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# Impact of Zinc Fertilization on Tomato (*Solanum lycopersicum* L.) Yield, Zinc use Efficiency, Growth and Quality Parameters in Eastern Dry Zone (EDZ) Soils of Karnataka, India

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Authors PNSP and CTS designed the study, performed the statistical analysis, wrote the protocol. Author PNSP wrote the first draft of the manuscript. Authors PNSP and CTS managed the analyses of the study. Authors VR and AS managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

The present investigation was carried out with one green house experiment at the University of Agricultural Sciences, Bangalore during 2016-17 and two field experiments during 2017-18 at tomato growing soils of eastern dry zone (EDZ), Karnataka to assess the impact of zinc on tomato. Results suggested that all parameters were significantly improved in both deficient and sufficient soils upon the addition of external zinc along with RDF. The treatment $T_9$ in high zinc soils significantly improved the quality parameters like TSS (6.00$^0$Brix), titratable acidity (0.39%), Vitamin C (53.71 mg 100 g$^{-1}$), lycopene (13.24 mg 100 g$^{-1}$) and shelf life (24 days) when compared with other treatments. The zinc uptake and zinc use efficiency was recorded higher in $T_9$ as 238.91 g ha$^{-1}$ and 2.47% which is more than that of RDF. But in low zinc soils treatment $T_{10}$ significantly improved the quality parameters like TSS (5.80$^0$Brix) which is on par with $T_9$ (5.90$^0$Brix), titratable

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acidity (0.47%), Vitamin C (55.24 mg 100 $g^{-1}$), lycopene (13.30 mg 100 $g^{-1}$) and shelf life (23 days).The zinc uptake and zinc use efficiency was recorded higher in $T_{10}$as 291.53 g $ha^{-1}$ and 2.64% which is more than that of RDF.

*Keywords: Tomato; zinc; lycopene; titratable acidity; vitamin c and zinc use efficiency.*

## 1. INTRODUCTION

India is the second largest producer of vegetables in the world after China and accounts for 14.47 per cent of production with 15.7 per cent of the area of the world. Tomato, onion, brinjal, cabbage, cauliflower, okra and pea are among the most important vegetables grown in India. Tomato (*Solanum lycopersicum* L.), a popular solanaceous vegetable crop, is cultivated throughout the world. India ranks third in the world's tomato production, next to potato and sweet potato and thus ranks first as processing crop among the vegetables as it is a rich source of lycopene, vitamin 'A', vitamin 'C', minerals and organic acids. Karnataka (10.65%) stood second in the production of tomato next to Andhra Pradesh (28.63%) and it is mainly grown in Kolar, Chikkaballapura and Bangalore districts.

Tomato growing farmers use high inputs including NPK fertilizers to attain high productivity. This has caused huge nutrient imbalances in tomato growing soils as a result, deficiencies of secondary and micronutrients are becoming more common, affecting both yield and quality. Zinc deficiency appears one of the major constraints for obtaining high yield and quality of tomato. Zinc is one of the 17 essential elements necessary for the normal growth and development of plants. Zinc plays a key role in plants with enzymes and proteins involved in carbohydrate metabolism, protein synthesis, gene expression, auxin (growth regulator) metabolism, pollen formation, maintenance of biological membranes, protection against photo-oxidative damage and heat stress and resistance to infection by certain pathogens [1]. Zinc deficiency in plants retards photosynthesis and nitrogen metabolism, reduces flowering and fruit development, prolong growth periods (resulting in delayed maturity), decreases yield, quality and results in sub-optimal nutrient-use efficiency. Some of the common deficiency symptoms of zinc in plants are light green, yellow or bleached spots in interveinal areas of older leaves.

Although genotypic factors are important in determining either tolerance or susceptibility of a crop cultivar to zinc deficiency, it is soil factors that are responsible for low available zinc supply. In general, most soils commonly associated with zinc deficiency due to the factors like an alkaline in reaction, high calcium carbonate content in topsoil or in subsoil exposed by removal of the topsoil during field leveling or by erosion, coarse texture (sandy soil) with a low organic matter content, permanently or intermittently water logged soils, high available phosphate content, high bicarbonate or magnesium concentrations in soil or irrigation water and acid soil of low zinc status developed on highly weathered parent material [1].

The green revolution fulfilled the food demand of crowded millions and from the time of the green revolution to date high yielding and fertilizer responsive varieties have evolved to increase the production per unit area. To improve the productivity only major nutrients are concentrated in almost all crops. Though the importance of micronutrients realized during past decades, in most of the crops but it is not effectively materialized in general crop cultivation practices. The micronutrient deficiencies in soil are not only hampering crop productivity but also deteriorating the produce quality. To overcome these problems foliar spray and soil application are being recommended but it is not a crop specific or soil specific recommendation. The tomato - growing soils in Karnataka are very much deficient in zinc [2,3]. Keeping the above facts in view the present study was under taken.

## 2. MATERIALS AND METHODS

### 2.1 Green House Experiment

One hundred and fifty (150) soils of tomato growing areas were collected from different places of EDZ of Karnataka. Out of these fifteen bulk soil samples of depth 0-20 cm were selected for experiment, belonging to different categories of each 5 samples of low, medium and high available zinc status soils. Green house experiment was conducted at College of Agriculture, GKVK, University of Agricultural Sciences, Bangalore during Kharif 2017. Experiment was conducted with tomato as test crop (Hybrid US – 440) by applying graded levels of zinc along with a standard check. Healthy and uniform seedlings are raised on normal soil beds are selected and transplanted into the experimental pots. The plants are maintained uniformly with normal watering and treatments comprised of five levels of Zn application ($T_1$ : RDF (250:250:250 kg N, $P_2O_5$, $K_2O$ ha$^{-1}$); $T_2$ : RDF + $ZnSO_4$ @ 5 kg ha$^{-1}$; $T_3$ : RDF + $ZnSO_4$ @ 10 kg ha$^{-1}$ ;$T_4$ : RDF + $ZnSO_4$ @ 15 kg ha$^{-1}$ ;$T_5$ : RDF + $ZnSO_4$ @ 20 kg ha$^{-1}$ with three replications for each soil location. All together a total of 225 pots were arranged in a Factorial completely randomized design (FCRD). Approximately 10 kg air-dried soil was filled in each plastic pot. Ninety days (90) after transplanting, crop was harvested. The plant and fruit samples were air dried in a forced air oven at 65 $^0$C and dry weight was recorded. Plant and fruit samples were finely ground and digested with di acid digestion mixture and the amount of Zn was determined in the digestates of plant and fruit samples by atomic absorption spectrophotometer.

## 2.2 Details of Field Experiments

Two field experiments were conducted to study the effect of zinc on growth, yield, and nutrient uptake of tomato in farmer's field during 2017-18. The experiment was carried out in Vijayapura, Bangalore rural district of eastern dry zone of Karnataka at 13° 18' 12.5" N latitude and 077°47́ 49.5" East longitude and second experiment was carried out in Konapalli village, Chikkaballapura district of eastern dry zone of Karnataka at 13°24' 37.2" N latitude and 078° 01́ 29.6" East longitude with an elevation of 633 m above mean sea level. Mean maximum temperature varies from 29.7$^0$C to 30.6 $^0$C and minimum temperature varies from 15.6°C to 19.9°C respectively during 2017-18. Total annual rainfall of area is 600 to 690 mm and mean monthly relative humidity varied from 63.9% to 73.1% during experimentation.

The two field experiments were laid out in randomized complete block design (RCBD) with three replications and 11 treatments with plot size 24 m$^2$ (6.0m X 4.0m). The details of treatments are as follows $T_1$ : Farmers practice, $T_2$ : RDF (Recommended dose of fertilizer), $T_3$ : $T_2$+$ZnSO_4$ @ 20 kg ha$^{-1}$ as Soil application (SA), $T_4$ : $T_2$+$ZnSO_4$ @ 30 kg ha$^{-1}$ as SA, $T_5$ : $T_2$+$ZnSO_4$ @ 40 kg ha$^{-1}$ as SA, $T_6$ : $T_2$+ Foliar application (FA) @ 0.25% $ZnSO_4$, $T_7$ : $T_2$+ FA @ 0.50% $ZnSO_4$,$T_8$ : $T_2$+ FA @ 0.75% $ZnSO_4$, $T_9$ : $T_2$+$ZnSO_4$ @ 20 kg ha$^{-1}$ as SA + FA @ 0.25% $ZnSO_4$, $T_{10}$ : $T_2$+$ZnSO_4$ @ 30 kg ha$^{-1}$ as SA + FA @ 0.50% $ZnSO_4$, $T_{11}$ : $T_2$+$ZnSO_4$ @ 40 kg ha$^{-1}$ as SA + FA @ 0.75 % $ZnSO_4$. As per University of Agricultural Sciences (UAS) package of practice recommended dose of fertilizers (RDF) for tomato is 250:250:250 kg N, $P_2O_5$, $K_2O$ ha$^{-1}$ and FYM 38 t ha$^{-1}$. Calculated quantities of fertilizers are applied i.e. 50 percent of the recommended dose of nitrogen and potassium and 100 per cent recommended dose of phosphorus were applied as basal dose at the time of transplanting through urea, single superphosphate and muriate of potash, respectively. The remaining half nitrogen and potassium were top dressed in two equal splits at 60 and 90 days, Zinc was applied through Zinc sulfate ($ZnSO_4.7H_2O$) ) during transplanting as soil application and as foliar spray before flowering to each plot in the experiment as per scientifically.

## 2.3 Biochemical Parameters

### 2.3.1 Titratable acidity

The acidity was determined by using the method of AOAC [4]. A sample of 1 gram was homogenized with 10 ml distilled water in a pestle and mortar and then the filtered through two layers of muslin cloth. Clear filtrate was used for the estimation of the acidity. An aliquot of 5 ml was titrated against 0.1 *N* NaOH using Phenolphthalein as an indicator. Appearance of light pink colour was taken as end point. The acidity was expressed as per cent citric acid, *i.e*. gram of citric acid per 100 g of tissue sample.

Titatable Acidity (%) =

$$\frac{(\text{Titre value x Normality x milli equivalent weight of acid})}{(\text{Initial weight})} \text{ X } 100$$

### 2.3.2 Total Soluble Solids (TSS) (°Brix)

Total soluble solids were estimated by using Erma Hand Refractometer (Erma Inc., Tokyo, Japan). Fruits were cut into halves and the middle portion of the fruit was squeezed on refractometer and value was recorded as Brix at room temperature.

### 2.3.3 Lycopene

Lycopene in the tomato samples was extracted by hexane: ethanol: acetone (2:1:1) mixture tomato fruits were homogenized using a mixer. Hundred micro litre of the homogenized sample were taken in a test tube and 8 ml of hexane: ethanol: acetone, which was added and mixed thoroughly. Blank sample was prepared using 100 ml water instead of tomato sample. Then samples and blank tubes were incubated out of bright light for 10 minutes. After 10 minutes, 1 ml of water was added to an each test tube and mixed. Tubes were allowed to stand for 10 minutes to separate into distinct polar and nonpolar layers. The absorbance was measured at 503 nm, using hexane as a blank [5].

Lycopene (mg 100 g$^{-1}$ fresh wt.) = $\frac{(A503 \times 537 \times 8 \times 0.55)}{(0.10 \times 172)}$= A503 x 137.4

Where 537 g mole$^{-1}$ is the molecular weight of lycopene, 8 ml is the volume of mixed solvent, 0.55 is the volume ratio of the upper layer to the mixed solvents, 0.10 g is the weight of tomato added, and 172 mM$^{-1}$ is the coefficient for lycopene in hexane.

#### 2.3.4 Shelf life

Shelf life of tomato fruits were observed at 7, 10 and 15 days after harvesting of the crop.

#### 2.3.5 Vitamin C (ascorbic acid)

Ascorbate content was estimated by procedure outlined by AOAC [4].A tissue sample of 1 gram was macerated with 4 ml of 3 per cent metaphosphoric acid in a mortar and pestle. The homogenate was centrifuged for 20 minutes at 1000 rpm and then the supernatant was carefully decanted into a flask and final volume was made up to 25 ml with 3 per cent metaphosphoric acid. An aliquot sample of the extract was titrated with 2, 6-dichlorophenol indophenol reagent until a pink end-point, which persists for 15 seconds, was reached. A standard curve was prepared by titrating a known amount of ascorbate (1-50 mg) with 2, 6-dichlorophenol indophenols reagent. The total amount of ascorbate present in the sample was calculated from the standard curve. The results were expressed in mg ascorbic acid per 100 g fresh weight. Ascorbic acid was calculated by using following formula.

$$\text{Ascorbic Acid } \left(\frac{\text{mg}}{100}\text{g}\right) = \frac{(\text{Titer value X Dye factor X Volume made up })}{(\text{Volume of filtrate taken X Wt. or volume of sample taken})} \text{X } 100$$

### 2.4 Sampling and Analysis

Soil samples from 0-20 cm depth were collected from the experimental site and were analysed for various physical and chemical properties such as sand, silt, clay percentage, pH, EC, organic carbon, available nitrogen, phosphorous, potassium, sulphur as outlined by Jackson [6] where as zinc, iron, copper, manganese by Lindsey and Norwell [7] and boron by Bergour and Trough method [8].

After harvest of tomato crop, it was dried in an electrical oven at a temperature of 80 - 85°C. Samples were ground using willey mill, sieved through 1 mm sieve and stored in plastic bags. The fruits were harvested when they attained breaker stage at one week regular interval at 3rd, 5th and 8th picking which gives meaningful information of various pickings to know better uptake of nutrients. Uptake of nutrients was worked out by multiplying percent concentration with dry matter yields, macronutrients uptake is expressed as kg ha$^{-1}$ and zinc uptake was expressed as g ha$^{-1}$ and fertilizer use efficiency viz., Apparent recovery efficiency (ARE) is calculated for zinc as zinc use efficiency (Zn.U.E).

ARE = {[Zinc uptake in the fertilized plot (g ha$^{-1}$)]-[Zinc uptake in unfertilized plot (g ha$^{-1}$)] / Quantity of zinc applied (g ha$^{-1}$)} x 100

### 2.5 Statistical Analysis

The observations recorded from pot and field experiments were subjected for statistical analysis using Factorial Complete Randomized Design (FCRD) and Randomized Block Design (RBD), respectively to draw the valid differences among the treatments. Significance of treatment on fruit yield, concentration and uptake of zinc by tomato plant was tested by adopting the procedure for pot experiment as recommended by Federer [9] and Gomez and Gomez [10].

## 3. RESULTS AND DISCUSSION

### 3.1 Green House Experiment

The studied soils are sandy loam and sandy clay loam in texture with a pH ranging from slightly acidic (5.98) to slightly alkaline (7.76) and non saline (0.39 dS m$^{-1}$) in nature. The mean major nutrient status of N, $P_2O_5$, $K_2O$ and S are 252.85, 74.15, 389.64 and 61.19 kg ha$^{-1}$, where as mean micro nutrient status of Zn, Fe, Cu, Mn and B are 1.67, 5.73, 1.53, 5.89 and 0.77 mg kg$^{-1}$ respectively.

### 3.1.1 Effect of zinc application on growth and quality parameters in different soils

The results of the investigation showed that with increasing zinc content the plant height increased significantly irrespective of all the locations. Highest plant height is recorded in the treatments receiving 20 kg $ZnSO_4$ $ha^{-1}$ and the lowest was recorded in the control. The mean plant height in the control treatment is 75.61 cm, whereas in the treatments receiving 5, 10, 15, 20 kg $ZnSO_4$ $ha^{-1}$ the plant height is 94.48, 100.28, 109.82 and 115.29 cm respectively (Fig. 1). The above results clearly showed that there was a significant improvement in plant height with the application of zinc. These results are in conformity with the findings of Muhammad et al. [11]. Increase in plant height may be attributed to the role of zinc in auxin synthesis and also helps in cell differentiation which helps in root and shoot growth of plants. These results are similar to the findings of Basavarajeswari et al. (2008). Nitrogen encourages vegetative growth while phosphorus and zinc encourages reproductive growth [12,13]. Nawaz et al. [14] reported that nitrogen shifts the balance from reproductive to vegetative growth as a result excessive vegetative growth but minimum flowerings.

There was a significant variations were observed among the treatments in respect of the chlorophyll content of the tomato. The lowest chlorophyll was recorded in all the control pots, where as the highest was recorded in the pots treated with 15 kg $ZnSO_4$ $ha^{-1}$ with RDF. The mean chlorophyll content was varied from 9.63 to 12.31 SPAD reading. The SPAD readings for $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ are 9.63, 10.27, 10.70, 12.31 and 11.93 respectively. The highest mean chlorophyll content was observed in low zinc fertility soils followed by high and medium soils and are statistically significant between the treatments (Fig. 1). This showed that the zinc application increased the chlorophyll content. These results are similar to the findings of Gurmaniet al. [15], and Prasad and Subbarayappa [16] and Salman et al. [17].

Total soluble solid content of the fruits varied due to different zinc levels. The mean values ranged from 4.90 to 5.90$^0$Brix. The mean TSS for $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ are 4.90, 5.42, 5.30, 5.42 and 5.90$^0$Brix, respectively (Fig. 2).The highest TSS content was recorded in the fruits which are grown with 20 kg $ZnSO_4$ $ha^{-1}$ along with recommended dose of NPK, where it was recorded the lowest in control. There is a slight variation of TSS in different locations of experimental soils, and they are statistically significant. These results are also in conformity with the findings of Salam et al. [17]. The mean Total Soluble Solids (TSS) was almost same in all the fertility levels of the soils irrespective of low, medium and high zinc status.

Vitamin C is an important vitamin to human health. Marked differences were observed in vitamin C content of the fruit due to the varied zinc levels. The mean vitamin C for studied soils ranges from 29.11 to 47.19 mg 100 $g^{-1}$. With varied zinc level application the mean vitamin C content is 29.11, 35.01, 38.09, 40.60 and 47.19 @ $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$, respectively (Fig. 2). The highest mean was recorded in the treatment receiving 20 kg $ZnSO_4$ $ha^{-1}$ along with recommended dose of NPK and lowest was recorded in control. Highest mean was recorded in high zinc soils followed by medium and low zinc fertility soils. Dube et al. [18] opined that vitamin C content of the fruits improved with zinc sulphate @ 20 kg $ha^{-1}$ respectively. These results are also similar to that of the findings made by Salam et al. [17] and Prasad and Subbarayappa [16].

The results of the investigation revealed that lycopene content of the fruits increased with the increasing zinc levels. The mean lycopene content ranges from 8.36 to 17.26 mg 100 $g^{-1}$. With varied levels of zinc application, the lycopene content is 8.36, 9.65, 11.76, 14.84 and 17.26 mg 100 $g^{-1}$ for $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ respectively (Fig. 2). The highest mean lycopene was recorded in treatment $T_5$ with 20 kg $ZnSO_4$ with RDF. On the other hand the lowest was recorded in control where no zinc application. This clearly shows that zinc plays an important role in increasing the lycopene content in the fruit. In the experiment, the lycopene is statistically significant irrespective of all the locations. These results are also in conformity with the findings made by Salam et al. [17] and Prasad and Subbarayappa [16].

Titratable acidity is an important factor for canning of fruits. High acidity is better for canning purpose. Considering the main effect of zinc, acidity was significantly influenced. Acidity content of the fruits increased with the increasing zinc levels. The mean titratable acidity ranged from 0.22 – 0.40%. With varied zinc levels such as $T_1$, $T_2$, $T_3$, $T_4$ and $T_5$ the titratable acidity is 0.22, 0.28, 0.32, 0.34 and 0.40 percent (Fig. 2). The results of the investigation reflected that the mean titratable acidity for high zinc fertility soils is more followed by medium and low fertility soils. The highest acidity (0.45%) was recorded in fruits which were produced with 20 kg $ZnSO_4$ $ha^{-1}$+ RDF and lowest (0.14%) was recorded in control. Puspha [19] obtained the highest acidity under 100% recommended dose of the fertilizers with biofertilizers. These results are similar to that of the findings made by Salam et al. [17] and Prasad and Subbarayappa [17].

## 3.2 Field Experiments

The initial physico chemical properties, major, secondary and micro nutrient status are presented in Table. 1 and For classification of experimental soils as Zinc sufficient (High Zinc soils) and zinc deficient (Low zinc soils) the procedure of Cate and Nelson graphical method is followed and critical limits are redefined for tomato growing areas of EDZ of Karnataka as < 1.08 mg $kg^{-1}$ (low),1.08 - 1.99 mg $kg^{-1}$ (medium) and > 1.99 mg $kg^{-1}$ (high) [20,21].

### 3.2.1 Effect of soil and foliar applications of zinc on growth and yield parameters of tomato

*3.2.1.1 Plant height (cm)*

The data on plant height of tomato as influenced by different levels of zinc in high zinc and low zinc status soils are presented in the Table 2. Tomato plant height was recorded at 30, 60 and 100 days after transplanting (DAT). There is a significant increase in plant height at all stages *i.e.*, 30, 60 and 100 days after transplanting, but more significant increase in plant height was observed during 60 DAT. At 30 days after transplanting $T_9$ and $T_{10}$ treatments recorded highest plant height (39 cm) and these were on par with each other. Lowest plant height (28 cm) was recorded in control ($T_1$), followed after treatment $T_2$ (32 cm). In Low zinc soils at 60 DAT and 100 DAT highest plant height was recorded in treatment $T_{10}$ which shows that combined soil and foliar application of the nutrients improved highest plant height than individual application. In all the stages highest plant height was recorded in treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) in high zinc soils $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) in low zinc soils.

*3.2.1.2 Chlorophyll content (SPAD reading)*

The data on chlorophyll content for high zinc soils at different stages of tomato as influenced by different levels of zinc is presented in Table 2. Chlorophyll content of tomato was recorded at 30, 60 and 100 DAT. There is a significant increase in chlorophyll content among the treatments at all the growth stages. The lowest chlorophyll content was recorded in control ($T_1$) and Treatment $T_2$. At 30 DAT treatments $T_9$, $T_4$ and $T_5$ are on par with each other. At 60 DAT highest chlorophyll content was recorded in treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) as 19.70 and lowest was recorded in $T_1$ (11.50). At 100 DAT highest was recorded in treatment $T_9$ (22.20) which is on par with $T_5$ (22.10) and lowest was recorded in $T_1$ (16.10). The treatments with combined application of soil and foliar applied zinc recorded significantly higher chlorophyll content at all growth stages followed by only soil application of zinc and only foliar application of zinc. But in low zinc soils, there is a significant increase in chlorophyll content among the treatments at all the growth stages. The lowest chlorophyll content was recorded in absolute control ($T_1$) and treatment $T_2$. At 30 DAT treatments $T_8$ and $T_{10}$ recorded highest chlorophyll content and are on par with each other. At 60 DAT highest chlorophyll content was recorded in treatment $T_9$ (18.20) which is on par with the treatment $T_8$ and lowest was recorded in $T_1$ (12.10) compared to $T_2$ (13.70). At 100 DAT highest was recorded in treatment $T_{10}$ (23.10) and lowest was recorded in $T_1$ (15.10) compared to $T_2$ (14.20).

The results of the experiment revealed that the application of various levels of zinc along with recommended dose of fertilizers (NPK) and FYM have significant influence on plant height and chlorophyll content. Zinc plays an important role in active synthesis of tryptophan and is a precursor of IAA biosynthesis, stimulates the growth of plant tissue, as result plant height was improved in the treatments which are supplied with zinc [22]. Zinc is an important component for development of chloroplast and it plays a prominent role in photosynthesis which helps in production of chlorophyll as a result net photosynthetic rate will be improved [23]. The other reasons for improving growth attributes is due to better moisture holding capacity, supply of zinc which improves availability of major nutrients and application of FYM, improved physical conditions of soil like structure, moisture holding capacity and aeration [24]. Zinc is a component of almost 60 enzymes like dehydrogenases, aldolases, isomerases, transphosphorylases, RNA and DNA polymerases which are invoved in chlorophyll, starch, carbohydrate and protein metabolism in plant, which inturn has a role in synthesis of growth promoter hormone, which in turn enhance plant growth by auxin production [25,26].

*3.2.1.3 Number of fruits*

The data on number of fruits per plant in high zinc soils of tomato as influenced by different levels of zinc during different pickings is presented in the Table 3. There was a significant difference in number of fruits of tomato at 3rd, 5th and 8th picking. Treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) had significantly increased the number of fruits per plant at all pickings (181.8) as compared to other treatments. The lowest was recorded in control (135). Combined application of soil and foliar application of zinc was significantly superior than individual foliar and soil application of zinc, where as in low zinc soils treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) has significantly increased the number of fruits per plant at all pickings (153.83) as compared to other treatments. The lowest was recorded in absolute control (103). During 5th and 8th picking individual soil application treatments $T_3$, $T_4$ and $T_5$ are on par with each other and individual foliar application treatments $T_6$, $T_7$ and $T_8$ are on par with each other. Combined application of soil and foliar application of zinc was significantly superior than individual foliar and soil application of zinc.

*3.2.1.4 Weight of fruits*

The data on total yield and weight of fruits (kg 5 $plants^{-1}$) during different pickings in high zinc soils and low zinc soils as influenced by different levels of zinc are presented in the Table 3. There was a significant difference in fruit weight of tomato due to application of different levels of zinc. Application of soil and foliar zinc recorded significant increase in fruit weight. Treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) has significantly increased weight of fruits per 5 plant (8.6 kg 5 $plants^{-1}$) at all pickings compared to other treatments but this is on par with the treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) as 8.6 kg $plants^{-1}$. Among the mean weight of all pickings combined application of soil and foliar treatments are best followed by individual soil and foliar applications. However, significantly lowest fruit weight was recorded in control ($T_1$) (5.20 kg $plants^{-1}$).

There was a significant difference in fruit weight of tomato in low zinc soils.Treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) has significantly increased weight of fruits per 5 plant (7.8 kg 5 $plants^{-1}$) at all pickings compared to other treatments. Among the mean weight of all pickings, combined application of soil and foliar treatments are best followed by individual soil and foliar applications. However, significantly lowest fruit weight was recorded in absolute control ($T_1$) (5.10 kg $plants^{-1}$) compared to treatment $T_2$ (6.50 kg $plants^{-1}$) [NPK + FYM based on UAS (B)].

### 3.2.2 Effect of soil and foliar application of zinc on quality parameters of tomato

The data on quality parameters such as TSS, titratable acidity, vitamin C, lycopene and shelf life of tomato as influenced by different levels of zinc through soil and foliar application are presented in Table 4.

*3.2.2.1 Total soluble solids ($^0$Brix)*

Total soluble solids varied significantly due to the application of varied levels of zinc through soil and foliar application. In higher zinc soils, significantly higher total soluble solids (6.00$^0$Brix) was recorded in the treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) and $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) respectively. The treatments which are undergone with soil application of zinc are having significantly higher TSS than foliar application treatments. However, significantly lower TSS was recorded with absolute control (4.30$^0$Brix) followed after treatment $T_2$ (NPK + FYM based on UAS (B)) with 4.60 $^0$Brix reading. But in low zinc soils, TSS varied significantly due to the application of varied levels of zinc through soil and foliar application. Significantly higher total soluble solids (5.90$^0$Brix) was recorded in the treatment $T_9$($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$). The treatments which are undergone with soil application of zinc are having significantly higher TSS than foliar application treatments. However, significantly lower TSS was recorded with absolute control (4.20 $^0$Brix) compared to treatment $T_2$ (NPK + FYM based on UAS (B)) with 4.50$^0$Brix reading.

Zinc is involved in synthesis of tryptophan that is a precursor of auxin, auxins help in mobilization of carbohydrate from source to sink which intern increases TSS. Zinc is a component of molecular structure of enzymes carbonic anhydrase which involved in photosynthesis and causes increase in the level of soluble sugars [27]. Application of micronutrients may increase the mobilization of carbohydrates from source to sink. An association of zinc with synthesis of auxins in plants played a vital role in increasing enzymatic activities. This leads the bio chemical reactions involving conversion of complex food i.e. starch into simple sugars [28,29,30,23,17].

*3.2.2.2 Titratable acidity (%)*

Titratable acidity varied significantly due to the application of different levels of zinc through soil and foliar application. In high zinc soils, there is a significant higher titratable acidity (0.39%) was recorded in the treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$). The next best treatments are $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) and $T_5$ ($T_2$+$ZnSO_4$ @ 40 kg $ha^{-1}$). This shows that titratable acidity was recorded more with soil application than the treatments receiving only foliar application. Lowest titratable acidity (0.24%) was recorded in absolute control ($T_1$) followed by the treatment $T_2$ which is NPK + FYM based on UAS (B) with 0.27% as titratable acidity. But in low zinc soils, there is a significant higher titratable acidity (0.47%) was recorded in the treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$). The next best treatments are $T_9$($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) and $T_5$($T_2$+$ZnSO_4$ @ 40 kg $ha^{-1}$). This shows that titratable acidity was recorded more with soil application than the treatments receiving only foliar application. Lowest titratable acidity (0.25%) was recorded in absolute control ($T_1$) followed after the treatment $T_2$ which is NPK + FYM based on UAS (B) with 0.27% as titratable acidity. The increase in acidity by zinc application may be due to formation of starch which is end product of photosynthesis [29,17]

*3.2.2.3 Vitamin C (mg 100 $g^{-1}$)*

Vitamin C content was significantly differed due to application of varied levels of zinc through soil and foliar application. In high zinc soils, highest vitamin C content (53.71 mg 100 $g^{-1}$) was recorded in the treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) which is also on par with the treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$). Lowest vitamin C content (28.08 mg 100 $g^{-1}$) was recorded in absolute control ($T_1$) followed by the treatment $T_2$ which is NPK + FYM based on UAS (B) with 33.16 mg 100 $g^{-1}$ as vitamin C content. Combined application of soil and foliar zinc recorded the highest vitamin C content than individual application of soil and foliar zinc. In low zinc soils, Vitamin C content was significantly differed due to application of varied levels of zinc through soil and foliar application. Highest vitamin C content (55.24mg 100 $g^{-1}$) was recorded in the treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$). Lowest vitamin C content(28.00mg 100 $g^{-1}$) was recorded in absolute control ($T_1$) compared to the treatment $T_2$ which is NPK + FYM based on UAS (B) with 29.40 mg 100 $g^{-1}$ as vitamin C content. Combined application of soil and foliar zinc recorded highest vitamin C content than individual application of soil and foliar zinc.

The increase in ascorbic acid content due to application of zinc might be due to synthesis of some metabolic intermediary substances that promoted greater synthesis of the precursors of ascorbic acid due to increasing the activity of ascorbic acid oxidase enzyme [29,17]. A significant increase in vitamin C content may be due to the role of zinc as an activator of many enzymes [31] and a component of many proteins, particularly carbonic anhydrase and carboxylase that led to enhanced vitamin C content of the fruit. Higher vitamin C may be attributed due to adequate supply of hexose sugars *via* photosynthetic activity [28,29,23,17].

*3.2.2.4 Lycopene (mg 100 $g^{-1}$)*

Lycopene varied significantly due to application of different levels of zinc through soil and foliar application. In high zinc soils significantly higher lycopene content (13.38 mg 100 $g^{-1}$).was recorded with the treatment $T_{11}$ ($T_2$+$ZnSO_4$ @ 40 kg $ha^{-1}$ as soil application + Foliar application of @ 0.75% $ZnSO_4$), where as lowest lycopene content was recorded in absolute control $T_1$ (11.43 mg 100 $g^{-1}$). However, significantly higher lycopene content was recorded in the treatments receiving combined application of soil and foliar zinc and lowest excluding control was recorded in foliar zinc applied treatments. Where as in low zinc soils, Lycopene varied significantly due to application of different levels of zinc through soil and foliar application. Significantly higher lycopene content (13.30 mg 100 $g^{-1}$) was recorded with the treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$), where as lowest lycopene content was recorded in absolute control $T_1$ (9.87 mg 100 $g^{-1}$) followed after treatment $T_2$ (NPK + FYM based on UAS (B)).. However, significantly higher lycopene content was recorded in the treatments receiving combined application of soil and foliar zinc and lowest excluding control was recorded in foliar zinc applied treatments. Similar reports were made by Salman et al. [17] and Mishra et al. [29].

*3.2.2.5 Shelf life (days)*

Shelf life varied significantly due to application of various levels of zinc through soil and foliar application. In high zinc soils, the mean shelf life was highest (25 days) in the treatment $T_5$ which is on par (24 days) with treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$). However absolute control $T_1$ was recorded with lowest shelf life (16 days). In low zinc soils, the mean shelf life was highest (23 days) in the treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$)which is on par (23 days) with treatment $T_{11}$ ($T_2$+$ZnSO_4$ @ 40 kg $ha^{-1}$ as soil application + Foliar application of @ 0.75% $ZnSO_4$). However, absolute control $T_1$ was recorded with lowest shelf life (14 days). Combined soil and foliar zinc application treatments are superior than other treatments. Zinc is responsible for metabolism of RNA, stimulates carbohydrates, proteins and DNA formation. Zinc plays an important role in synthesis of cell wall which helps to withstand prolonged period without desiccation of middle lamella, as a result improved resistance power against microbial activities, thereby increase the shelf life [29,32].Zinc also helps to overcome the heat stress as a result the surface skin of fruit will not be distorted easily as a result improves the post harvest storage quality [33,29,34].

### 3.2.3 Zinc content in tomato plant during different stages of pickings

The data on concentration of zinc in tomato plant varied significantly due to soil and foliar application of zinc. The results are presented in the Table 5. During 3rd picking treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) recorded higher zinc content (42.1 mg $kg^{-1}$) followed by treatment $T_5$ (40.4 mg $kg^{-1}$), $T_{11}$ (40.3 mg $kg^{-1}$) and $T_{10}$ (40.2 mg $kg^{-1}$), which shows that soil application of zinc improved zinc content in plant than foliar application. During 5th and 8th picking also significantly higher zinc content was recorded in treatment $T_9$ (40.1 and 32.1 mg $kg^{-1}$) and lowest was recorded in control followed by treatment $T_2$ (30.1 and 29.1 mg $kg^{-1}$). In low zinc soils, during 3rd picking treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) recorded higher zinc content (54.10 mg $kg^{-1}$) followed by treatment $T_{11}$ (54.00 mg $kg^{-1}$), $T_9$ (53.90 mg $kg^{-1}$) and $T_5$ (52.10 mg $kg^{-1}$), which shows that soil application of zinc improved zinc content in plant than foliar application. During 5th and 8th picking also significantly higher zinc content was recorded in treatment $T_{10}$ (48.94 and 40.40 mg $kg^{-1}$) and lowest was recorded in control compared to treatment $T_2$ (39.97 and 23.10 mg $kg^{-1}$).

However, the combined application of soil and foliar zinc improved better zinc content of tomato in all the pickings. With increasing the number of pickings there is a gradual reduction of zinc content in the plants, which shows that the applied zinc was used for plant metabolic processes.

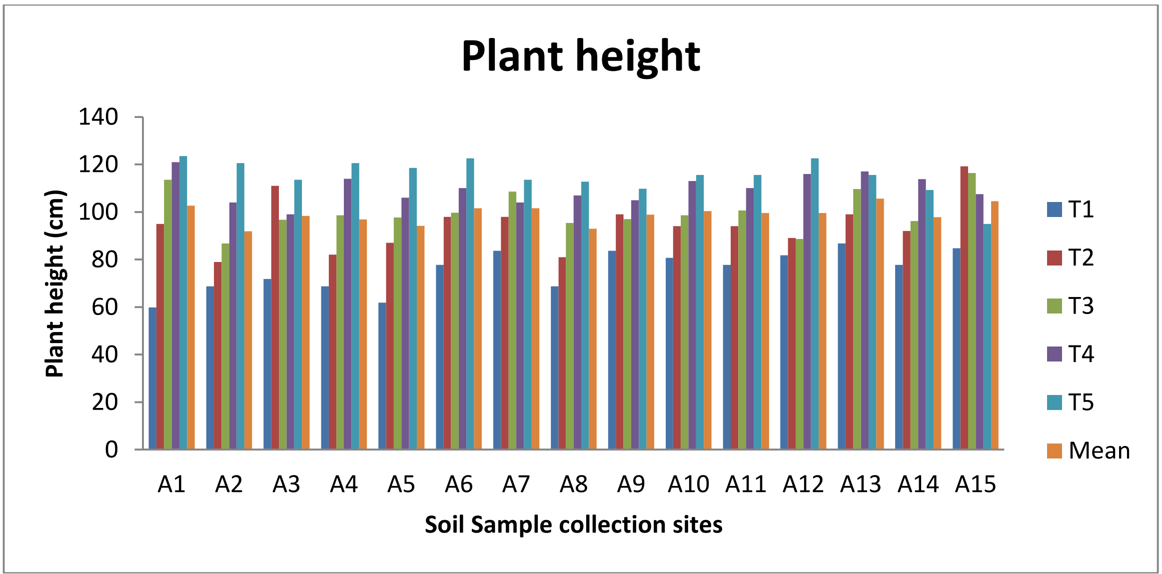
### 3.2.4 Zinc content in tomato fruit during different stages of picking

The data on concentration of zinc in tomato fruit varied significantly due to soil and foliar application of zinc and the results are presented in the Table 5. During 3rd picking treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) recorded higher zinc content (66.7 mg $kg^{-1}$). During 5th and 8th picking also significantly higher zinc content was recorded in treatment $T_9$ (55.6 and 46.1 mg $kg^{-1}$) and lowest was recorded in control compared to treatment $T_2$ (40.02 and 31.2 mg $kg^{-1}$). But in low zinc soils during 3rd picking, treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) recorded higher zinc content (78.10 mg $kg^{-1}$) which is on par with $T_{11}$. During 5th and 8th picking significantly higher zinc content was recorded in treatment $T_{10}$ (64.88 and 55.40 mg $kg^{-1}$) and lowest was recorded in control compared to treatment $T_2$ (55.92 and 44.10 mg $kg^{-1}$). With increasing the number of pickings there is a reduction of zinc content in the fruit which reveals that zinc is an essential component for many enzymes for improvement of quality parameters. However fruit zinc content was more when compared to that of plant zinc content which infers that there is a good transfer coefficient of zinc between plant and fruit shows that the applied zinc through external source was efficiently utilized by the crop (Table 5). However, the combined application of soil and foliar zinc improved better zinc content of tomato in all the pickings. The significant increase in zinc content of plant and fruit may be due to application of zinc through zinc sulphate which is readily soluble in water and hence improved its absorption and concentration in plant tissue and fruit [35]. Dube et al. [18] obtained the highest zinc content of leaves with the high rate of zinc application. Similar results were reported by Salman et al. [17].

### 3.2.5 Zinc uptake and zinc use efficiency (Zn.U.E)

The data pertaining to zinc uptake and zinc use efficiency in high zinc soils by tomato plant was significantly differed due to soil and foliar application of zinc and the results are presented in the Table 5. Significantly higher zinc uptake was recorded in treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25% $ZnSO_4$) as 238.91 g $ha^{-1}$ followed after treatment $T_{10}$ (235.22 g $ha^{-1}$) which are on par with each other and lowest was recorded in control followed after treatment $T_2$ (144.28 g $ha^{-1}$). Highest zinc use efficiency was recorded in treatment $T_9$ with 2.47%. Among different treatments combined application of various levels of soil and foliar zinc recorded higher zinc use efficiency than that of alone soil applied zinc treatments.

But in low zinc soils treatment $T_{10}$ ($T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50% $ZnSO_4$) as 291.53 g $ha^{-1}$ and lowest was recorded in control followed by treatment $T_2$ (203.94 g $ha^{-1}$). Highest zinc use efficiency was recorded in treatment $T_9$ with 3.73% followed by treatment $T_{10}$ (2.64%) and treatment $T_3$ (2.45%). These results are in line with the reports made by Banerjee et al. [36] in potato and Abbas et al. [37] in Wheat.Application of various levels of zinc through soil and foliar application improved the uptake of zinc. This may be due to the application of zinc sulphate which is readily soluble in water, which led to the increased availability and absorption of zinc when applied to soil and also direct absorption of zinc through leaves by foliar application. These results are similar to the findings made by Ranjitha [23].



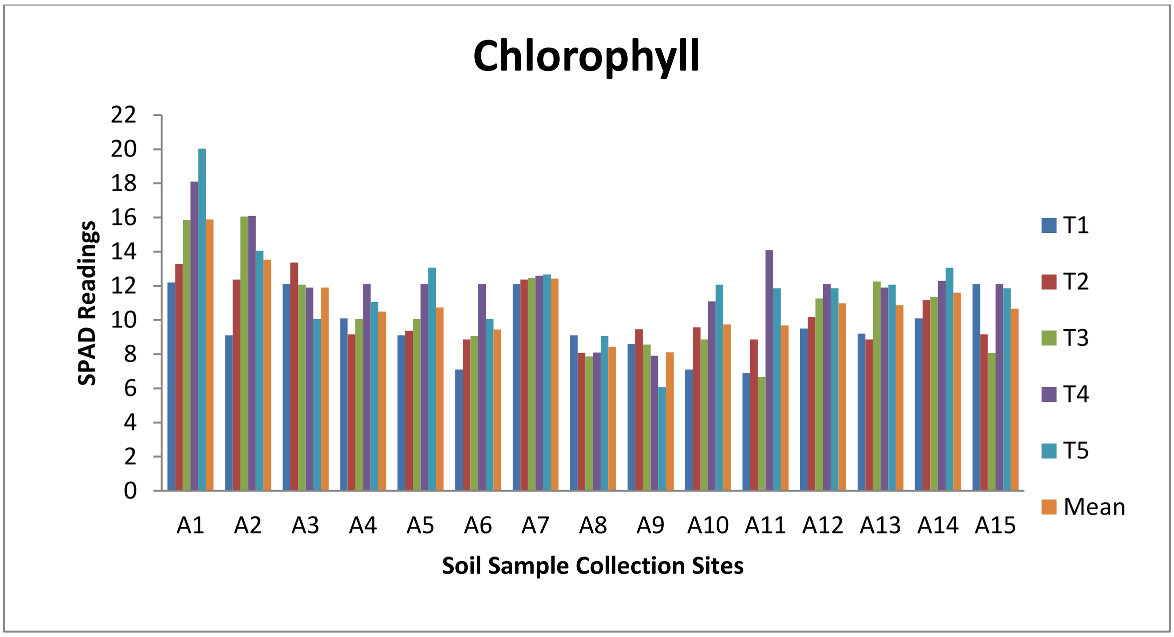



**Fig. 1. Effect of zinc application on growth parameters of tomato grown in different collected soils with varied fertility levels of zinc**

*Note: $T_1$ : RDF; $T_2$ : $T_1$ + $ZnSO_4$ @ 5 kg $ha^{-1}$; $T_3$ : $T_1$+ $ZnSO_4$ @ 10 kg $ha^{-1}$ ;$T_4$ : $T_1$+ $ZnSO_4$ @ 15 kg $ha^{-1}$ ; $T_5$ : $T_1$+ $ZnSO_4$ @ 20 kg $ha^{-1}$*

**Table. 1. Initial physico- chemical properties of the soils for field experiment**

| S. No | Parameters | Experiment No.1 | Experiment No.2. |
|---|---|---|---|
| 1 | Sand (%) | 68.00 | 79.00 |
| 2 | Silt (%) | 11.00 | 9.50 |
| 3 | Clay (%) | 21.00 | 21.50 |
| 4 | Textural class | Sandy clay loam | Sandy clay loam |
| 5 | pH (1:2.5) | 6.99 | 7.55 |
| 6 | EC (1:2.5) (dS/m) | 0.32 | 0.26 |
| 7 | SOC (%) | 0.83 | 0.75 |
| 8 | Available N (kg $ha^{-1}$) | 260.40 | 270.10 |
| 9 | Available $P_2O_5$ (kg $ha^{-1}$) | 52.40 | 49.10 |
| 10 | Available $K_2O$ (kg $ha^{-1}$ ) | 272.00 | 269.10 |
| 11 | Exchangeable Ca (c mol ($p^+$) $kg^{-1}$) | 2.90 | 3.20 |
| 12 | Exchangeable Mg (c mol ($p^+$) $kg^{-1}$) | 1.20 | 1.60 |
| 13 | Available S (kg $ha^{-1}$) | 44.12 | 40.15 |
| 14 | Available DTPA -Zn ( mg $kg^{-1}$ ) | 1.99 | 1.02 |
| 15 | Available Mehlich-3 Zn ( mg $kg^{-1}$ ) | 3.44 | 2.04 |
| 16 | Available AB-DTPA Zn ( mg $kg^{-1}$ ) | 1.86 | 1.01 |
| 17 | Available Fe ( mg $kg^{-1}$ ) | 18.12 | 23.12 |
| 18 | Available Mn ( mg $kg^{-1}$ ) | 5.82 | 6.42 |
| 19 | Available Cu ( mg $kg^{-1}$ ) | 1.12 | 1.81 |
| 20 | Available B ( mg $kg^{-1}$ ) | 0.71 | 0.84 |

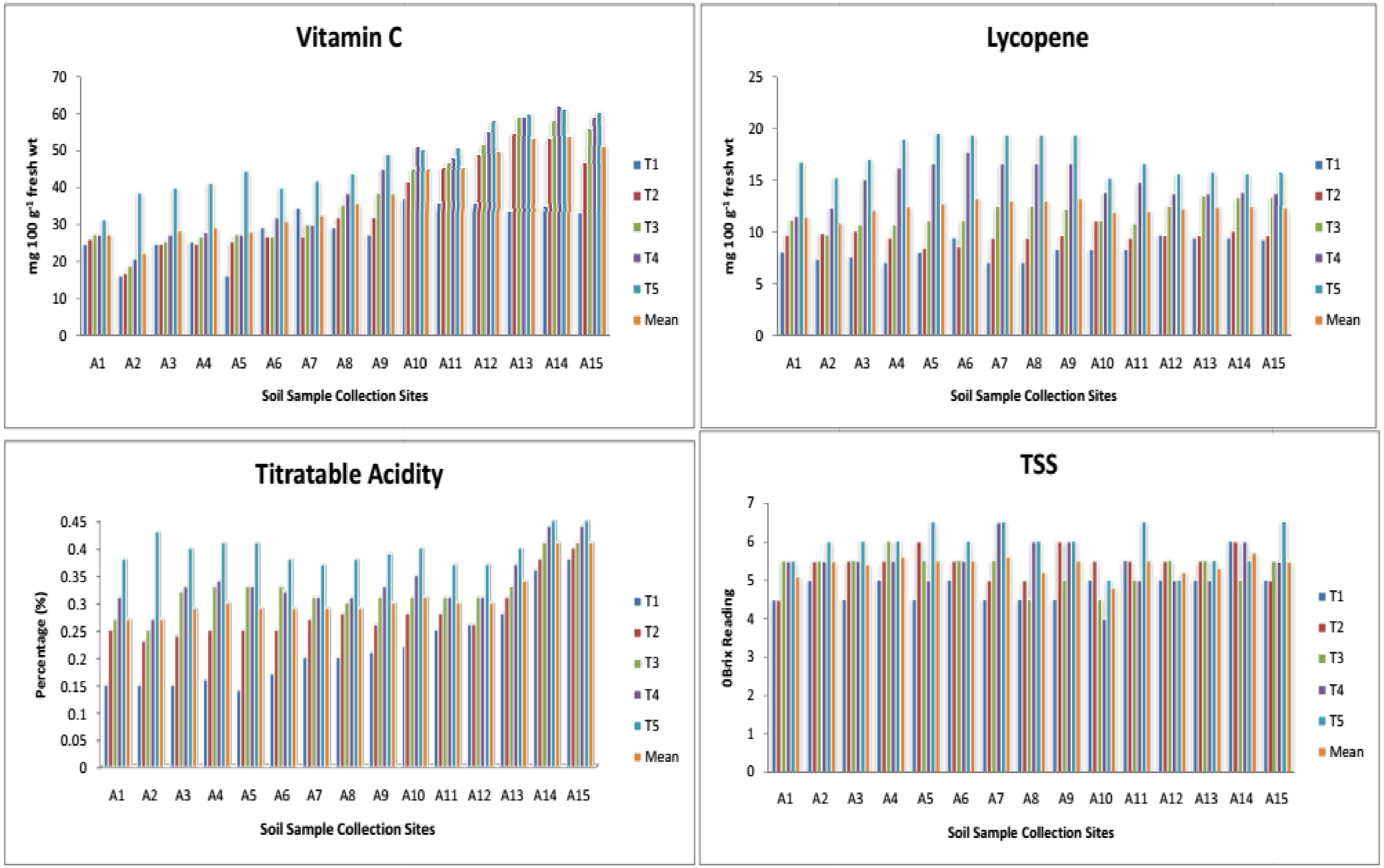



**Fig. 2. Effect of zinc application on quality parameters of tomato grown in different collected soils with varied fertility levels of zinc**

*Note: $T_1$ : RDF; $T_2$ : $T_1$ + $ZnSO_4$ @ 5 kg $ha^{-1}$; $T_3$ : $T_1$+ $ZnSO_4$ @ 10 kg $ha^{-1}$ ;$T_4$ : $T_1$+ $ZnSO_4$ @ 15 kg $ha^{-1}$ ;$T_5$ : $T_1$+ $ZnSO_4$ @ 20 kg $ha^{-1}$*

**Table 2. Effect of soil and foliar application of zinc on growth parameters of tomato in soils**

| Treatments | High Zinc (Sufficient Soils) | | | | | | Low Zinc (Deficient Soils) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plant Height (cm) | | | Chlorophyll content (SPAD reading) | | | Plant Height (cm) | | | Chlorophyll content (SPAD reading) | | |
| | 30 DAT | 60 DAT | 100 DAT | 30 DAT | 60 DAT | 100 DAT | 30 DAT | 60 DAT | 100 DAT | 30 DAT | 60 DAT | 100 DAT |
| $T_1$ : Farmers practice | 28.00 | 64.00 | 104.00 | 11.20 | 11.50 | 16.10 | 25.00 | 60.00 | 91.00 | 10.90 | 12.10 | 15.10 |
| $T_2$ : RDF (Recommended dose of fertilizer) | 32.00 | 74.00 | 110.00 | 16.10 | 13.20 | 17.20 | 30.00 | 71.00 | 99.00 | 12.90 | 13.70 | 14.20 |
| $T_3$ : $T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ SA | 33.00 | 82.00 | 108.00 | 14.30 | 13.40 | 17.80 | 31.00 | 72.00 | 102.00 | 13.90 | 14.20 | 15.90 |
| $T_4$ : $T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as SA | 35.00 | 101.00 | 126.00 | 17.20 | 16.10 | 19.10 | 33.00 | 95.00 | 129.00 | 15.90 | 16.70 | 17.10 |
| $T_5$ : $T_2$+$ZnSO_4$ @ 40 kg $ha^{-1}$ as SA | 36.00 | 105.00 | 138.00 | 16.90 | 16.20 | 22.10 | 34.00 | 96.00 | 134.00 | 15.90 | 16.10 | 21.10 |
| $T_6$ : $T_2$+ FA @ 0.25% $ZnSO_4$ | 34.00 | 78.00 | 109.00 | 14.20 | 13.40 | 16.20 | 33.00 | 88.00 | 111.00 | 14.10 | 14.10 | 15.80 |
| $T_7$ : $T_2$+ FA @ 0.50% $ZnSO_4$ | 34.00 | 89.00 | 124.00 | 15.20 | 14.10 | 18.20 | 32.00 | 92.00 | 114.00 | 12.20 | 14.20 | 15.30 |
| $T_8$ : $T_2$+ FA @ 0.75% $ZnSO_4$ | 35.00 | 94.00 | 129.00 | 16.10 | 15.40 | 17.10 | 32.00 | 94.00 | 122.00 | 17.10 | 18.20 | 19.20 |
| $T_9$ : $T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as SA + FA @ 0.25% $ZnSO_4$ | 39.00 | 110.00 | 140.00 | 17.00 | 19.70 | 22.20 | 34.00 | 101.00 | 133.00 | 15.80 | 18.20 | 20.10 |
| $T_{10}$ : $T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as SA + FA @ 0.50% $ZnSO_4$ | 39.00 | 102.00 | 132.00 | 16.50 | 16.70 | 19.10 | 32.00 | 109.00 | 138.00 | 16.00 | 17.40 | 23.10 |
| $T_{11}$ : $T_2$+$ZnSO_4$ @ 40 kg $ha^{-1}$ as SA + FA @ 0.75% $ZnSO_4$ | 35.00 | 109.00 | 138.00 | 16.80 | 16.20 | 20.10 | 32.00 | 103.00 | 132.00 | 15.90 | 17.90 | 19.10 |
| S.Em± | 0.703 | 1.111 | 0.164 | 0.319 | 0.162 | 0.024 | 0.646 | 1.097 | 0.187 | 0.296 | 0.024 | 0.207 |
| CD (P=0.05) | 2.07 | 3.28 | 0.46 | 0.94 | 0.48 | 0.07 | 1.91 | 3.24 | 0.55 | 0.87 | 0.07 | 0.61 |

*Note: DAT : Days after Transplanting SA : Soil application FA : Foliar application*

**Table 3. Effect of soil and foliar application of zinc on productivity of tomato in soils**

| Treatments | High Zinc (Sufficient Soils) | | | | | | | Low Zinc (Deficient Soils) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of fruits | | | Wt. of fruits (kg 5 plants$^{-1}$) | | | Yield(t ha$^{-1}$) | No. of fruits | | | Wt. of fruits (kg 5 plants$^{-1}$) | | | Yield(t ha$^{-1}$) |
| | $P_1$ | $P_2$ | $P_3$ | $P_1$ | $P_2$ | $P_3$ | | $P_1$ | $P_2$ | $P_3$ | $P_1$ | $P_2$ | $P_3$ | |
| $T_1$ : Farmers practice | 49.00 | 47.84 | 35.10 | 2.40 | 1.60 | 1.20 | 35.10 | 42.00 | 31.89 | 29.00 | 2.60 | 1.50 | 1.00 | 36.44 |
| $T_2$ : RDF (Recommended dose of fertilizer) | 56.00 | 50.83 | 50.05 | 3.20 | 2.50 | 1.90 | 50.05 | 50.00 | 37.87 | 31.00 | 3.00 | 2.20 | 1.30 | 52.46 |
| $T_3$ : $T_2$+$ZnSO_4$ @ 20 kg ha$^{-1}$ SA | 59.00 | 47.84 | 59.61 | 3.30 | 2.20 | 1.90 | 59.61 | 51.00 | 40.86 | 40.00 | 3.10 | 2.40 | 1.20 | 58.24 |
| $T_4$ : $T_2$+$ZnSO_4$ @ 30 kg ha$^{-1}$ as SA | 59.00 | 45.85 | 59.35 | 3.40 | 2.30 | 1.10 | 59.35 | 54.00 | 43.85 | 40.00 | 3.40 | 2.60 | 1.00 | 59.23 |
| $T_5$ : $T_2$+$ZnSO_4$ @ 40 kg ha$^{-1}$ as SA | 61.00 | 47.84 | 57.65 | 3.50 | 2.10 | 1.10 | 57.65 | 55.00 | 49.83 | 41.00 | 3.30 | 2.10 | 1.50 | 55.94 |
| $T_6$ : $T_2$+ FA @ 0.25% $ZnSO_4$ | 66.00 | 48.84 | 52.35 | 3.20 | 2.30 | 1.30 | 52.35 | 54.00 | 40.86 | 38.00 | 3.40 | 2.10 | 1.50 | 53.14 |
| $T_7$ : $T_2$+ FA @ 0.50% $ZnSO_4$ | 64.00 | 46.84 | 51.93 | 3.10 | 2.10 | 1.40 | 51.93 | 54.00 | 38.87 | 38.00 | 3.30 | 2.10 | 1.60 | 53.01 |
| $T_8$ : $T_2$+ FA @ 0.75% $ZnSO_4$ | 69.00 | 43.85 | 52.07 | 3.10 | 2.30 | 1.50 | 52.07 | 51.00 | 39.87 | 39.00 | 3.40 | 1.80 | 1.20 | 54.24 |
| $T_9$ : $T_2$+$ZnSO_4$ @ 20 kg ha$^{-1}$ as SA + FA @ 0.25% $ZnSO_4$ | 71.00 | 60.80 | 64.52 | 4.20 | 2.80 | 1.60 | 64.52 | 55.00 | 45.85 | 41.00 | 3.30 | 2.10 | 1.60 | 59.84 |
| $T_{10}$ : $T_2$+$ZnSO_4$ @ 30 kg ha$^{-1}$ as SA + FA @ 0.5% $ZnSO_4$ | 69.00 | 48.84 | 62.32 | 4.10 | 2.40 | 1.70 | 62.32 | 61.00 | 50.83 | 42.00 | 3.90 | 2.10 | 1.80 | 62.11 |
| $T_{11}$ : $T_2$+$ZnSO_4$ @ 40 kg ha$^{-1}$ as SA + FA @ 0.75% $ZnSO_4$ | 64.00 | 50.83 | 60.48 | 3.90 | 2.10 | 1.10 | 60.48 | 60.00 | 49.83 | 39.00 | 3.60 | 2.10 | 1.90 | 60.12 |
| S.Em± | 0.075 | 0.355 | 0.079 | 0.069 | 0.003 | 0.022 | 0.079 | 0.059 | 0.479 | 0.775 | 0.067 | 0.020 | 0.029 | 0.058 |
| CD (P=0.05) | 0.22 | 1.05 | 0.23 | 0.20 | 0.01 | 0.07 | 0.23 | 0.17 | 1.41 | 2.29 | 0.20 | 0.06 | 0.08 | 0.17 |

*Note: $P_1$: 3rd picking $P_2$: 5th picking $P_3$: 8th picking SA: Soil application FA : Foliar application*

**Table 4. Effect of soil and foliar applied zinc on quality parameters of tomato in soils**

| Treatments | High Zinc (Sufficient Soils) | | | | | Low Zinc (Deficient Soils) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | TSS | Titratable acidity | Vitamin C | Lycopene | Shelf life | TSS | Titratable acidity | Vitamin C | Lycopene | Shelf life |
| | $^0$Brix | % | mg 100 $g^{-1}$ fresh wt | | days | $^0$Brix | % | mg 100 $g^{-1}$ fresh wt | | days |
| $T_1$ : Farmers practice | 4.30 | 0.24 | 28.08 | 11.43 | 16 | 4.20 | 0.25 | 28.00 | 9.87 | 14.00 |
| $T_2$ : RDF (Recommended dose of fertilizer) | 4.60 | 0.27 | 33.16 | 12.56 | 18 | 4.50 | 0.27 | 29.40 | 10.17 | 17.00 |
| $T_3$ : $T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ SA | 4.80 | 0.27 | 35.05 | 12.24 | 18 | 4.80 | 0.26 | 33.17 | 10.27 | 17.00 |
| $T_4$ : $T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as SA | 5.20 | 0.29 | 38.94 | 13.14 | 22 | 5.20 | 0.38 | 47.12 | 12.81 | 21.00 |
| $T_5$ : $T_2$+$ZnSO_4$ @ 40 kg $ha^{-1}$ as SA | 5.80 | 0.36 | 49.54 | 13.12 | 25 | 5.20 | 0.41 | 49.62 | 12.82 | 22.00 |
| $T_6$ : $T_2$+ FA @ 0.25% $ZnSO_4$ | 4.90 | 0.28 | 39.04 | 12.17 | 19 | 4.90 | 0.33 | 38.17 | 11.24 | 20.00 |
| $T_7$ : $T_2$+ FA @ 0.50% $ZnSO_4$ | 4.90 | 0.28 | 36.15 | 12.52 | 23 | 4.90 | 0.37 | 39.17 | 11.17 | 21.00 |
| $T_8$ : $T_2$+ FA @ 0.75% $ZnSO_4$ | 4.90 | 0.29 | 39.04 | 12.92 | 22 | 4.90 | 0.36 | 48.12 | 12.62 | 22.00 |
| $T_9$ : $T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as SA + FA @ 0.25% $ZnSO_4$ | 6.00 | 0.39 | 53.71 | 13.24 | 24 | 5.90 | 0.42 | 53.82 | 12.96 | 22.00 |
| $T_{10}$ : $T_2$+$ZnSO_4$ @ 30 kg $ha^{-1}$ as SA + FA @ 0.50% $ZnSO_4$ | 6.00 | 0.36 | 53.06 | 13.32 | 23 | 5.80 | 0.47 | 55.24 | 13.30 | 23.00 |
| $T_{11}$ : $T_2$+$ZnSO_4$ @ 40 kg $ha^{-1}$ as SA + FA @ 0.75% $ZnSO_4$ | 5.20 | 0.34 | 47.91 | 13.38 | 23 | 5.80 | 0.42 | 54.16 | 13.20 | 23.00 |
| S.Em± | 0.043 | 0.014 | 0.693 | 0.014 | 0.243 | 0.104 | 0.011 | 0.124 | 0.244 | 0.211 |
| CD (P=0.05) | 0.12 | 0.02 | 2.04 | 0.02 | 0.70 | 0.31 | 0.02 | 0.34 | 0.72 | 0.62 |

*Note: SA : Soil application FA : Foliar application*

**Table 5. Effect of soil and foliar applied zinc on nutrient content, uptake and NUE of tomato soils**

| **Treatments** | **High Zinc (Sufficient Soils)** | | | | | | | | **Low Zinc (Deficient Soils)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Tomato Leaves Zn Content (mg kg$^{-1}$)** | | | **Tomato Fruit Zn Content(mg kg$^{-1}$)** | | | **Zn uptakeg ha$^{-1}$** | **Zn.U.E(%)** | **Tomato Leaves Zn Content (mg kg$^{-1}$)** | | | **Tomato Fruit Zn Content (mg kg$^{-1}$)** | | | **Zn uptake g ha$^{-1}$** | **Zn.U.E(%)** |
| | **$P_1$** | **$P_2$** | **$P_3$** | **$P_1$** | **$P_2$** | **$P_3$** | | | **$P_1$** | **$P_2$** | **$P_3$** | **$P_1$** | **$P_2$** | **$P_3$** | | |
| $T_1$ : Farmers practice | 22 | 23.1 | 26.1 | 41.7 | 35.6 | 32.5 | 134.75 | - | 24.10 | 20.03 | 19.00 | 40.12 | 35.99 | 30.12 | 124.88 | - |
| $T_2$ : RDF (Recommended dose of fertilizer) | 33.1 | 30.1 | 29.1 | 48.7 | 40.2 | 31.2 | 144.28 | - | 42.10 | 39.97 | 23.10 | 66.10 | 55.92 | 44.10 | 203.94 | - |
| $T_3$ : $T_2$+$ZnSO_4$ @ 20 kg ha$^{-1}$ SA | 34.9 | 30.4 | 27.1 | 55.3 | 46.1 | 30.4 | 144.22 | 0.22 | 43.10 | 39.97 | 24.10 | 68.10 | 58.90 | 48.10 | 228.19 | 2.45 |
| $T_4$ : $T_2$+$ZnSO_4$ @ 30 kg ha$^{-1}$ as SA | 39.4 | 36.7 | 28.1 | 64.2 | 54.1 | 40.1 | 193.43 | 0.93 | 48.10 | 49.93 | 32.40 | 70.10 | 61.20 | 52.40 | 252.76 | 2.02 |
| $T_5$ : $T_2$+$ZnSO_4$ @ 40 kg ha$^{-1}$ as SA | 40.4 | 38.4 | 27.1 | 63.4 | 57.4 | 42.7 | 207.68 | 0.87 | 52.10 | 48.94 | 34.70 | 70.10 | 64.09 | 54.30 | 264.09 | 1.65 |
| $T_6$ : $T_2$+ FA @ 0.25% $ZnSO_4$ | 35.7 | 30.2 | 26.1 | 58.2 | 47.4 | 35.2 | 179.62 | - | 44.10 | 39.97 | 25.10 | 69.10 | 57.91 | 49.40 | 252.08 | - |
| $T_7$ : $T_2$+ FA @ 0.50% $ZnSO_4$ | 36.4 | 34.1 | 29.1 | 61.4 | 49.8 | 36.7 | 175.57 | - | 45.10 | 44.95 | 26.40 | 68.10 | 57.21 | 50.10 | 239.67 | - |
| $T_8$ : $T_2$+ FA @ 0.75% $ZnSO_4$ | 37.7 | 38.1 | 27.1 | 63.7 | 51.4 | 39.1 | 185.49 | - | 46.10 | 50.93 | 28.40 | 69.10 | 58.90 | 51.20 | 242.89 | - |
| $T_9$ : $T_2$+$ZnSO_4$ @ 20 kg ha$^{-1}$ as SA + FA @ 0.25% $ZnSO_4$ | 42.1 | 40.1 | 32.1 | 66.7 | 55.6 | 46.1 | 238.91 | 2.47 | 53.90 | 48.94 | 39.60 | 72.10 | 63.49 | 54.40 | 281.93 | 3.73 |
| $T_{10}$ : $T_2$+$ZnSO_4$ @ 30 kg ha$^{-1}$ as SA + FA @ 0.50 % $ZnSO_4$ | 40.2 | 38.9 | 28.1 | 65.2 | 54.6 | 44.7 | 235.22 | 1.59 | 54.10 | 48.94 | 40.40 | 78.10 | 64.88 | 55.40 | 291.53 | 2.64 |
| $T_{11}$ : $T_2$+$ZnSO_4$ @ 40 kg ha$^{-1}$ as SA + FA @ 0.75% $ZnSO_4$ | 40.3 | 34.1 | 26.1 | 63.5 | 56.2 | 43.1 | 221.65 | 1.03 | 54.00 | 47.94 | 38.40 | 74.70 | 62.59 | 54.20 | 278.73 | 1.83 |
| S.Em± | 0.40 | 0.69 | 0.02 | 0.56 | 1.02 | 0.06 | 2.63 | 0.07 | 0.09 | 0.72 | 0.531 | 1.38 | 0.65 | 0.08 | 0.53 | 0.11 |
| CD (P=0.05) | 1.18 | 2.05 | 0.06 | 1.66 | 3.02 | 0.19 | 7.75 | 0.20 | 0.29 | 2.13 | 1.57 | 4.08 | 1.91 | 0.25 | 1.58 | 0.32 |

*Note: $P_1$: 3$^{rd}$ picking $P_2$: 5$^{th}$ picking $P_3$: 8$^{th}$ picking SA: Soil application FA : Foliar application*

## 4. CONCLUSION

From the present investigation it is concluded that there is a need of external zinc application through soil and foliar spray in both sufficient and deficient zinc soils along with RDF is recommended for better productivity of tomato. In low zinc soils, the treatment $T_{10}$ [$T_2$ (RPP) + $ZnSO_4$ @ 30 kg $ha^{-1}$ as soil application + Foliar application of @ 0.50 % $ZnSO_4$] and in high zinc soils treatment $T_9$ ($T_2$+$ZnSO_4$ @ 20 kg $ha^{-1}$ as soil application + Foliar application of @ 0.25 % $ZnSO_4$) helped to increase growth parameters, yield parameters, quality parameters, nutrient concentration in plant and fruit, nutrient uptake in plant and fruit, use efficiency of zinc when compared to other treatments.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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