} (T_8) and lowest ascorbic acid content (12.43 mg 100 g^{-1}) was seen in absolute control (T_1) (Fig. 30). It is due to the fact that application of magnesium increased ascorbic acid content of tomato compared to plots with no magnesium application. Gulshan *et al.* (1991) assessed nine tomato assortments during summer in Tarai locale variety and concluded that magnesium was involved in carbohydrate synthesis, and as ascorbic acid is a form of carbohydrate and any factor which could induce the synthesis of carbohydrates would also improve the ascorbic acid content. Shibli *et al.* (1995) also recorded comparable outcomes in tomato.

The ascorbic acid content was found to be positively influenced by addition of organic manure. It was reported by Nanthakumar and Veeraragavathatham (1999) that the application of organic manures not only supplied major and micro nutrients which favor photosynthetic activity but also resulted in higher sugar content duly accompanied by increase in ascorbic acid content. Similar findings were also reported by Sankaran *et al.* (2005) and Kuppusamy (2008). The significant and positive correlation of ascorbic acid content with nitrogen ($r = 0.813^{**}$), phosphorus ($r = 0.841^{**}$), potassium ($r = 0.915^{**}$), calcium ($r = 0.830^{**}$), magnesium ($r = 0.868^{**}$), iron ($r = 0.698^{*}$), manganese ($r = 0.803^{**}$), zinc ($r = 0.879^{**}$) and copper ($r = 0.946^{**}$) uptake further confirms the above inference.

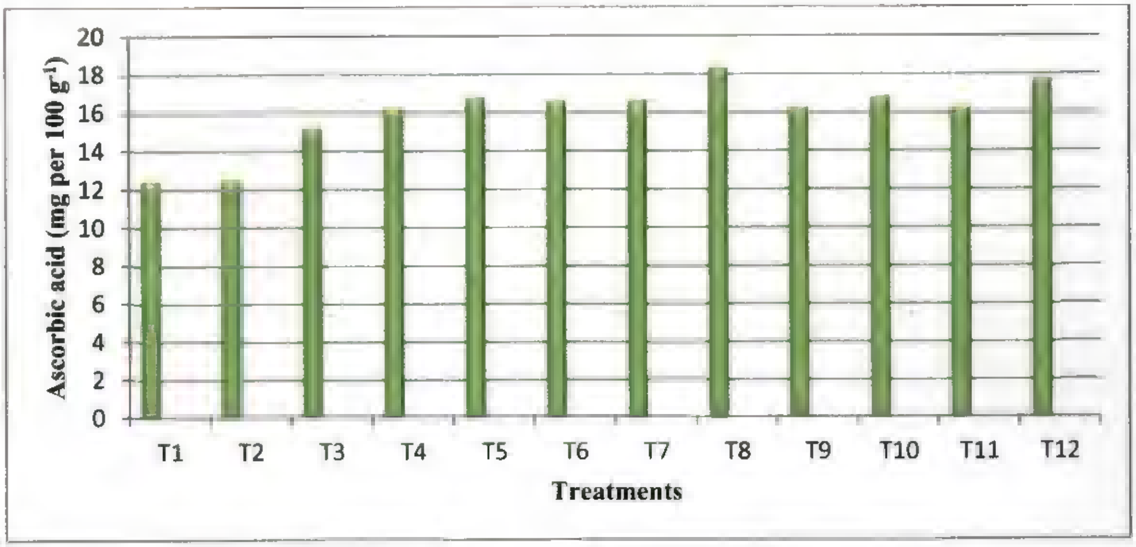


Fig. 30 Effect of different treatments on ascorbic acid content of tomato fruit

T_1	:	Absolute control	T_7	:	T_3+$MgSO_4$ @ 80 kg ha^{-1}
T_2	:	Soil test based POP of KAU	T_8	:	T_3+$MgSO_4$ @ 120 kg ha^{-1}
T_3	:	STCR+IPNS for target 25t ha^{-1}	T_9	:	T_4+$MgSO_4$ @ 40 kg ha^{-1}
T_4	:	STCR+IPNS for target 30t ha^{-1}	T_{10}	:	T_4+$MgSO_4$ @ 60 kg ha^{-1}
T_5	:	T_3+$MgSO_4$ @ 40 kg ha^{-1}	T_{11}	:	T_4+$MgSO_4$ @ 80 kg ha^{-1}
T_6	:	T_3+$MgSO_4$ @ 60 kg ha^{-1}	T_{12}	:	T_4+$MgSO_4$ @ 120 kg ha^{-1}

Summary

6. SUMMARY

Sustained agriculture is based on effective utilization of nutrients by management practices. Fertilizer use efficiency is an important factor to be accounted in crop production as inefficient use of nutrients leads not only to economic loss but also environmental hazards. In this context, fertilizer recommendations based on targeted yield concept (Ramamoorthy *et al.*, 1967) are more quantitative, precise and meaningful as it takes into account the soil fertility and crop requirement in scheduling of fertilizers to the crops and aims at achieving higher yield, benefit cost ratio and sustained soil fertility through balanced nutrition of crops.

At this context, Soil Test Crop Response based Integrated Plant Nutrition System (STCR-IPNS) is a key strategy to mitigate the above issues in an intensive crop production system. Field experiment entitled "Soil test based fertilizer prescriptions for tomato (*Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala" was conducted in STCR field, College of Horticulture, Vellanikkara during *rabi* 2016, to validate the formulated fertilizer prescription equations for tomato and to identify optimum rate of magnesium to be applied along with recommended fertilizer package for maximizing the yield. The field experiment consisted of twelve treatments with three replications. The treatments were, absolute control (T_1), soil test based package of practices recommendations of KAU (T_2), Soil test crop response correlation studies (STCR) + Integrated plant nutrient system (IPNS) for target 25 t ha^{-1} (T_3), STCR + IPNS for target 30 t ha^{-1} (T_4), T_3 + $MgSO_4$ at 40 kg ha^{-1} (T_5), T_3 + $MgSO_4$ at 60 kg ha^{-1} (T_6), T_3 + $MgSO_4$ at 80 kg ha^{-1} (T_7), T_3 + $MgSO_4$ at 120 kg ha^{-1} (T_8), T_4 + $MgSO_4$ at 40 kg ha^{-1} (T_9), T_4 + $MgSO_4$ at 60 kg ha^{-1} (T_{10}), T_4 + $MgSO_4$ at 80 kg ha^{-1} (T_{11}) and T_4 + $MgSO_4$ at 120 kg ha^{-1} (T_{12}). The targeted yield equations used were as follows,

$$FN = 8.21T - 0.246SN - 0.25ON$$

$$FP_2O_5 = 4.92T - 8.437SP - 0.46OP$$

$$FK_2O = 10.07T - 0.439SK - 0.23OK$$

173

The initial soil fertility status was analysed and based on soil nutrient availability, fertilizers were applied. Effect of different levels of fertilizers on growth and yield attributes, post-harvest soil properties, nutrient uptake, nutrient requirement and benefit: cost ratio in tomato cultivation under irrigated condition was studied and the results are summarized in this chapter.

- The growth parameters like plant height and number of days to flowering were found to be significantly different due to various levels of fertilizer application. Significantly highest plant height was noticed in T_7 with average plant height of 33.86 and 60.80 cm at 30 and 60 DAT respectively. At 90 DAT, T_{12} showed highest plant height (75.26 cm). Significantly maximum number of days to flowering was noticed in T_{10}.
- The number of fruits was significantly influenced by various treatments. Highest number of tomato fruits (79.66) was noticed in T_8 while lowest number of fruits (32.00) was seen in T_1. The fruit yield was maximum in T_8 (37.75 t ha^{-1}) and lowest yield (17.54 t ha^{-1}) was noted in T_1.
- There was no significant difference in post harvest soil pH and soil organic carbon among the various treatments. However, significantly highest EC (0.235 dS m^{-1}) was observed in the treatment, T_9. Among the different treatments, T_{10} recorded highest available nitrogen (180.71 kg N ha^{-1}). Significantly highest (53.05 kg ha^{-1}) available phosphorus was recorded in T_3. Whereas, significantly highest available potassium content (379.33 kg ha^{-1}) was noticed in T_{10}.
- Available calcium was not significantly influenced by various levels of fertilizer application. Whereas highest magnesium content (32.64 mg kg^{-1}) was noted in T_{12} and lowest available magnesium (20.40 mg kg^{-1}) was observed in T_1. Available sulfur was maximum in T_{11} (35.30 mg kg^{-1}) and minimum in T_1 (16.14 mg kg^{-1}). Micronutrients were not significantly influenced by various treatments except for manganese and zinc. Significantly highest manganese

(76.37 mg kg^{-1}) and zinc (8.06 mg kg^{-1}) was noticed in T_3 and T_{10} respectively. The lowest Mn (42.37 mg kg^{-1}) and Zn (4.57 mg kg^{-1}) was observed in T_1.

- The total uptake of major, secondary and micronutrients were significantly influenced by various treatments. Significantly highest uptake of N (185.19 kg ha^{-1}), K (182.22 kg ha^{-1}) and Mg (15.81 kg ha^{-1}) was noticed in T_8 whereas P (30.47 kg ha^{-1}), S (64.94 kg ha^{-1}), Mn (540.65 g ha^{-1}) and Zn (397.90 g ha^{-1}) was highest in T_9. The calcium (28.68 kg ha^{-1}) uptake was maximum in T_{10}. Fe (2468.55 g ha^{-1}) uptake was more in T_{12}, highest Cu (83.12 g ha^{-1}) uptake in T_{11} and significantly highest uptake of B (35.72 g ha^{-1}) was noticed in T_4.
- The nutrient content of tomato fruit was found to be significantly different except for nitrogen, phosphorus and sulfur. Significantly highest potassium (2.50%) was found in T_6, highest content of calcium (0.18 %), magnesium (0.17%), iron (96.63 mg kg^{-1}) and manganese (32.93 mg kg^{-1}) was observed in T_8. Maximum content of zinc (48.23 mg kg^{-1}), copper (12.83 mg kg^{-1}) and boron (13.54 mg kg^{-1}) was noticed in T_9.
- The results of quality aspects of tomato revealed that the titratable acidity, ascorbic acid content, total soluble solids (TSS) and chlorophyll content were influenced by different treatments imposed. Significantly highest titratable acidity (1.31 %), ascorbic acid content (18.34 mg $100g^{-1}$), total soluble solids (5.93 °B) and chlorophyll content was noticed in T_{12}, T_{10} and T_6 respectively.
- The total uptake of magnesium and nitrogen, available soil magnesium and nitrogen were found to be significantly and positively correlated with fruit yield. P and Mg were positively and significantly correlated with titratable acidity of tomato fruit. Ascorbic acid content of fruit was found to be positively and significantly correlated with all major, secondary and minor nutrients (except boron). TSS was significantly and positively correlated with phosphorus uptake. Chlorophyll a and b were significantly and positively correlated with uptake of plant N and Mg. No. of days to flowering was significantly and positively correlated with phosphorus.

- The B: C ratio was found to be highest in the treatments which received magnesium. Among the treatments, T_8 recorded highest B:C ratio (3.09) and lowest was in T_1 (1.98).
- Response curve was fitted to determine the optimum level of magnesium to realize maximum yield response. Optimum dose of magnesium required in order to maximize yield is found as 105.10 kg ha^{-1}.

Based on the summary, it is concluded that application of magnesium sulfate along with N, P and K was helpful for getting higher yield and improved quality attributes in tomato crop. It is also confirmed that targeted yield equation developed at STCR centre, Vellanikkara, for tomato was found to produce good result and fixed target is achieved.

Future line of work

- Experiments to determine appropriate doses of magnesium for other major crops in Mg deficient Kerala soils.
- STCR studies can be conducted with foliar application of micronutrients in vegetables.
- Modification in STCR equations developed for crops based on the deficiency of secondary and micronutrients.

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187

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188

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201

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Appendix

Appendix- I

Weather data during the cropping period

Week	Temperature (°C)		RH (%)		Rainfall (mm)	Rainy days	Mean evaporation (mm day^{-1})	Sunshine hours
	Maximum	Minimum	Morning	Evening				
27/08/16- 02/09/16	30.2	23.3	95	71	16.3	3	2.6	3.4
03/09/16- 09/09/16	30.0	22.8	94	66	12.0	1	2.5	3.8
10/09/16- 16/09/16	30.8	24.1	95	66	10.2	1	3.3	6.5
17/09/16- 23/09/16	30.6	23.4	95	67	40.8	4	3.4	6.5
24/09/16- 30/09/16	29.9	24.0	95	75	18.9	3	2.7	3.7
01/10/16- 07/10/16	31.5	22.5	93	63	0.0	0	3.3	9.1
08/10/16- 14/10/16	31.1	23.1	91	68	14.5	1	3.0	5.7
15/10/16- 21/10/16	32.1	23.2	94	70	0.6	0	2.6	4.2
22/10/16- 28/10/16	31.1	22.2	94	69	3.5	1	2.4	3.1
29/10/16- 04/11/16	32.0	22.4	94	70	18.7	2	2.4	4.5
05/11/16- 11/11/16	32.3	21.3	88	53	2.9	0	2.9	6.3
12/11/16- 18/11/16	33.2	23.0	82	53	10.9	1	2.9	5.6
19/11/16- 25/11/16	34.0	22.5	74	48	0.0	0	3.3	6.7
26/11/16- 02/12/16	32.5	21.3	83	55	0.8	0	3.1	4.5
03/12/16- 09/12/16	32.8	22.5	83	52	46.3	2	3.3	6.3
10/12/16- 16/12/16	30.8	21.8	91	61	5.8	1	2.4	4.0
17/12/16- 23/12/16	33.3	22.8	85	46	0.0	0	3.8	9.0
24/12/16- 31/12/16	32.9	22.6	79	46	0.0	0	4.0	7.8

SOIL TEST BASED FERTILIZER PRESCRIPTIONS FOR TOMATO (*Solanum lycopersicum* L.) IN MAGNESIUM DEFICIENT ULTISOLS OF KERALA

By

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Abstract

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ABSTRACT

In Kerala, a major portion (80 %) of cultivated soils is deficient in available magnesium and in many cases, crop growth is found to be limited by magnesium deficiency. Tomato (*Solanum lycopersicum* L.) which belongs to the family solanaceae is an important vegetable crop of Kerala susceptible to magnesium deficiency. Hence the particular study will be helpful in deciding the rate of magnesium to be applied along with major nutrients for yield maximization of tomato in magnesium deficient Ultisols.

Field experiment entitled "Soil test based fertilizer prescriptions for tomato (*Solanum lycopersicum* L.) in magnesium deficient Ultisols of Kerala" was conducted at College of Horticulture, Vellanikkara during *rabi* 2016, to test verify the formulated fertilizer prescription equations for tomato (*var.* Anagha) and to identify optimum rate of magnesium to be applied, along with recommended fertilizer package, for maximizing the yield. Experiment consisted of 12 treatments *viz.*, absolute control (T_1), soil test based package of practices recommendations of KAU (T_2), Soil test crop response correlation studies (STCR) + Integrated plant nutrient system (IPNS) for target 25t ha^{-1} (T_3), STCR + IPNS for target 30 t ha^{-1} (T_4), T_3 + $MgSO_4$ at 40 kg ha^{-1} (T_5), T_3 + $MgSO_4$ at 60 kg ha^{-1} (T_6), T_3 + $MgSO_4$ at 80 kg ha^{-1} (T_7), T_3 + $MgSO_4$ at 120 kg ha^{-1} (T_8), T_4 + $MgSO_4$ at 40 kg ha^{-1} (T_9), T_4 + $MgSO_4$ at 60 kg ha^{-1} (T_{10}), T_4 + $MgSO_4$ at 80 kg ha^{-1} (T_{11}) and T_4 + $MgSO_4$ at 120 kg ha^{-1} (T_{12}).

Among the different treatments, T_8 (STCR + IPNS for target 25 t ha^{-1} + $MgSO_4$ at 120 kg ha^{-1}) gave the maximum yield (37.75 t ha^{-1}), number of fruits (79.66) and benefit- cost ratio (3.09). With regard to the quality of fruits, the highest titratable acidity (1.31 %), total soluble solids (TSS, 5.93 ^{o}B) and ascorbic acid content (18.34 mg 100 g^{-1}) were observed in treatments T_{10}, T_{12} and T_8 respectively. Chlorophyll content of the leaves was higher in magnesium applied plots compared to absolute control.

Results of the linear correlation studies revealed that fruit yield and chlorophyll content were positively correlated with the uptake of nitrogen and magnesium. Quality parameters were also positively and significantly correlated with the nutrients applied. Among the nutrients, phosphorus and magnesium were positively correlated with titratable acidity. Ascorbic acid content of fruit was found to be positively and significantly correlated with all macro and micro nutrients. Total soluble solids were significantly and positively correlated with phosphorus uptake.

Response curve was fitted to determine the optimum level of magnesium to realize maximum yield response. The results revealed that the optimum dose of magnesium sulphate required is 105.10 kg ha^{-1}, in order to get maximum yield of tomato.

From the study, it can be concluded that the fertilizers applied as per STCR + IPNS target yield equations along with required magnesium application contribute much towards the crop requirements for better yield. Future works have to be done in varying soil conditions with different sources of magnesium for different crops.