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EFFECT OF SOIL AND FOLIAR APPLIED MICRONUTRIENT CONSORTIA ON ALLEVIATION OF MICRONUTRIENT DEFICIENCY IN KINNOW (*CITRUS NOBLIS X CITRUS DELICIOSA*)

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Abstract

The deficiency of micronutrients in citrus orchards is a big issue. It not only deteriorates the fruit quality, buts also plays a major role in decreasing the yield. High soil pH, electrical conductivity (EC), $CaCO_3$, and low organic matter contents are some of the vital factors which usually decrease the uptake of applied micronutrients in plants. On the other hand, foliar application of micronutrients is considered as one of the meaningful approaches to overcome this issue; it not only increases nutrient uptake, but also decreases the application rate of inorganic fertilizer. Scientists have worked on soil and foliar application of micronutrients to plants, but limited literature is available on the effect of micronutrient consortia on citrus. Due to this reason, the current study was conducted to explore the effectiveness of application of micronutrient consortia to alleviate micronutrient deficiency in citrus. There were 10 treatments applied with 4 replications following a randomized complete block design. Results showed that application of T10 as soil (T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant) and foliar application (T1 + 0.6% $ZnSO_4$ + 0.5% boric acid + 0.6% $FeSO_4$ + 0.5% $CuSO_4$ + 0.5%$MnSO_4$). remained significantly best compared to all other treatments for improving fruit weight, vertical diameter, horizontal diameter, number of seeds, and seed weight in citrus. A significant enhancement in the yield of citrus due to T10 as soil and foliar application validated the effectiveness of the treatment compared to the control. In conclusion, growers are recommended to apply T10 as soil (T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant) and foliar application (T1 + 0.6% $ZnSO_4$ + 0.5% boric acid + 0.6% $FeSO_4$ + 0.5% $CuSO_4$ + 0.5%$MnSO_4$) for the improvement of citrus growth and yield.

Key words: Nutrient deficiency; Application methods; Growth attributes; Yield attributes. Micronutrients uptake.

Introduction

Citrus (*Citrus sinensis* L.) has occupied the third position in subtropical fruits and is considered an important fruit due to its nutritional value and daily requirement as food (Gregory, 1993). It contributes almost 30% to the orchard-cultivated area covering Pakistan (Ashraf *et al*., 2013). According to world data analysis, production of citrus increased up to 4.14% from 1970 to 2019 in Pakistan. However, this improvement in citrus production was quite low as compared to China (10.65% average annual rate) and India (5.24% average annual rate) (Knoema, 2021). However, farmers in various regions are still unaware of the use of micronutrient fertilizers in citrus. Due to this, orchard plants have to face a deficiency of micronutrients, e.g., zinc (Zn), manganese (Mn), boron (B), iron (Fe) and copper (Cu) (Jiskani, 2017).

Imbalance and inappropriate application of fertilizers are some of the major drawbacks in the orchard cultivation system. Various studies have highlighted the deficiencies of micro-nutrients, especially B, Zn, Fe, and Cu (Zia *et al*., 2006; Ibrahim *et al*., 2007). Various factors reduce micronutrient availability in soils, such as low organic matter, high pH, soil temperature, $CaCO_3$, and other agronomic practices (Fageria *et al*., 2002; Rashid & Ryan, 2004). Poor nutrition of citrus plants also affects fruit yield and quality. It may cause fruit impairment, earlier fruit drop, and reduced yield (Ashraf *et al*., 2012). Due to improper practice of micronutrient fertilization, soils are becoming more deficient, leading to nutrient-deficient plant production (Zia *et al*., 2006; Ibrahim *et al*., 2007). This situation can be tackled with proper micronutrient fertilization.

Micronutrients can be applied via the soil /foliar method, and both methods have their boon and bane. Soil-applied fertilizers are faced with various kinds of chemical reactions, which reduce their efficiency. Moreover, Pakistan's soils are high in calcium carbonate content and high pH, which mediate unfavorable soil micro-nutrient mobility (Zekri & Obreza, 2003). Another technique used is the foliar application of micronutrients, which is gaining attention due to its higher efficiency rate that has been reported in various studies (Bastakoti *et al*., 2022). Foliar application of Zn, B, and Mn increases the absorption of these micronutrients in the leaf tissues (Piri, 2012). Kinnow mandarin is widely cultivated in Aridsols, considered less fertile soils with high soil pH, usually 8.5-9 or above. High-pH soils are usually deficient in micronutrients. For sustaining citrus production in such regions, the application of micronutrients is becoming a mandatory practice (Zia *et al*., 2006).

Due to this reason, the current study focused on the effect of soil and foliar micronutrient application on citrus growth, leaf nutrient concentrations, and yield. This study fills the knowledge gap regarding the use of micronutrient application methods and combinations of different types of micronutrients for improving citrus growth, leaf nutrient concentrations, and fruit yield. The selection of a better application method for citrus grown in calcareous alkaline soils under different micronutrient combinations is the novel aspect of the current study. It is hypothesized that foliar application of micronutrients is a better approach for improving citrus growth, leaf nutrient concentrations, and fruit yield under calcareous alkaline soils.

Material and Methods

Experimental site and selection of citrus trees: In Layyah District, a field trial was conducted to determine the effect of micronutrient applications on citrus growth and yield. For experimental purposes, a total of 40 citrus trees at 12-14 years of age were chosen. The experiment was performed according to a randomized complete block design. Each tree was considered as a single experimental unit.

Characteristics of soil: Analysis of the soil of the selected site was done following the standard protocols for the assessment of pre-experimental soil attributes. A total of 10 different soil samples were collected in a zig-zag manner for the preparation of each of composite samples. The characteristics of the soil are presented in (Table 1).

Fertilizer: Macronutrients (NPK) were applied in all treatments at a 1000:500:500 rate. Micronutrients were applied as soil basal and foliar spray. Zinc, iron, boron, copper, and manganese sources were applied as zinc sulfate, ferrous sulfate, borax, copper sulfate, and manganese sulfate (Table 2). In each treatment, the NPK was applied as urea, single super phosphate, potassium sulfate, and 30 kg FYM. For soil application, micronutrients were mixed in soil and applied under the tree canopy. Whereas for foliar application, surfactant Tween-20 @ 0.01% was added to the solution of micronutrients for proper adhering of spray particles on the leaf surface. The treatments were applied in the last week of January and in the 2nd week of May.

Data collection: A top-loading balance was used for recording the data for citrus fruit weight. However, horizontal and vertical diameters were assessed by using a vernier caliper. For peel weight, a laboratory analytical grade balance was used.

Table 1. Pre-experimental soil attributes.

Attributes	Units	Values	References
Textural class	-	Sandy loam	(Gee & Bauder, 1986)
Soil pH	-	8.1	(Page *et al*., 1983)
Soil EC	(dS m^{-1})	0.94	(Rhoades, 1996)
Organic matter	(%)	0.32	(Nelson & Sommers, 1982)
$CaCO_3$	(%)	8.53	(Loeppert & Suarez, 2018)
DTPA-Extractable Zn		0.43	
DTPA-Extractable Fe		3.7	
DTPA-Extractable B	µg/g	0.34	(Lindsay & Norvell, 1978)
DTPA-Extractable Cu		0.05	
DTPA-Extractable Mn		0.8	

Table 2. Treatment chart of soil and foliar application of micronutrients.

T	Soil	Foliar
T1	NPK (1000:500:500 g/plant) + 30 kg FYM	NPK (1000:500:500 g/plant)+ 30kg FYM + water spray
T2	T1 + 250 g $ZnSO_4$/plant	T1 + 0.6% $ZnSO_4$
T3	T1 + 150 g borax/plant	T1 + 0.5% boric acid
T4	T1 + 550 g $FeSO_4$/plant	T1 + 0.6% $FeSO_4$
T5	T1 + 200 g $CuSO_4$/plant	T1 + 0.5% $CuSO_4$
T6	T1 + 350 g $MnSO_4$/plant	T1 + 0.5% $MnSO_4$
T7	T1 + 250 g $ZnSO_4$ + 150 g borax/plant	T1 + 0.6% $ZnSO_4$ + 0.5% boric acid
T8	T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant	T1 + 0.6% $ZnSO_4$ + 0.5% boric acid + 0.6% $FeSO_4$
T9	T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant	T1 + 0.6% $ZnSO_4$ + 0.5% boric acid + 0.6% $FeSO_4$ + 0.5% $CuSO_4$
T10	T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant	T1 + 0.6% $ZnSO_4$ + 0.5% boric acid + 0.6% $FeSO_4$ + 0.5% $CuSO_4$ + 0.5%$MnSO_4$

Micronutrient analysis: Initially, the samples were digested by using di-acid (Miller, 1998). After that filtration was done to remove the insoluble particles. Finally, the digested plant samples were run on an atomic absorption spectrophotometer to quantify Zn, Fe, Cu, and Mn (Hanlon, 1998).

Boron analysis: Boron was determined by ashing one-gram sample in a muffle furnace at 550 °C for 6 h. The ash was then wetted with water and 10 mL 0.36 N H_2SO_4 were added and the samples were heated for 20 min in a steam bath. After cooling and stirring the samples for one hour, they were filtered, and the final volume was brought to 50 mL. In 1 mL of prepared aliquot, 2 mL of buffer and 2 mL azomethine-H (Azomethine-H + ascorbic acid + water) solution were added. The absorbance of the samples was then determined on a spectrophotometer at 420 nm wavelength (Bingham, 1982).

Statistical Analysis

Standard statistical analysis was done by following standard statistical procedures (Steel *et al*., 1997). Origin2021 software was used for statistical computation of data and graph making. Treatment means were compared by LSD at $p \leq 0.05$ (OriginLab Corporation, 2021).

Results

The effect of treatments was significant on the fruit weight of citrus. The results showed that T10 (T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant) performed significantly better compared to T1 during 1st and 2nd years when applied in the soil as a treatment for an increase in citrus fruit weight. It was observed that T10 performance was significantly better over T1 in 1st and 2nd year where treatment application was done as foliar for the enhancement in citrus fruit weight. No significant change was observed among T9 and T8 for fruit weight in 1st and 2nd years when the mode of application was soil and foliar. It was also noted that T7 was significantly better than T6 for increment in fruit weight when applied as soil application in 1st and 2nd years (Fig. 1). However, T7 and T6 remained statistically alike to each other for fruit weight when added as foliar application during 1st and 2nd years. The maximum increase in fruit weight was noted where T10 was applied as treatment over T1 as soil and foliar application in 1st and 2nd years.

The influence of applied treatments was significant on fruit vertical diameter of citrus. It was observed that T7 during 1st year and T7 and T8 during 2nd year differed significantly better over T1 when applied in the soil as a treatment for enhancement in citrus fruit vertical diameter. On the other hand, treatment T10 was significantly better than T1 in 1st and 2nd years when applied as foliar for the increment in citrus fruit vertical diameter. A significant change was observed in T2, T3, T4, T5, and T6 for fruit vertical diameter in 1st and 2nd years compared to T1 when the mode of application was soil. However, T2, T3, T4, T5, and T6 did not differ significantly over T1 for fruit vertical diameter when the mode of application was foliar during 1st and 2nd years (Fig. 2). The maximum increase in fruit vertical diameter was noted where T7 and T10 were applied as treatment over T1 as soil and foliar application respectively in 1st and 2nd years.

In the case of horizontal diameter, the impact of applied treatments was significant. Treatments T3, T4, T5, T6, T7, T8, T9, and T10 during 1st and 2nd years were significantly better compared to T1 when applied in the soil as a treatment for improvement in citrus fruit horizontal diameter. Furthermore, treatment T2 did not differ significantly over T1 in 1st and 2nd years when applied as a soil treatment for the increment in citrus fruit horizontal diameter. A significant change was observed fruit horizontal diameter in 1st and 2nd years over T1 when the mode of application was foliar and T2 was applied. Similarly, T3, T4, T5, T6, T7, T8, T9, and T10 differed significantly over T1 for fruit horizontal diameter when the mode of application was foliar during 1st and 2nd years (Fig. 3). The maximum increase in fruit horizontal diameter was noted where T10 was applied as treatment over T1 as soil and foliar application in 1st and 2nd years.

The impact of treatments was significant on citrus fruit peel weight. The results exhibited that T2, T3, T4, T5, T6, T7, T8, T9, and T10 during 1st and 2nd years performed significantly better compared to T1 when applied in the soil as a treatment for an increase in citrus fruit peel weight. Similarly, T2, T3, T4, T5, T6, T7, T8, T9, and T10 during 1st and 2nd years also performed significantly better compared to T1 where treatment application was done as foliar for the increase in citrus fruit peel weight (Fig. 4). The maximum increase in fruit peel weight was noted when T10 and T7 were applied as soil and foliar application, respectively, in 1st and 2nd years.

For several seeds, the influence of treatments was significant. The results exhibited that T2, T3, and T4 during 1st and 2nd years did not show any significant difference in citrus fruit number of seeds compared to T1 when applied in the soil. Similarly, T2 and T3 during 1st and 2nd years also remained statistically alike to T1 where treatment application was done as foliar for citrus fruit number of seeds. A significant enhancement in the number of seeds was observed in T8, T9, and T10 compared to T1 applied as soil and foliar application methods during 1st and 2nd years (Fig. 5). A maximum increase in fruit number of seeds was noted where T10 was applied as treatment over T1 as soil and foliar application in 1st and 2nd years.

In the case of seed weight, the effect of treatments was significant. It was observed that T2, T3, T4, T5, T6, T7, T8, T9, and T10 during 1st and 2nd years showed a significant change compared to T1 when applied in the soil as a treatment for citrus fruit seeds weight. Similarly, T2, T3, T4, T5, T6, T7, T8, T9, and T10 during 1st and 2nd years also induced a significant improvement in seeds weight over T1 where treatment application was done as foliar. Furthermore, T2, T3, T4, T5, and T6 when applied as soil and foliar treatments remained statistically alike to each other for fruit seed weight during 1st and 2nd years (Fig. 6). However, T10 and T9 performed significantly better for an increase in fruit weight compared to T2, T3, T4, T5, and T6 applied as soil and foliar treatments in 1st and 2nd years. The maximum increase in fruit seed weight was noted under T10 as soil and foliar application in 1st and 2nd years. Compared to that in T1.

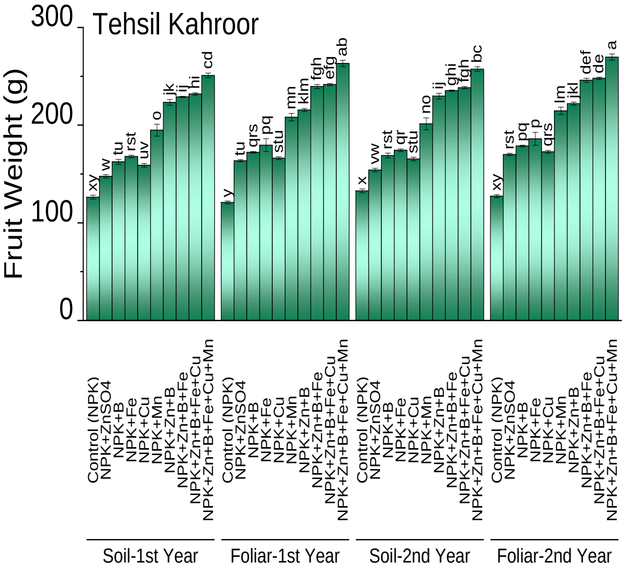

Fig. 1. Effect of treatments applied as soil and foliar application on citrus fruit weight for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars show significant change at $p≤0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

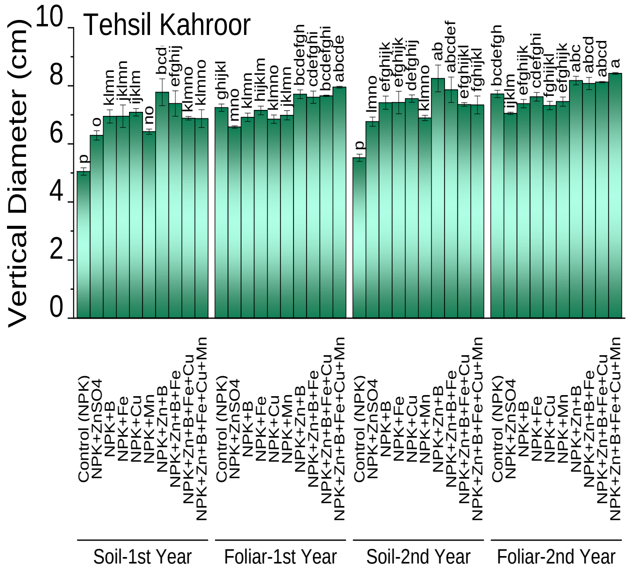

Fig. 2. Effect of treatments applied as soil and foliar application on citrus fruit vertical diameter for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars show significant change at $p≤0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

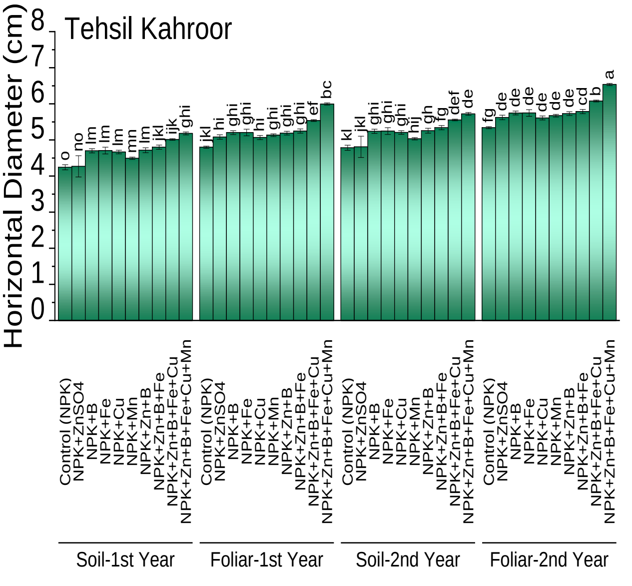

Fig. 3. Effect of treatments applied as soil and foliar application on citrus fruit horizontal diameter for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars show significant change at $p≤0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

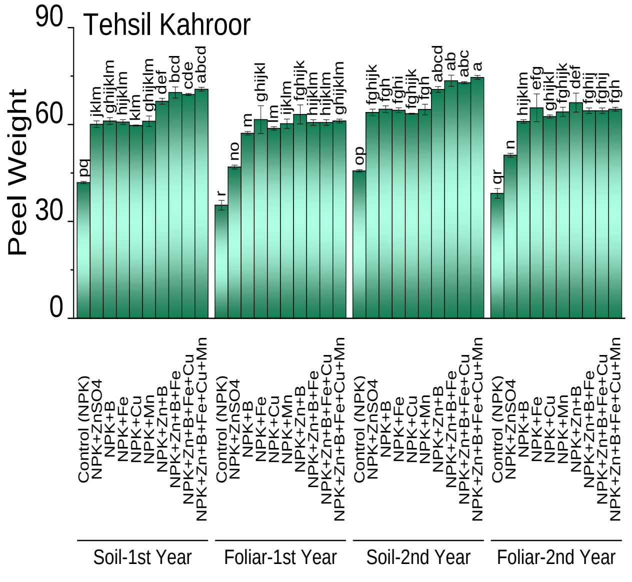

Fig. 4. Effect of treatments applied as soil and foliar application on citrus fruit peel weight for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars show significant change at $p≤0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

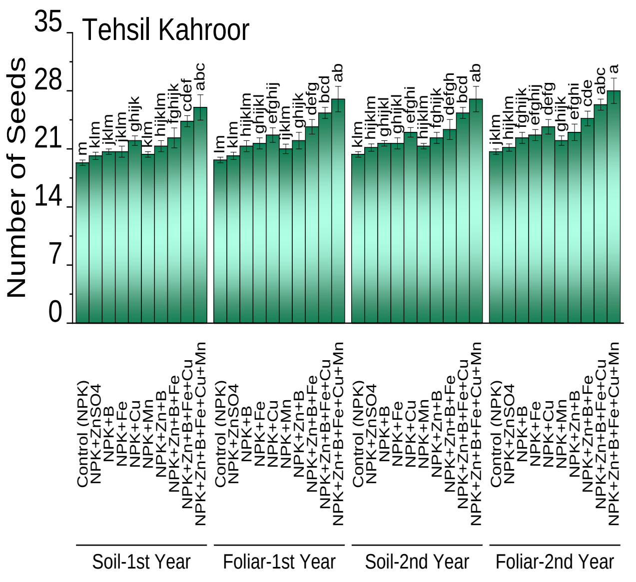

Fig. 5. Effect of treatments applied as soil and foliar application on citrus fruit number of seeds for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars show significant change at $p \leq 0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

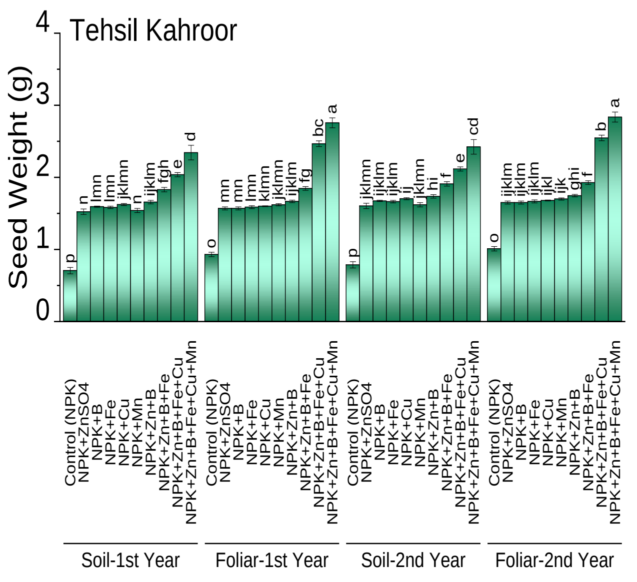

Fig. 6. Effect of treatments applied as soil and foliar application on citrus fruit seeds weight for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars show significant change at $p \leq 0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

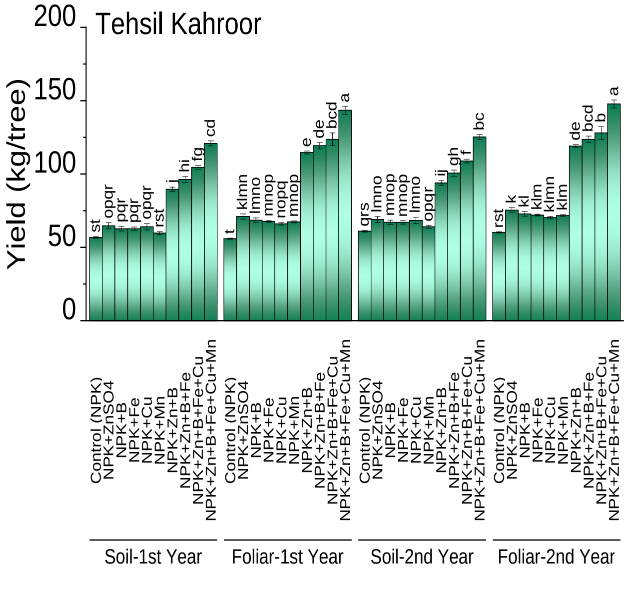

Fig. 7. Effect of treatments applied as soil and foliar application on citrus fruit yield for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars show significant change at $p \leq 0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

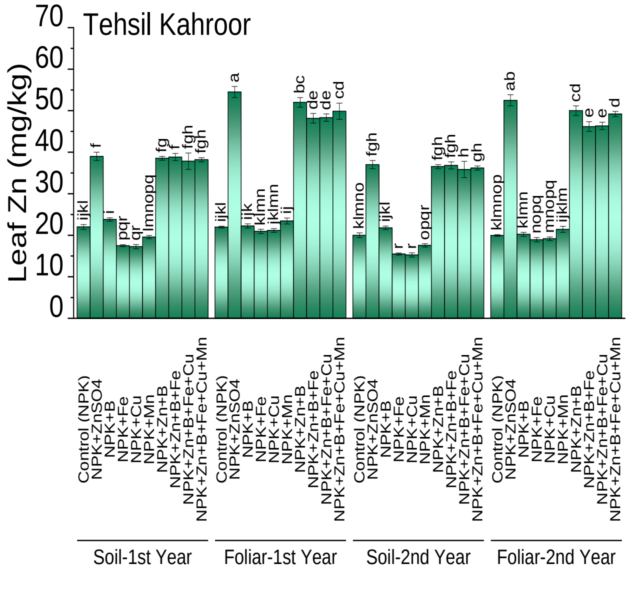

Fig. 8. Effect of treatments applied as soil and foliar application on citrus leaf Zn concentration for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars are showing significant change at $p \leq 0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

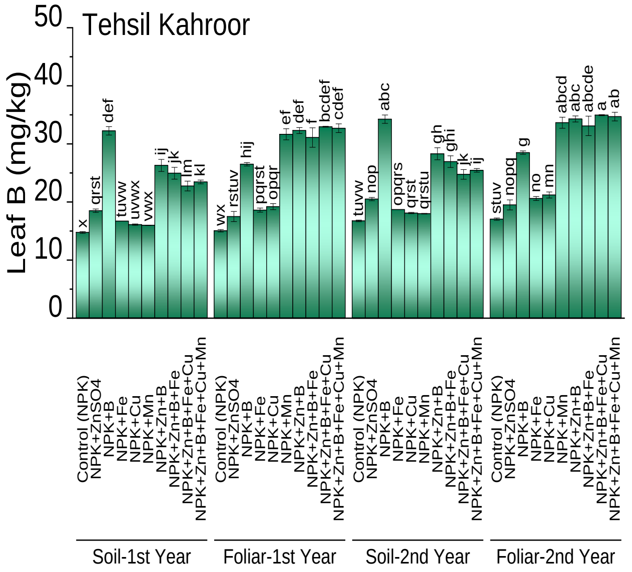

Fig. 9. Effect of treatments applied as soil and foliar application on citrus leaf B concentration for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars are showing significant change at $p \leq 0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

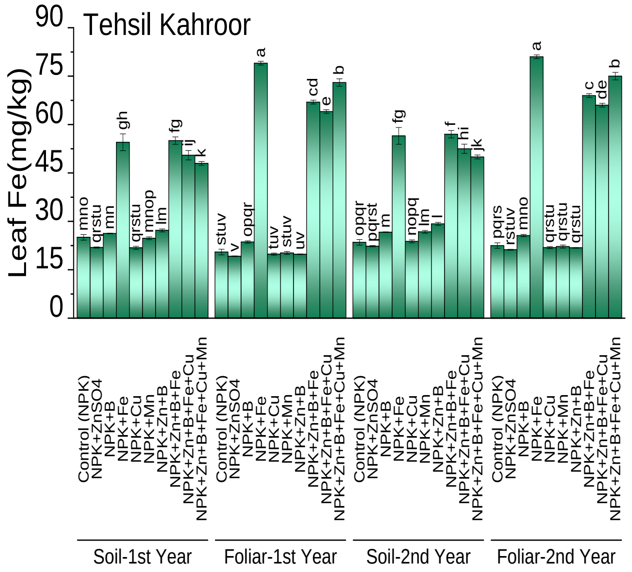

Fig. 10. Effect of treatments applied as soil and foliar application on citrus leaf Fe concentration for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars are showing significant change at $p \leq 0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

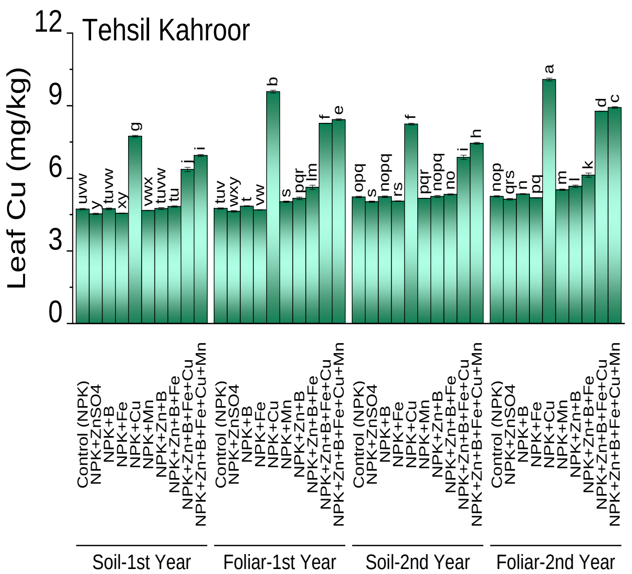

Fig. 11. Effect of treatments applied as soil and foliar application on citrus leaf Cu concentration for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars are showing significant change at $p \leq 0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

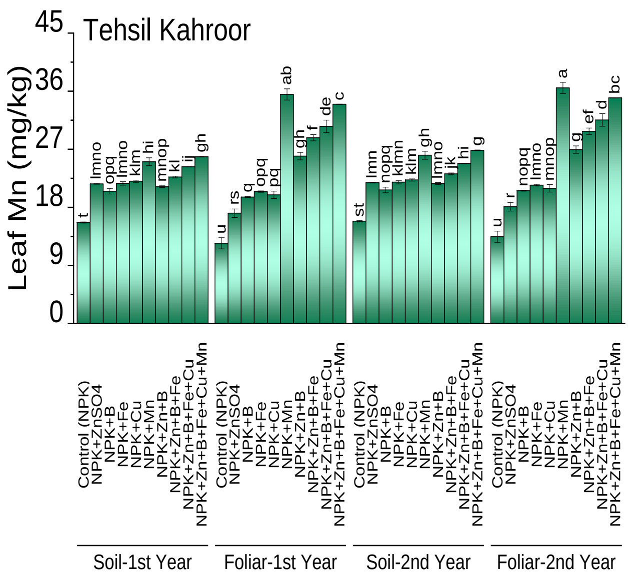

Fig. 12. Effect of treatments applied as soil and foliar application on citrus leaf Mn concentration for two years (2019-2020). Bars are means of four replicates ± SE. Different letters on bars are showing significant change at $p \leq 0.05$; Fisher LSD. T1 = NPK (1000:500:500 g/plant) + 30 kg FYM; T2 = T1 + 250 g $ZnSO_4$/plant ; T3 = T1 + 150 g borax/plant; T4 = T1 + 550 g $FeSO_4$/plant; T5 = T1 + 200 g $CuSO_4$/plant; T6 = T1 + 350 g $MnSO_4$/plant ; T7 = T1 + 250 g $ZnSO_4$ + 150 g borax/plant; T8 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$/plant; T9 = T1 + 250 g $ZnSO_4$ + 150 g borax + 550 g $FeSO_4$ + 200 g $CuSO_4$/plant and T10 = T1 +250 g $ZnSO_4$ +150 g borax + 550 g $FeSO_4$ +200 g $CuSO_4$ + 350 g $MnSO_4$/plant.

Results showed that the application of treatments significantly affects the yield of citrus fruit. Addition of treatments T2, T3, T4, and T5 during 1st and 2nd years induced significant enhancement than T1 when applied in the soil as a treatment for citrus fruit yield. Similarly, T2, T3, T4, and T5 addition as foliar during 1st and 2nd years also caused a significant improvement in yield over T1 where treatment application was done as foliar. Furthermore, T7, T8, T9, and T10 performed significantly better for yield during 1st and 2nd years when applied as soil and foliar treatments (Fig. 7). The maximum increase in yield was noted where T10 was applied as treatment over T1 as soil and foliar application in 1st and 2nd years.

For leaf Zn concentration, the impact of treatments remained significant. It was observed that T2, T7, T8, T9, and T10 during 1st and 2nd years gave a significant change over T1 when applied in the soil as a treatment for citrus leaf Zn concentration. Similarly, T2, T7, T8, T9, and T10 during 1st and 2nd years also caused a significant enhancement in leaf Zn concentration over T1 where the application of treatments was done as foliar. However, on average, the impact of foliar application of treatments was better compared to soil application in 1st and 2nd year for enhancement in leaf Zn concentration (Fig. 8). Maximum enhancement in leaf Zn concentration was noted where T2 was applied as treatment over T1 as soil and foliar application in 1st and 2nd years.

The application of treatments significantly changed the leaf B concentration of citrus. Results demonstrated that T3, T7, T8, T9, and T10 during 1st and 2nd years gave a significant change over T1 when applied in the soil as a treatment for citrus leaf B concentration. Similarly, T3, T7, T8, T9, and T10 during 1st and 2nd years also caused a significant enhancement in leaf B concentration over T1 where the application of treatments was done as foliar. However, on average, the impact of foliar application of treatments was better compared to soil application in 1st and 2nd year for enhancement in leaf B concentration (Fig. 9). Maximum enhancement in leaf B concentration was noted where T2 and T9 were applied as treatment over T1 under the soil and foliar application in 1st and 2nd years.

The addition of treatments significantly changed the leaf Fe concentration of citrus. Results showed that T4, T8, T9, and T10 during 1st and 2nd years gave a significant change over T1 when applied in the soil as a treatment for citrus leaf Fe concentration. Similarly, T4, T8, T9, and T10 during 1st and 2nd years also caused a significant enhancement in leaf Fe concentration over T1 where the application of treatments was done as foliar. However, on average, the impact of foliar application of treatments was better compared to soil application in 1st and 2nd year for enhancement in leaf Fe concentration (Fig. 10). Maximum enhancement in leaf Fe concentration was noted where T4 was applied as treatment over T1 under the soil and foliar application in 1st and 2nd years.

The influence of treatments was significant for leaf Cu concentration of citrus. Results showed that T5, T9, and T10 during 1st and 2nd years gave a significant change over T1 when applied in the soil as a treatment for citrus leaf Cu concentration. Similarly, T5, T9, and T10 during 1st and 2nd years also caused a significant enhancement in leaf Cu concentration over T1 where the application of treatments was done as foliar. However, on average, the impact of foliar application of treatments was better compared to soil application in 1st and 2nd year for enhancement in leaf Cu concentration (Fig. 11). Maximum enhancement in leaf Cu concentration was noted where T5 was applied as treatment over T1 under the soil and foliar application in 1st and 2nd years.

The impact of treatments was significant for leaf Mn concentration of citrus. Results showed that T6 and T10 during 1st and 2nd years gave a significant change over T1 when applied in the soil as a treatment for citrus leaf Mn concentration. Similarly, T6 T10 during 1st and 2nd years also caused a significant enhancement in leaf Mn concentration over T1 where the application of treatments was done as foliar. However, on average, the impact of foliar application of treatments was better compared to soil application in 1st and 2nd year for enhancement in leaf Mn concentration (Fig. 12). Maximum enhancement in leaf Mn concentration was noted where T6 was applied as treatment over T1 under the soil and foliar application in 1st and 2nd years.

Discussion

It was observed that the application of micronutrients increased the fruit yield and nutrient concentrations compared to soil application. Similar results were also observed by Yadav *et al*., (2013) and Siddique *et al*., (2020), in which yield (in terms of fruit weight) was increased by the application of Zn, B, and Fe. Iron is an essential micronutrient for plant growth and development. It plays a number of roles in plants, including helping with the synthesis of chlorophyll, the production of enzymes, and the regulation of gene expression (Singh *et al*., 2017). In another experiment conducted by Tariq *et al*., (2007), foliar application of Zn, B, and Mn was reported to increase citrus fruit yield. Sole application of micronutrients did not maximize the yield of citrus compared with consortia of micronutrients, which might be due to synergistic interaction among various micronutrients like Zn and B (Razzaq *et al*., 2013). Boron is an essential micronutrient for plant growth and development. It plays a number of roles in plants, including helping with the synthesis of cell walls, regulating enzyme activity, and contributing to the transport of sugars and other nutrients within the plant (Ali *et al*., 2017). The application of micronutrient consortia (Zn+B+Fe+Cu+Mn) produced the highest yield due to improved plant nutrition, enabling the plant to produce more flowers and reduce the early fruit drop (Garcia *et al*., 1984). Micronutrients played a role in flower emergence and fruit set, so their application increased the fruit yield (Ganesh & Kannan, 2013). Foliar application of micronutrients increased the concentration of micronutrients more than soil application, so the yield of plants was also maximized with foliar application of Zn+B+Fe+Cu+Mn.

Tariq *et al*., (2007) reported that Zn and Mn were highly correlated with fruit quality and size, as observed in the present experiment. The vertical diameter of fruit did not influence statistically with an application of micronutrients, as also reported by Tariq *et al*., (2007).

However horizontal diameter of the fruit was improved, which showed that the application of micronutrients improved the size of the fruits. Although the number of seeds and seed weight were improved with micronutrient application, there was a non-significant difference among the different micronutrient effects.

Similarly, Chaudhry & Loneragan (1970) found negative interaction of Cu and Zn that the application of $ZnSO_4$ aggravated the Cu deficiency symptoms in plants and vice versa. Whereas consortia micronutrients, especially the combination of Zn + B improved the micronutrient concentrations as also observed by Tariq *et al.* (2007) that Zn+B foliar spray provided synergistic interaction with each other. Application of Zn + B + Fe + Cu + Mn improved the micronutrient concentrations in the Kinnow leaves, as was also observed by Tariq *et al*., (2007) and Siddique *et al*., (2020).

Improvement in leaf micronutrients was attributed to an increase in the availability of micronutrients in the soil solution. The sole application of micronutrients was not provided significantly better due to nutrient-nutrient interaction. For example, Zn availability in the soil was restricted with Cu and Fe application and vice versa. Their negative interaction was also reported by Soil application of micronutrients directly increased the soil nutrients availability, whereas foliar fertilization was ineffective. Although foliar application sometimes increased the respective nutrient concentration, which could be due to the dropping of spray drops in the soil of the trunk canopy. Due to less expanded roots in citrus and fewer root hairs, in alkaline calcareous soils, foliar application of micronutrients was preferred to soil application which was also confirmed by Ibrahim *et al*., (2007) and Siddique *et al*., (2020). Therefore, the present study recommends the combined application of micronutrients with the foliar spray method. Better uptake of Zn helps in the synthesis of proteins and DNA, regulating enzyme activity, and contributing to the formation of chlorophyll. In mango trees, zinc is particularly important for the proper development of flowers, fruits, and leaves which eventually played an important role in yield enhancement (Suganya *et al*., 2000).

Conclusion

It is concluded that consortia of micronutrient application are beneficial for the improvement in citrus fruit growth, leaf micronutrient contents, and fruit yield. Compared to soil application, foliar application of micronutrient consortia is a better technology for achieving maximum citrus productivity. Farmers must have to include Zn, B, Cu, Mn, and Fe in foliar applications for achieving better quality and yield of citrus fruits. Growers are recommended to employ NPK+Zn+B+Fe+Cu+Mn as exogenous application to achieve optimum benefits of micronutrients in citrus production. More investigations are suggested at different field levels and agro-climatic zones to declare NPK+Zn+B+Fe+Cu+Mn as the best foliar application combination to get maximum benefits in terms of enhanced citrus production.

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