Micronutrient management for okra [*Abelmoschus esculentus* (L.) Moench] under different irrigation methods

By

ARYA P

(2017-11-038)

THESIS

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DECLARATION

I, hereby declare that the thesis entitled **"Micronutrient management for okra [*Abelmoschus esculentus* (L.) Moench] under different irrigation methods"** a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that the thesis entitled **"Micronutrient management for okra [*Abelmoschus esculentus* (L.) Moench] under different irrigation methods"** is a record of research work done independently by **Arya P (2017-11-038)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

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Introduction

1. INTRODUCTION

Intensive cropping and imbalanced use of high analysis fertilizers have induced deficiencies of micronutrients in many part of the country. Studies show that 40-55 per cent of soils are moderately deficient in micronutrients like zinc, while 25-30 per cent is deficient in boron. Deficiency of other micronutrients occurs in 15 per cent of soil (Shukla *et al*, 2014). To achieve high yield and sustain the same over years, it becomes pertinent to foresee the emerging nutrient deficiencies and to evolve suitable ameliorating technologies. Balanced fertilization is inevitable to boost crop productivity.

Micronutrient deficiencies in soils not only hamper crop productivity, but also deteriorates quality of produce. In severe deficiency conditions, the yield loss could be as high as 100 percent. Micronutrients play an important role in the enzymatic processes in plants, synthesis of chlorophyll, carbohydrate production and respiration. They also activate a number of biochemical processes in plants. Even though micronutrients have such a major role in crop growth and yield, research on micronutrient application and schedule of application for various crops are limited.

Foliar application has proven to be an excellent method of supplying plant requirements for secondary and micronutrients. It has been shown to avoid the problem of leaching out in soils and prompts a quick reaction in plants.

Okra is an important vegetable crop of Kerala. It is a warm season crop well adapted to many areas of humid tropical and subtropical zones. It is grown throughout India for its tender fruits. In Kerala, okra is grown in all seasons both under drip and conventional irrigated condition. Foliar application has proven to be an excellent method for supplying plant requirements for secondary and micronutrients. It has been shown to avoid the problem of leaching out in soils and prompts a quick reaction in plants. In Kerala the soils are deficient in zinc and boron in many part. Foliar application of micronutrients showed yield responses in many crops. Response of okra to zinc, boron and its combinations is not available. Information on optimum scheduling of micronutrients in okra needs to be generated. The present study was proposed with the objective to find out the effect of foliar application of micronutrients on productivity of okra under conventional and drip irrigation.

Review of literature

2. REVIEW OF LITERATURE

Micronutrients are essential elements that are used by plants in small quantities. They have important role in plant growth, development and disease resistance. Intensive agriculture and use of high analysis fertilizer resulted in micronutrient deficiencies which in turn lead to reduction in yield of crops. Therefore application of micronutrient to crops is important since it can improve crop yield to a greater extent.

Drip irrigation conveys water directly to the root zone of plants which helps to reduce the water loss and improve the plant growth when compared to conventional irrigation. Input information regarding effect of micronutrient application and irrigation methods on growth and yield of okra needs to be generated.

Literature regarding growth and yield response of okra towards different micronutrient application under different irrigation methods are presented in this chapter

2.1. Effect of irrigation methods on growth and yield of crops

Imtiyaz *et al*. (2000) found that 80% pan evaporation replenishment gave highest mean marketable yield for broccoli, carrot, rape and cabbage under drip irrigation. They also observed that further increase in irrigation (100% pan evaporation replenishment) did not increase the marketable yield of these crops.

Gajbhiye *et al*. (2016) observed higher yield in cashew when provided with drip irrigation at 80% CPE. Nut yield of cashew was increased by 145 per cent over control in this treatment. Kakade *et al*. (2017) observed that drip irrigation have significant impact on growth and yield of pigeon pea. Singh *et al*. (2010) observed that drip irrigation at 1.0 ETC saved about 25 per cent water and 40 per cent increase in yield of seed cotton over conventional irrigation.

Londhe *et al.* (2017) reported that, drip irrigation significantly influenced the yield of ground nut + pigeon pea intercropping system. They observed a higher number of pods per plant, seeds per pod, seed weight and 100 seed weight in drip irrigated plant which resulted in higher yield compared to surface irrigation methods.

Bhasker *et al.* (2018) reported that irrigation methods have significant influence on growth and yield parameters of onion and drip irrigated plants showed higher plant height and number of leaves than surface irrigated plants. The increase in vegetative growth is attributed to enhanced root growth as well as reduced water loss in drip irrigated crop. Drip irrigated onion also showed greater bulb size and bulb yield than surface irrigated crop. Increased yield of 24.55 per cent is observed for drip irrigated plants over surface irrigated plants.

Salma *et al.* (2018) reported that, Gladiolus under drip irrigated condition performed better than conventional irrigation. Plant height as well as number of leaves were higher with drip irrigated plants on raised beds compared to furrow irrigation. They observed that spike initiation was early in drip irrigated plants and it also improved floral characters like spike length, rachis length, and number of florets per spike.

2.2. Effect of Zinc on growth of plants

Zinc is one of the important plant micronutrient which has an important role in many physiological functions. The inadequate supply of zinc will leads to reduction in crop yields. Almost all crops and calcareous, sandy soils, peat soils, and soils with high phosphorus and silicon are expected to be deficient in zinc. Deficiency of zinc can cause stunted growth, decreased number of tillers, chlorosis and smaller leaves increased crop maturity period, spikelet sterility and inferior quality of harvested produce.

Zinc affects plant metabolism by influencing the activities of hydrogenase and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome (Tisdale *et al*. 1958). Zinc activates plant enzymes which are involved in carbohydrate metabolism, maintenance of the integrity of cellular membranes, protein synthesis, regulation of auxin synthesis and pollen formation. Zn deficiency increases the plant susceptibility to infections by fungal infections and high light intensity and temperature injury. (Marschner *et al*. 1995).

Cakmak (2000) reported that gene expression required for the tolerance of environmental stresses in plants are zinc dependent. Deficiency of Zinc results in abnormal development of plants which become visible as stunted growth, chlorosis and smaller leaves, spikelet sterility. Zn deficiency can also affect the quality of harvested produce. Zinc influence the capacity of water uptake and transport in plants and also give tolerance to salt and heat stress (Peck and McDonald. 2010, Disante *et al*. 2011, Tavallali *et al*. 2010). Zinc involved in the production of an essential growth hormone auxin and it is also required for the synthesis of tryptophan which is precursor of IAA (Alloway, 2004).

Dash *et al*. (2005) found that Zn (@ 5 kg/ha) application along with FYM (@ 5 Mg/ha) in soybean significantly increased the plant height, number of branches per plant, leaf area index and dry matter accumulation which is statistically at par with FYM (5t/ha). Soil application of Zinc improved the uptake of micro and macro nutrients from the organic matter which helped in an improved growth and yield. Seed yield in soybean was also maximum for the above treatment.

Shirpurkar *et al*. (2006) stated that soybean plants applied with Zn (@ 10 kg/ha) + FYM (@ 10 t/ha) +RDF showed higher pod yield at 60 DAS, 75 DAS and 90DAS. Zinc application resulted in accelerated vegetative growth and nutrient assimilation which might have been translocated to reproductive parts.

Kinase *et al*. (2008) observed higher grain and straw yield in soybean which are applied with zinc application @ 10 kg/ha. They reported that the increase in yield might be due to increased enzymatic activity due to zinc application which resulted in an increased translocation of assimilates from roots to vegetative and reproductive plant parts. They also observed superiority of zinc sulphate over Zinc Oxide because of the synergistic effect between sulphur and zinc.

Singh *et al*. (2010) reported that green pod yield, net return and B: C ration were highest when Zn @ 60ppm was applied to okra as foliar spray. Manna et al. (2014) found that foliar application of 0.5% zinc to onion significantly improved the plant height as well as quality parameters of bulb.

An experiment conducted by Karloo *et al*. (2014) showed that there was a significant increase in plant height of chilies with increase in concentration of Zn from 0.1% to 0.5% which is applied through foliar spray. In this experiment it was observed that shortest plant height was for control plants. Unlike plant height, there was a decrease in days to flower emergence with increase in the concentration of zinc. This is attributed to the increased plant growth which increased the growth period of the plant, number of branches, number of fruits, fruit length and fruit weight also increased with increased concentration of zinc by foliar application.

Yadav *et al*. (2014) reported that foliar spray of Zn have significant effect on the vegetative growth as well as yield of cauliflower. They observed significant increase in plant spread and number of unfolded leaves per plant. Zinc (@ 40 ppm) application also reduced the curd maturity and significantly increased curd diameter and fresh weight of curd.

Shinde *et al*. (2015) studied the effect of different levels of fertilizer and micronutrients on growth, yield and quality of soybean. Micronutrients B, Zn, and Fe were applied. Among this, plants applied with Zn showed higher plant height, number of branches, leaf area, total dry matter and number of pods per plant. Zinc application also improved the mean seed yield, straw yield, biological yield, protein content, oil content and oil yield than the other two micronutrients.

Tawab *et al.* (2015) conducted an experiment to find out the response of brinjal cultivars to different zinc levels. In this experiment four different levels of zinc (0, 0.1%, 0.2%, and 0.3%) were applied as foliar sprays. They observed a regions of the plant such as root tips, new leaf and bud development. Requirement of boron is more in meristematic cells than in mature tissues (Rerkasem, B. 1996). Boron influences nodule weight, number and nitrogen fixation capacity of legumes (Bolanos *et al.* 1994). Boron is required for pollen germination and tube growth, hence it influences seed setting and yield (Aslam *et al.* 2002)

Kumari in 2012 reported that soil application of boron increased the germination percentage of tomato. Sarkar *et al.* (2017) found that application of boron @ 1.5 g/L twice at 15 days interval in water spinach remarkably improved the vine length, number of nodes per plant and average internode length which is statistically at par with soil application of borax @ 25 kg/ha.

Dordas in 2006 observed that leaf concentration of boron was increased with boron application rates (0,400,800 and 1200 mg/L) up to 85.1 mg/kg dry weight in cotton. He also observed significant increase in plant height in boron applied plants compared to control even though there were no significant increase was observed between different rates of boron application. Boron application also increases the number of nodes. Boron applied at the rate of 400mg/L showed maximum increase in yield, but the number of balls per plant was higher for B @ 200mg/L.

Davis *et al.* (2003) reported that boron plays an important role in potassium nutrition in tomato. The plants applied with boron either by foliar or soil applied contained more boron and potassium than plants not applied with boron. They also observed more physiological growth as well as yield attributes in boron applied plants when compared to control.

Yadav *et al.* (2006) observed that when boron is applied as multiplex in different doses starting from 0.10 %, 0.15% etc... up to 0.35%, maximum number of fruits per plant, number of fruits per plant, yield per plant, yield per plot and yield per ha were found with the 0.20% application of boron in tomato. Maximum fruit weight was given by the treatment 0.10% multiplex. Control gave the minimum yield attributes, but lowest fruit weight was given by 0.20% multiplex application.

Aravindkumar *et al*. (2012) reported that application of B @ 4 ppm gave significantly higher seed yield, quality parameters when compared to control in tomato. Naz *et al*. (2012) reported that soil application of boron @ 2 kg per ha gave significantly higher number of flower cluster per plant, fruit percentage, total yield and the lowest fruit loss in tomato.

Patil *et al*. (2008) observed that among the different micronutrients applied (B, Zn, Mo, Cu, Fe, Mn, mixture of all and Multiplex), foliar application of boron as boric acid (@100 ppm) recorded maximum plant height, number of branches and fruits per plant in tomato.

Singh *et al*. (2010) found that plant height, leaves per plant, primary and secondary branches per plant, pod length, pods per plant and fresh weight per pod were significantly higher in okra plants receiving 60 ppm boron as foliar spray. Manna *et al*. (2014) reported that foliar application of 0.5% boron to onions significantly improved bulb diameter, neck thickness, individual bulb weight and marketable and total yield.

Haque *et al*. (2011) reported that application of boron at 0.6kg/ha gave maximum plant height, number of flower cluster per plant, number of fruits per cluster and number of fruits per plant in tomato. Jyolsna and Mathew in 2008 reported that with increase in level of Boron from 0.1, 0.5, 1.0 and 1.5 kg/ha soil application, number of primary branches, percent fruit set, dry matter production and yield increased significantly. So from the result they concluded that boron is a limiting nutrient in laterite soils of Kerala.

Adkine *et al*. (2011) reported that maximum B: C ratio was obtained for soybean plants treated with boron @ 1 kg/ha soil application along with RDF. They also observed that foliar spray of B @ 0.5% + Mo @ 0.2% gave higher plant height.

Patil *et al.* (2013) conducted an experiment to study the response of foliar application of micronutrients on yield and economics of bitter gourd. They found that foliar application of borax @ 100 ppm and mixture of all micronutrients showed higher number of fruits per vine single fruit weight and fruit yield per vine. Foliar spray of boric acid @ 100 ppm gave significantly higher yield per plot and yield per ha.

Suganya *et al.* (2015) reported that application of boric acid @ 150 ppm as foliar application can significantly improve flowering percentage, fruit set and fruit yield per plant of ratoon crop of brinjal.

Harris and Lavanya (2016) reported that boron applied as boric acid @350 ppm resulted in higher yield in tomato. But a higher pulp weight was observed for plants sprayed with 150 ppm of boric acid. Maurya and Devi (2016) stated that borax @ 10 kg/ha when applied to soil influenced growth, yield and quality of radish. This treatment improved plant height, number of leaves, length and diameter of roots and fresh weight of tops and roots. But application of higher doses of borax reduces the growth parameter considerably.

Sultana *et al.* (2017) reported that soil application of boron @ 1.25kg/ha gave the highest yield fruit length., fruit girth, and fruit weight when compared to boron application @ 0.5 kg/ha,0.75 kg/ha and 1.0 kg/ha. They also observed that shedding of flowers was reduced up to 52.8% due to boron application @ 1.25 kg/ha. Their experiment also revealed that application of boron directly affects the concentration of boron in bitter gourd fruit and it also affected the concentration of zinc in plant. That is zinc concentration increased with boron application up to a certain level and then decreased. They also reported that boron application increased concentration of potassium in bitter gourd.

Goyal *et al.* (2017) reported that application of boron @ 0.25% to onion showed significantly higher fresh weight of bulb per plant and maximum dry weight of bulb per plant. Also highest net returns and B: C ratio was obtained for plants treated with boron

Ahmad and Tahir (2017) observed that maize plants treated with three foliar sprays of boron @ 0.5% (first at 4-5 leaves stage, second and third with one week interval) with RDF have got significant increase in plant height. This treatment also recorded the highest cob length, cob diameter, number of grains per cob, 1000 grain weight and biological yield.

The experiment conducted by Harris *et al.* (2018) revealed that foliar application of Boron (H_3BO_3) and Mg ($MgSO_4$. $7H_2O$) at 100 ppm significantly enhanced growth and yield of chilli. Plants applied with above treatment showed highest plant height, number of branches, number of leaves, and number of flowers. Number of fruits per plant and fresh weight of fruits were also higher for this treatment.

2.4. Effect of Combined application of zinc and boron on growth and yield of plants

Soil application of $ZnSO_4$ @ 40 kg/ha along with borax @ 15 kg/ha significantly improved the plant height, fruit length, fruit diameter, average fruit weight, number of fruits and yield in okra. But maximum chlorophyll content in leaves is observed when a combination of $ZnSO_4$ (30 kg/ha) and borax (15 kg/ha) were applied (Kumar and Rana, 2009).

Singh *et al.* (2014) reported that foliar application of B(@10 ppm) + Zn(@ 100 ppm)significantly improved plant height, fruit length, number of fruits per plant, green fruit yield per plant when compared to their individual application.

Hosseini *et al.* (2007) found that height of corn plant and dry weight decreased with increase in boron rate in the absence of Zn. So they concluded that zinc alleviated the suppressive effect of high concentration of boron on plant height and dry weight. They also observed that zinc suppressed the boron concentration in shoot when boron applied. However, in boron untreated plants, zinc increased the shoot boron concentration significant increase in plant height, number of leaves per plant, number of fruits per plant, fruit weight and total yield with increase in zinc levels, Plants treated with zinc @ 0.2% recorded higher plant height, number of leaves per plant, fruit weight and total yield. Number of days to flowering and fruiting were the least for plants treated with 0.2% zinc. Plants applied with 0.3% zinc showed maximum number of days to fruiting.

Pandav *et al.* (2016) reported that foliar application of zinc Sulphate @ 0.5% significantly improved the plant height, number of fruits, fruit length, fruit diameter fruit weight and reduced the days to physiological maturity of fruits.

Sharma *et al.* (2017) reported that zinc application improved the supply of micronutrients and enhances the availability and uptake of nutrients from soil. They found that application of zinc at the rate of 7.5 kg/ha significantly improved the growth as well as yield attributes and yield. Plant applied with zinc at the rate of 7.5 kg/ha showed higher plant height, number of branches, leaf area fruit length, fruit diameter, fruit yield per plant and per ha compared to soil application of zinc @ 0 kg/ha, 2.5 kg/ha and 5 kg/ha.

Goyal *et al.* (2017) reported that zinc application significantly influenced the morphological parameters in onion. Plants applied with Zn (0.5%) showed maximum length and width of leaves. zinc application improved the photosynthetic activity and chlorophyll content, nitrogen metabolism and auxin content in plants. This lead to a higher leaf area.

2.3. Effect of Boron on growth of plants

Boron is required for normal plant growth. Boron plays an important role in cell wall strengthening and development, sugar transport and hormone development. Boron is related with nitrogen, phosphorus, potassium and calcium in plants. It is involved in the synthesis and stability of cell wall by forming esters with cis and diol groups present in the cell wall. This imparts rigidity, strength and shape to the cell wall (Loomis. 1991). Boron is required for actively growing

Kumar *et al*. (2009) reported that okra plants applied with zinc @ 40kg/ha along with boron @ 15 kg/ha showed maximum plant height, fruit length, fruit diameter, fruit weight, fruit number and yield.

Ejaz *et al*. (2011) found that yield increase of 83% was observed over control in tomato when combined application of N (2%) +B (5%) + Zn (6%) was done. It also resulted in substantial increase in plant height, number of fruits per plant and average fruit weight.

Singh and Tiwari (2013) reported that foliar application of zinc, boron and copper @ 250ppm each have significantly improved plant height, number of leaves, number of flowers, fruit weight and quality parameters of tomato.

Manas *et al*. (2014) reported that combined application of humic acid (0.05%) + Zn(0.05%) + B (0.02%) as foliar sprays significantly improve the plant height, number of leaves per plant, average leaf area and number of branches per plant in chilli. It also significantly improved average number of fresh fruits per plant, length of fresh fruit, average diameter of fresh fruit and average weight of 20 fresh fruits.

Experiment conducted by Ali *et al*. (2015) showed that summer tomato plants sprayed with Zn and B @ 12.5 ppm showed maximum plant height, number of leaves, leaf area, number of branches, cluster number of fruits, fruit length and diameter and minimum days to 50% flowering.

Sarkar *et al*. (2017) reported that foliar sprays of borax @ 1.5 g/L along with foliar spray of Zinc Sulphate @ 1.5 g/L twice at 15 days interval significantly improved the vine length, number of nodes per plant and average inter node length in water spinach. Dry chilli yield was significantly improved by soil application of Zn (@3 kg/ha) +B (@ 2 kg/ha) (Shil *et al*. 2013).

Minz *et al*. (2018) found that among different combinations of rate of zinc and boron, maximum number of fruits per cluster, number of fruits per plant, fruit weight, fruit yield per plant and fruit yield were observed for foliar application of Zn (@ 1.75 g/L) + B(@1.25 g/L) followed by Zn (@2.25 g/L) +B (@1.25 g/L).

Goyal *et al.* (2017) reported that combination of zinc (0.5%) + Mn (1.0%) + Cu (1%) +B (0.25%) when applied to onion showed maximum number of leaves.

Singh *et al.* (2014 reported that foliar spray of zinc (0.4%) with boron (0.4%) significantly improved the tomato yield. Solanki *et al.* (2017) reported that soil application of zinc @ 10 mg/kg gave significantly higher plant height, number of leaves, number of branches and total number of fruits in brinjal.

2.5. Effect of micronutrient mixes on growth and yield of plants

Baloch *et al.* (2008) reported that HiGrow, a compound fertilizer containing macro and micronutrients aimed for foliar application when applied to chillies resulted in increase in growth and yield attributes. It contain Nitrofen (4%), nitrogen compound (12%), Iron (2%), magnesium (2%), manganese (2%), boron (2%), copper (4%), molybdenum (2%), potash (8%), P_2O_5 (12%), and calcium (18%) W/V. Plants sprayed with HiGrow @ 8 ml/L showed maximum plant height, no of branches, maximum number of fruits, significantly longer fruits, highest fruit weight and maximum fresh fruit yield. Kumari in 2012 reported that multiplex, a micronutrient mix containing all the secondary and micro nutrients when applied to soil significantly increased the seedling length of tomato.

Mehraj *et al.* (2015) stated that growth and yield of okra can be improved by foliar application of micronutrient mixtures. Okra plants sprayed with 1% micronutrient mix twice (20 DAS and 35 DAS) showed maximum plant height, stem diameter, number of leaves, leaf area, number of branches, fresh and dry weight, yield and other yield attributing characters. These plants also showed early flowering.

Polara *et al.* (2017) opined that provision of multi- micronutrient mixes either as foliar spray or soil test based soil application is beneficial and economical in increasing yield of okra. They observed a significant increase in vegetative growth as well as yield and yield attributes in okra plants applied with multi micronutrient mix either as foliar spray or by soil application based on soil test values.

Singh *et al*. (2018) reported that zinc, boron and iron content were higher in fruits, leaves and soil when the tomato plants are applied with foliar sprays of B (50ppm)+Fe(100ppm)+ Zn (100ppm) compared to control and individual application. So they concluded that increase in nutrient content may due to improved mineral absorption and root growth as a result of application of micronutrient mix.

2.6. Effect of zinc on nutrient content and uptake of crops

Imtiaz *et al*. (2003) reported that zinc application had a negative impact on the content and uptake of Fe, Mn and Cu. The sand culture experiment using wheat showed that during first growth stage upto 15 μg/ml of zinc application, Fe uptake increased but, it decreased significantly during second stage by zinc application. With increasing zinc application, there was a significant decrease in Mn and Cu concentration in plant tissue was also noticed. Higher concentration of these micronutrients in plant tissue was noticed during the first growth stage than the second growth stage.

Yang *et al*. (2011) reported that foliar application of zinc as ZnO to wheat significantly increased the nitrogen content of grain regardless of application time. Chaudhary *et al*. (2002) reported that soil application of Zinc sulphate increased the zinc content markedly. So they inferred that an antagonistic relation exists between zinc and boron.

A hydroponic pot experiment using mung bean showed that plant phosphorus content declined significantly with increasing the level of zinc application. Uptake of zinc depressed the root phosphorus uptake. They also observed a decrease in iron uptake with increasing zinc levels and inferred that there is a competitive interaction between zinc and iron at the absorption zone.

Increase in the concentration of zinc in the rooting media increased the zinc content of mung bean (Samreen *et al.* 2013).

Ram *et al.* (2013) reported that soil application of zinc as zinc EDTA @ 1kg/ha in two splits improved the N, P and K content in rice. They also observed an increase in zinc content of grain with soil application of zinc EDTA @ 1 kg/ha. Kandolia and Kunjadia (2018) observed that foliar application of chelated zinc @ 1.5% recorded highest zinc uptake in wheat plants which was 136.2% higher than control treatment. They also reported that soil application of $ZnSO_4$ @ 10 kg/ha + $FeSO_4$ @20 kg/ha showed highest Cu and Mn uptake which was statistically on par with Cu and Mn uptake of plants sprayed with chelated zinc @ 1.5% at 30 and 60 DAS.

Chakerolhosseini *et al.* (2016) reported that combined application of zinc and calcium as foliar spray to orange significantly increased the concentration of of zinc in leaf. Combined application of zinc and calcium @ 0.25% decreased boron content in leaves of orange. They also observed increase in zinc content of fruit with increase in zinc concentration which is applied as foliar spray of $ZnSO_4$.

Sahu *et al.* (2017) reported that combined application of $ZnSO_4$ (0.2%), $MnSO_4$ (0.2%) and FeSO4 (0.1%) significantly improved the content of N. P, K, Zn, Mn and Fe in gerbera. El- Gizawy and Mehasen (2009) observed significant increase in content and uptake of nitrogen and phosphorus with increasing level of zinc from 0.0 to 0.004%.

2.7. Effect of boron on nutrient content and uptake

An experiment conducted by Davis *et al.* (2003) with tomato revealed that foliar application of boron increased the content and uptake of K by plants, but boron treatment did not affected the shoot concentration of N, P, Mg and S. So they inferred that boron plays an important role in maintaining K levels in plants.

Devi *et al.* (2012) reported that soil application of boron @ 1.5 kg/ha significantly improved the boron uptake by soybean plants. Sultana *et al.* (2017)

reported that soil application of boron to bitter gourd significantly improved the boron concentration in bitter gourd fruit. It also increased the concentration of N and P in bitter gourd non-significantly with boron application.

Abdulnour *et al.* (2014) reported that higher concentration of boron in propagation media reduced the Ca uptake of micro propagated plantlets.

Nagula *et al.* (2015) reported that foliar application of potassium silicate (0.5%) +borax (0.5%) increased the N, K and Ca uptake of rice plants. This treatment also improved the content and uptake of Mg, Zn, and Cu. Sarker *et al.* (2002) reported that soil application of boron @2.0 and 4.0 kg/ha significantly improved the S and B uptake of soybean.

Koohkan and Maftoun (2015) observed that soil application of boron at higher level (40 mg/kg) increased the concentration of nitrogen in shoot tissue. Ziaeyan and Rajaee (2012) reported that both foliar and soil application of boron increased the boron concentration in leaf tissue of corn, but boron application significantly reduced N and P concentration in leaf.

2.8. Effect of combined application of zinc and boron on nutrient content and uptake of crops

Hosseini *et al.* (2007) reported that in corn when zinc and boron were applied together zinc suppressed the tissue concentration of boron at lower levels of boron application, but this suppressive effect of boron declined as the level of boron decreased. They also observed that increased boron concentration elevated K concentration irrespective of zinc supply.

Biswas *et al.* (2015) conducted an experiment in wheat. The result of the experiment revealed that combined soil application of zinc and boron had significant influence on nutrient uptake of wheat. They observed that soil application of zinc and boron increased the uptake of N, P, K, Zn and B in wheat.

Rajkumar *et al.* (2017) reported that foliar application of zinc and boron (@1%) significantly improved the content and uptake of nitrogen and potassium in guava. It also enhanced the concentration of zinc and boron in leaves compared to control. Quddus *et al.* (2018) reported that combined application of zinc and boron (@ 3 kg/ha and 2 kg/ha) significantly improved the zinc and boron uptake of field pea.

2.9. Effect of foliar application of micronutrients on soil nutrient status

Radhika *et al.* (2013) reported that kiecite, a micronutrient mixture when applied through foliar spray improved the availability of micronutrients viz., Fe, Mn, Zn, Cu and Mo. They opined that higher micronutrient status in soil due to foliar application might be due to lesser depletion of soil nutrients by plant absorption as the plant requirement of these nutrients were met from foliar application.

Mini and Mathew (2016) reported that two consecutive foliar application of multi micro nutrient mixture significantly enhanced the soil status of Zn, Cu and B. Boaretto and Boaretto (2002) reported that foliar application of zinc to citrus improves soil zinc status, mainly in the soil near the tree trunks. Gudade *et al.* (2015) reported that foliar application of chelated Zn, Mn and Mg either single or in combination did not produce any significant change in soil content of available Mg, Fe, Mn, Cu and B.

Micronutrient solution containing Fe, B, and Zn when applied to cowpea as foliar spray improved the soil nitrogen content, but reduced the calcium content (Salih, 2013). Divyashree *et al.* (2018) reported that available Fe, Mn, Zn, Cu and B status of soil increased after application of micronutrient mixture along with recommended dose of fertilizers.

2.10. Effect of foliar application of micronutrients on economics of cultivation

Yaseen *et al.* (2013) reported that foliar application of micronutrients Zn, B, Mn, Cu and Fe resulted in a higher seed cotton yield led to 20 to 30% more economic benefit over NPK fertilizer alone. Singh *et al.* (2015) reported that foliar application of $MgSO_4$ (1%) along with $ZnSO_4$ (0.5%) caused 44.1 per cent increase in gross return and 55.1 per cent increase in net return over control. Ali *et al.* (2011) reported that foliar application of zinc and boron in combination at the rate of 0.75 kg/ha zinc and 1 kg/ha boron significantly improved the net return from cotton. Hussain *et al.* (2011) reported that foliar application of boron to rice crop significantly increased the net income and ratio of benefit to cost compared to control.

Guvvali *et al.* (2017) reported that combined application of Zn, B and Fe when applied to cowpea as foliar spray along with recommended dose of fertilizers gave maximum yield, hence maximum gross return and the highest BC ratio.

Materials and methods

3. MATERIALS AND METHODS

An experiment on 'Micronutrient management for Okra (*Abelmoschus esculentus* (L.) Moench) under different irrigation methods' was carried out at Water Management Research Unit, Vellanikkara, Thrissur. This chapter includes the materials and methods adopted for the experiment

3.1. General Details

3.1.1. Location

The experiment was conducted at Water Management Research Unit, Vellanikkara, Thrissur, Kerala. The experimental plot is located geographically at $13^0$32N latitude and $76^0$26E longitude, at an altitude of 40.3 m above MSL.

3.1.2. Season of the experiment

Season selected for the experiment was summer. Sowing was done in December 2018 and crop duration ended in March 2019.

3.1.3. Weather condition during the experimental period

The area possesses a typical humid tropical climate. The metereological data for the period of investigation are given in Figure 3.1 and Appendix 2. The weather which prevailed during the cropping period was normal. The maximum and minimum temperature recorded during the cropping period were 34.48^0C and 22.78^0C respectively. The average relative humidity recorded was 60.5 percent. No rainfall was recorded during this period.

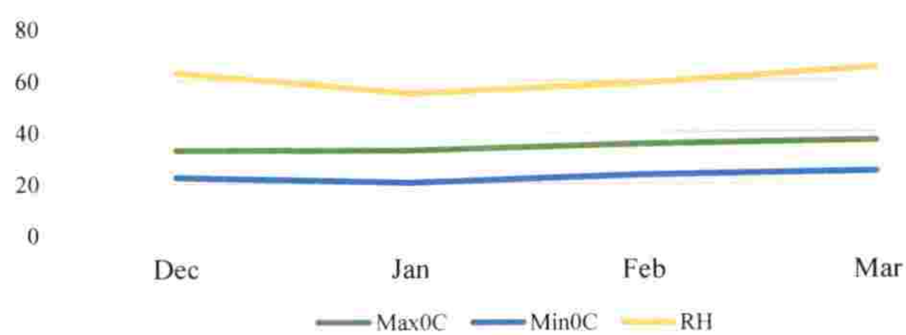

Figure 3.1. Mean monthly weather data of mean maximum temperature, mean minimum temperature and relative humidity

3.1.4. Crop and variety

Okra variety Arka Anamika was used for this study. The plants of this variety are tall, well branched and the stem is green with purple shade. Purple pigment is present on both sides of the petals. The fruits are green in color and long. Duration is 110 days and the variety is resistant to yellow vein mosaic disease. The yield potential of okra is 10 – 15 t/ha under good management practices.

3.1.5. Soil characters

Soil texture of the experimental site is sandy loam belonging to the taxonomic order Ultisol. The initial data on physical and chemical analysis of soils of experimental site are presented in Table 3.2.

3.1.6. Cropping history of the experimental site

The experimental area was under the cultivation of chilli and amaranth during the previous years.

3.2.Experimental Details

3.2.1. Design and layout

The experiment was laid out in Randomized Block Design (RBD) with five treatments replicated four times. Treatments of the experiment consisted of foliar application of Zn, B, combined application of Zn and B, KAU multi mix and a treatment without foliar application. Experiments were conducted separately for conventional and drip irrigated okra with five treatments for each experiment. The plot size was 3m x 3m. The lay out of the experiment is given in Figures 3.2&3.3.

3.2.2. Treatments

Table 3.1. Details of the treatments for conventional and drip irrigation experiment

Treatments	
T1	Foliar application of Zn ($ZnSO_4$ 0.5%)
T2	Foliar application of B (Solubor 0.5%)
T3	Foliar application of Zn (0.5%) and B (0.5%)
T4	Foliar application of KAU multimix (Sampoorna 0.5%)
T5	Without foliar application

For each micronutrient application treatment three foliar sprays were given, first at 15 DAS and subsequently at three weeks interval. Recommended dose of nutrients were applied based on soil test values, and FYM as per POP were applied uniformly to all the treatments.

Source of zinc was ZnSO4 and source of boron was Solubor® (Disodium Octaborate Tetrahydrate: Na2B8O13 4H2O). Sampoorna is a multi-nutrient mix released by Kerala Agricultural University which contains Mg, S, B, Zn, Cu, Fe, Mn and Mo.

Table 3.2. Physico- chemical properties of soil

Parameters	Value		Method used	Reference
1. Mechanical composition of soil Sand (%) Silt (%) Clay (%)	52.0 23.5 24.5		Robinson's International Pipette method	Piper, 1996
2. Physical properties of soil Bulk density (g /cm3) Water holding capacity (%)	1.1 – 1.2 56.4		Core sampler method	Piper, 1966
3. Chemical properties of soil	CI*	DI**		
Soil pH	5.23	5.86	Soil- water suspension of 1:2.5,read in pH meter	Jackson,1958
Organic carbon (%)	1.35	1.69	Walkley-Black method	Walkley and Black, 1934
Available N (kg/ha)	194.43	156.80	Alkaline permanganate method	Subbiah and Asija, 1956
Available P (kg/ha)	108.04	43.35	Ascorbic acid reduced molybdo phosphoric blue colour method	Bray and Kurtz,1945; Watanabe and Olsen,1965
Available K(kg/ha)	381.17	186.10	Neutral Normal NH_4OAC extract method using flame photometer	Jackson, 1958

Exchangeable Ca (mg/kg)	329.15	520.5	Neutral Normal NH4OAC extract titration with EDTA	Jackson, 1958
Exchangeable Mg (mg/kg)	86.4	40.85	Neutral Normal NH4OAC extract titration with EDTA	Jackson, 1958
Available S (mg/kg)	6.743	2.89	Turbidimetric method using Spectronic 20	Williams and Steinbergs, 1958
Available Fe (mg/kg)	13.11	9.74	0.1M HCl extract method using atomic absorption spectrophotometer	Sims and Johnson, 1991
Available Mn (mg/kg)	77.99	46.65	0.1M HCl extract method using atomic absorption spectrophotometer	Sims and Johnson, 1991
Available Zn (mg/kg)	2.34	1.79	0.1M HCl extract method using atomic absorption spectrophotometer	Sims and Johnson, 1991
Available Cu (mg/kg)	4.06	4.70	0.1M HCl extract method using atomic absorption spectrophotometer	Sims and Johnson, 1991
Available B (mg/kg)	0.179	0.277	Hot water extraction method	Berger and Troug, 1939

*CI – Conventional irrigation

**DI – Drip irrigation

3.3. Field Operations

3.3.1. Land preparation

Experimental area was ploughed twice to get a fine tilth. Each experimental plot was divided into 20 subplots. Lime ($CaCO_3$) was applied at the rate of 350 kg per ha two weeks before sowing and FYM applied at the rate of 20 Mg/ha before sowing and incorporated well.

3.3.2. Spacing: 60 cm x 30 cm

3.3.3. Manures and fertilizers

In all the treatments manures and fertilizers were applied based on soil test values as per Package of Practices Recommendation (KAU, 2016) FYM was applied at the rate of 20 t/ha incorporated before sowing. N, P, and K were applied based on the soil test values. Doses and schedule of fertilizer applications are given in Table 3.3.

Table 3.3. Quantity and schedule of fertilizer application

Fertilizer	Applied Quantity			
	Basal		Top dressing	
	*CI	** DI	*CI	** DI
N (kg/ha)	42.9	39.05	42.9	39.05
P_2O_5 (kg/ha)	8.75	8.75	-	-
K_2O (kg/ha)	17.5	58.1	-	-

*CI – Conventional irrigation

**DI – Drip irrigation

Figure 3.2. Lay out of conventional irrigation field

T_1R_1	T_2R_1	T_3R_1	T_4R_1	T_5R_1	T_1R_2	T_2R_2	T_3R_2	T_4R_2	T_5R_2
T_5R_3	T_4R_3	T_1R_3	T_3R_3	T_2R_3	T_5R_4	T_4R_4	T_1R_4	T_2R_4	T_3R_4

Figure 3.3. Lay out of drip irrigated field

T_1R_1	T_2R_1	T_3R_1	T_4R_1	T_5R_1
T_5R_2	T_4R_2	T_1R_2	T_2R_2	T_3R_2
T_1R_3	T_3R_3	T_5R_3	T_4R_3	T_2R_3
T_5R_4	T_4R_4	T_2R_4	T_3R_4	T_1R_4

3.3.4. Source of nutrients

Fertilizers used for the experiment were urea, rock phosphate, MOP, zinc sulphate, Solubor and KAU micronutrient mix (Sampoorna).

3.3.5 . Irrigation methods

For normal irrigation, water was applied at 1.5cm depth at two days interval. In drip irrigated field, drip lines were laid in such a way that each plant was provided with one emitter. Irrigation was given at 125 per cent Epan. The volume of water applied was calculated based on the formula

Volume = Pan evaporation [Epan (mm)] x Area (m)

The time of operation for drip irrigation system to deliver the required volume of water per plot was computed based on the formula

Time of application (hr) = Volume of water (L)/Discharge rate of emitter (Lph)

3.3.5. Micronutrient application

Micronutrients used for the experiment were $ZnSO_4$, Solubor and KAU micronutrient mix (Sampoorna). These were given as foliar sprays. Three foliar sprays were given, the first at 15 DAS, and subsequent applications at two weeks interval.

3.3.6. Weeding

Three hand weedings were given, first at 15 DAS, second at 30 DAS and third at 45 DAS.

3.3.7. Earthing up

Earthing up was done 30 DAS along with first top dressing

3.3.8. Plant protection measures

Tafgor® (Dimethoate 30%EC) was applied to control sucking pest and caterpillars during initial period.

3.3.9. Harvesting of fruits

Harvesting of tender fruits was started 50 DAS. Manual picking of fruits was done on alternate days.

3.4. Observation recorded

Five plants from each plot were selected and labelled. Biometric observations were taken at 30 DAS, 60 DAS and 90 DAS. During each harvest total yield from the plot as well as yield parameters from labelled plants were recorded

3.4.1. Biometric observations

Plant height

Height of the plant was measured from base of the plant to the tip. Height of five observation plants were taken and its mean was recorded in cm.

Number of leaves per plant

Average of total number of leaves produced from five observational plants was worked out.

Number of branches

Number of branches from each observational plant was taken and the average number of branches was computed

Leaf area per plant

Length and breadth of five leaves were measured and leaf area was calculated using factor method

Leaf are per plant = Length x breadth x factor (0.8) x total number of leaves

Total dry matter production

From each plot, one plant was uprooted at 30 DAS, 60 DAS and 90 DAS and oven dried at 80^0C. Weight of the dried plant was measured and expressed on per hectare basis

Crop duration

Total number of days from sowing to final harvest was taken as crop duration

Incidence of pest and diseases

Pest and disease incidence in both the field were monitored and recorded

3.4.2. Yield attributes

Days to 50 per cent flowering

Number of days from sowing to flowering of 50 per cent of the plants in each plot was recorded.

Number of harvests

Total number of pickings from the first to final harvest were noted and recorded as number of harvests.

Number of fruits per plant

Total number of fruits from five plants in all harvests were taken and the average was calculated.

Fruit weight

Weight of five randomly selected fruits from all harvests were recorded and then mean was calculated and expressed in grams

Per plant yield

Average of individual yield five plants from all harvests were measured and expressed in grams per plant

Yield (Mg/ha)

Yield from net plot was calculated and was expressed in Mg/ha.

3.4.3. Plant analysis

For estimating content and uptake of micronutrients and macronutrients, destructive sampling from each plot was done at 30, 60 and 90 DAS from each treatment. The collected samples were shade dried first and then oven dried at 80^0C. These samples were ground and 0.2g samples were taken, digested and nutrient content was estimated as per standard procedures (Table 3.4).

Plant uptake of both micronutrient and macronutrients was calculated by multiplying nutrient content of plant samples with total dry weight of the plants. The uptake values are expressed in kg/ha

3.4.4. Soil analysis

Soil analyses include pH, EC, available N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B. For soil analysis, soil samples were collected from each plot, shade dried, powdered and sieved. For organic carbon estimation, soil was ground and passed through 0.5mm sieve. Samples passed through 2mm sieve were used for estimation of other nutrients. Estimation of macronutrients and micronutrients was done using standard procedures (Table 3.2). For reading soil pH and E.C, soil water suspension of 1:2.5 was taken.

3.5. Economics

Cost of cultivation was calculated by adding labor charge, input costs and treatment costs. Gross return was calculated based on the market price of Okra. Net returns is the difference between gross returns and gross expenditure. It was expressed in rupees/ ha. The ratio of gross return to cost of cultivation was the benefit: cost ratio.

3.6. Statistical analysis

Data were compiled, tabulated and analyzed statistically by applying the techniques of analysis of variance using statistical package WASP 2.0.

Table 3.4. Procedure for analysis of plant samples

Sl No	Nutrient	Method	Reference
1	N	Microkjelhal method	Jackson, 1958
2	P	Diacid extract estimated colorimetrically in spectrophotometer	Jackson, 1958
3	K	Diacid extract method using Flame Photometer	Jackson, 1958
4	Ca, Mg	Titration with EDTA	Page *et al.*, 1982
5	S	Turbidimetry method using Spectronic 20	Williams and Steinbergs, 1958
6	Fe, Mn, Zn, Cu	Diacid method using atomic absorption spectrophotometer	Jackson, 1958
7	B	Dry ashing method	Williams and Vlamis, 1961

Plate 1: General view of the drip irrigated plot field

Plate 2: General view of the conventionally irrigated plot field

Results

4. RESULT

Observations on the experiment "Micronutrient management of Okra under different irrigation methods" conducted from December 2018 to March 2019 at Water Management Research Unit, Vellanikkara were statistically analyzed and the results obtained are given under the following sections.

4.1. Biometric observations

4.1.1. Plant height

Micronutrient application had no significant impact on plant height of okra under drip irrigation (Table. 4.1) at initial growth stages (30DAS and 60DAS). But at 90 DAS, it significantly influenced the plant height. Foliar application of zinc @ 0.5% showed maximum plant height (178.33 cm) which was on par with KAU multi mix application (176.06 cm) at 90 DAS. The least plant height was shown by combined application of zinc and boron (100.13 cm).

Under conventional irrigation only initial growth stage (30DAS) showed significant difference in plant height (Table 4.1). Maximum plant height was shown by plants treated with boron (23.65 cm) which was statistically on par with treatment without foliar application (22.05 cm). Least plant height was observed for KAU multi mix application (20.50 cm) which was statistically on par with zinc application and combined application of zinc and boron (20.60 cm and 20.50 cm respectively) at this stage.

4.1.2. Number of leaves per plant

Number of leaves per plant of okra were not significantly influenced by micronutrient application under both the irrigated condition (Table 4.2).

Table 4.1. Effect of micronutrient application on plant height (cm) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (cm)	60 DAS (cm)	90 DAS (cm)	30 DAS (cm)	60 DAS (cm)	90 DAS (cm)
T_1-Zn (0.5%)	20.95	92.50	178.33	20.60	75.75	84.65
T_2-B (0.5%)	19.85	95.40	111.83	23.65	66.00	72.17
T_3-Zn (0.5%) + B (0.5%)	17.45	87.65	100.13	20.50	62.40	82.17
T_4-KAU multi mix	23.70	81.03	176.06	20.50	63.05	77.25
T_5- Without foliar application (Control)	19.85	90.25	123.33	22.05	72.00	80.17
CD (0.05)	NS	NS	17.06	1.60	NS	NS

Table 4.2. Effect of micronutrient application on no of leaves per plant of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1-Zn (0.5%)	6.50	10.00	9.25	5.50	8.75	9.00
T_2-B (0.5%)	6.00	9.75	11.75	5.75	8.75	10.25
T_3-Zn (0.5%) + B (0.5%)	6.00	9.25	10.25	5.50	9.25	8.75
T_4- KAU multi mix	6.50	9.25	8.25	5.25	8.00	10.25
T_5- Without foliar application (Control)	5.50	10.25	8.75	6.25	8.00	10.50
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 4.3. Effect of micronutrient application on no of branches per plant of okra under different irrigation methods

Treatments	Drip irrigation		Conventional irrigation	
	60 DAS	90 DAS	60 DAS	90 DAS
T_1-Zn (0.5%)	1.00	1.50	1.00	1.00
T_2-B (0.5%)	1.00	1.25	1.25	1.25
T_3-Zn (0.5%) + B (0.5%)	1.75	2.00	1.25	1.50
T_4- KAU multi mix	1.00	1.00	1.00	2.00
T_5- Without foliar application (Control)	0.75	1.50	1.00	1.50
CD (0.05)	0.507	NS	NS	NS

Table 4.4. Effect of micronutrient application on leaf area (cm^2) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (cm^2)	60 DAS (cm^2)	90 DAS (cm^2)	30 DAS (cm^2)	60 DAS (cm^2)	90 DAS (cm^2)
T_1-Zn (0.5%)	803.32	2012.16	556.65	538.00	1709.40	181.78
T_2-B (0.5%)	696.60	2056.24	408.87	668.58	1733.72	325.05
T_3-Zn (0.5%) + B (0.5%)	362.12	1792.84	304.32	542.52	1781.36	357.36
T_4- KAU multi mix	1245.18	1782.24	392.12	502.00	1615.72	245.84
T_5- Without foliar application (Control)	956.90	1973.20	259.80	824.36	1311.00	361.11
CD (0.05)	349.075	NS	NS	NS	NS	NS

4.1.3. Number of branches per plant

Upto 30 DAS no branches were observed in different treatments. Micronutrient application under drip irrigation had significant influence on number of branches of okra only at 60 DAS (Table 4.3). Combined application of zinc and boron gave maximum number of branches (1.75) at this stage. Least number of branches were observed for treatment without foliar application (0.75) and for KAU multi mix application (1.0) at 90 DAS.

Number of branches of okra were not significantly influenced by micronutrient application under conventional irrigation in any stage of crop growth (Table 4.3).

4.1.4. Leaf area

Micronutrient application had significant effect on leaf area at 30 DAS under drip irrigation (Table 4.4). Highest leaf area was observed for KAU multi mix application (1245.18 cm^2) which is on par with treatment without foliar application (956.90 cm^2) at 30 DAS. The least leaf area was observed for combined application of zinc and boron (362.12 cm^2) at this stage. At 60 and 90 DAS, leaf area was not significantly influenced by micronutrient application.

Leaf area was not significantly influenced by micronutrient application at any of the stages under conventional irrigation (Table 4.4).

4.1.5. Dry matter production

Micronutrient application to okra under drip irrigation had significant effect on dry matter production at all growth stages (Table 4.5). At 30 DAS, dry matter production was highest for zinc applied plants (270.83 kg/ha) which was on par with KAU multi mix application (229.17 kg/ha) and treatment without foliar application (215.28 kg/ha). Combined application of zinc and boron produced lowest amount of dry matter (131.94 kg/ha) which was on par with boron application at this stage (166.67 kg/ha). At 60 DAS combined application of zinc and boron produced significantly higher dry matter (701.39 kg/ha) which was statistically on par with KAU multi mix application (548.61 kg/ha) and zinc application (527.78 kg/ha). Lowest dry matter production at this stage was for treatment without foliar application (354.17 kg/ha). At 90 DAS treatment without foliar application showed significantly higher dry matter production (1090.28 kg/ha) which was statistically on par with dry matter production of treatments receiving zinc application (965.28 kg/ha) and combined application of zinc and boron (979.19 kg/ha). The lowest dry matter production was recorded for treatment receiving boron application (740.28 kg/ha)

At 30 DAS and 60DAS, micronutrient application had no significant influence on dry matter production of okra under conventional irrigation (Table 4.5). Micronutrient application had significant influence on dry matter production at 90 DAS. At this stage, dry matter production was significantly higher for control (1159.72 kg/ha) and lowest dry matter production was recorded on combined application of zinc and boron (520.83 kg/ha) which was statistically on par with boron application and zinc application (583.33 kg/ha and 625.00 kg/ha respectively

4.1.6. Crop duration

The okra plant remained in the field for 98 days. Under both the irrigation methods and in all treatments crop duration was the same.

4.1.7. Incidence of pest and diseases

Minor infestation of leaf hoppers and fruit borers and incidence of yellow vein mosaic virus were observed during the cultivation of okra. But it was uniform in all the treatments as well as in both irrigation methods.

4.2.Yield attributes

Drip irrigation

Days to 50% flowering

Days to 50% flowering was same for all the treatments to okra under drip irrigation. 50% flowering was noticed at 32 DAS in all the treatments.

Fruit length

Under drip irrigated condition, significantly higher fruit length was observed for KAU multi mix application (17.97 cm) which was statistically on par with control (17.34 cm) and zinc application (17.12 cm). Lowest fruit length was for combined application of zinc and boron (16.25 cm) (Table 4.6).

Fruit weight

KAU micronutrient mix application gave significantly higher fruit weight under drip irrigated condition and was statistically on par with zinc application (13.22 g) (Table 4.6). Lowest fruit weight was observed for treatment without foliar application (10.47g) which was statistically on par with boron application (10.87 g) and combined application of zinc and boron (12.27 g).

Number of fruits per plant

Number of fruits per plant was significantly influenced by micronutrient application under drip irrigated condition (Table 4.6). Foliar application of boron produced significantly higher number of fruits (23.0) which was statistically on par with zinc application (22.5).Combined application of zinc and boron produced lowest number of fruits (17.0).

Number of harvests

Thirteen harvests were taken from all the plots. Micronutrient application did not have any influence on number of harvests of okra plants.

Per plant yield

Per plant yield of okra was significantly higher for KAU multi mix application (295.38 g) under drip irrigation followed by zinc application (242.59 g) (Table 4.6). Lowest per plant yield was observed for combined application of zinc and boron (199.37 g) which is on par with treatment without foliar application (216.92 g) and boron application (236.21 g).

Yield (Mg/ha)

Yield of okra was significantly influenced by micronutrient application (Table 4.6). Under drip irrigated condition, significantly higher yield was produced by KAU multi mix application (16.41 Mg/ha) which was followed by zinc application (13.48 Mg/ha). The lowest yield was recorded in combined application of zinc and boron (11.08 Mg/ha) which was statistically on par with treatment without foliar application (12.06 Mg/ha).

Conventional irrigation

Days to 50% flowering

Days to 50% flowering was same for all the treatments in okra under conventional irrigation. 50% flowering was noticed at 32 DAS.

Fruit length

Micronutrient application had significant influence on fruit length of okra under conventional irrigation (Table 4.7). Application of zinc resulted in significantly higher fruit length (17.15 cm) and the lowest fruit length was recorded for treatment without foliar application (13.24 cm).

Fruit weight

Under conventional irrigation fruit weight was significantly influenced by micronutrient application (Table 4.7). Highest fruit weight was observed for treatment without foliar application (12.56 g) which was statistically on par with zinc application (11.80 g). Lowest fruit weight was recorded for KAU multi nutrient application (9.62 g) which was on par with combined application of zinc and boron (15.25 g).

Number of fruits per plant

Significantly higher number of fruits were produced by zinc application (20.75) which was followed by boron application and KAU multi mix application under conventional irrigation (Table 4.7). Lowest number of fruits were produced by control (15.25).

Number of harvests

Thirteen harvests were taken from all the plots. Micronutrient application did not had any influence on number of harvests from okra plants.

Per plant yield

Per plant yield was significantly higher for zinc application (214.85 g) which was statistically on par with treatment without foliar application (207.45 g) under conventional irrigation. KAU multi mix application recorded lowest per plant yield (156.87 g) which was statistically on par with boron application (168.84 g) and combined application of zinc and boron (184.30 g) (Table 4.7).

Yield (Mg/ha)

Micronutrient application had significant influence on yield of okra under conventional irrigation (Table 4.7). Foliar application of zinc recorded highest yield (11.94 Mg/ha) followed by treatment without foliar application (11.53 Mg/ha). Lowest yield was recorded for KAU multi mix application (8.72 Mg/ha) which was statistically on par with boron application (9.38 Mg/ha)

Table 4.5. Effect of micronutrient application on dry matter production (kg/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)
T_1-Zn (0.5%)	270.83	527.78	965.28	222.22	548.60	625.00
T_2-B (0.5%)	166.67	423.61	740.28	340.28	479.167	583.33
T_3-Zn (0.5%) + B (0.5%)	131.94	701.39	979.17	263.89	541.67	520.83
T_4- KAU multi mix	229.17	548.61	834.72	291.67	437.50	916.67
T_5- Without foliar application (Control)	215.28	354.17	1090.28	305.56	423.61	1159.72
CD (0.05)	81.96	188.270	159.74	NS	NS	227.046

Table 4.6. Effect of micronutrients on yield attributes of okra under drip irrigation

Treatments	Fruit length (cm)	Fruit weight (g)	Number of fruits/plant	Per plant yield(g)	Yield(Mg/ha)
T_1-Zn (0.5%)	17.12	13.22	22.50	242.59	13.48
T_2-B (0.5%)	16.87	10.87	23.00	230.21	12.79
T_3-Zn (0.5%) + B (0.5%)	16.25	12.27	17.00	199.37	11.08
T_4- KAU multi mix	17.97	14.64	20.50	295.38	16.41
T_5- Without foliar application (Control)	17.34	10.47	19.00	216.99	12.06
CD (0.05)	0.99	1.95	1.29	36.74	2.04

Table 4.7. Effect of micronutrients on yield attributes of okra under conventional irrigation

Treatments	Fruit length (cm)	Fruit weight (g)	Number of fruits/plant	Per plant yield(g)	Yield(Mg/ha)
T_1-Zn (0.5%)	17.15	11.80	20.75	214.85	11.94
T_2-B (0.5%)	15.51	10.77	18.00	168.843	9.38
T_3-Zn (0.5%) + B (0.5%)	15.84	10.10	17.00	184.30	10.24
T_4- KAU multi mix	13.28	9.62	18.00	156.87	8.72
T_5- Without foliar application (Control)	13.24	12.56	15.25	207.45	11.53
CD (0.05)	1.03	1.55	1.19	31.79	1.77

4.3. Nutrient content

4.3.1. Nitrogen content

Drip irrigation

Nitrogen content was significantly influenced by micronutrient application only at 60 DAS. At 30 DAS and 90 DAS micronutrient application did not show any influence on nitrogen content (Table 4.8). Combined application of zinc and boron showed significantly highest nitrogen content at 60 DAS (2.67%) which was statistically on par with nitrogen content of zinc applied plants (2.49%) and boron applied plants (2.19%), and lowest N content at this stage was recorded for KAU multi mix applied plants (1.88%).

Conventional irrigation

Micronutrient application had no significant influence on nitrogen content of plants at initial stages of growth (30 DAS and 60 DAS). Significant variation in nitrogen uptake with micronutrient application was shown by okra plants at 90DAS (Table 4.8). Highest content of nitrogen was observed for zinc applied plants, boron applied plants and zinc and boron applied plants (2.10% for all). Lowest nitrogen content at this stage was for treatment without foliar application (1.14%).

4.3.2. Phosphorus content

Drip irrigation

Significant influence on P content was observed in okra plants applied with micronutrients under drip irrigation with higher content in KAU multi mix applied plants (0.30%) which was statistically on par with boron applied (0.28%) and treatment without foliar application (0.27%) plants. At 60 DAS, highest boron content was observed for plants receiving combined application of zinc and boron (0.69%). Plants receiving boron application recorded highest P content which was statistically on par with treatment without foliar application (0.48%) and plants receiving combined application of zinc and boron (0.47%) at 90 DAS (Table 4.9).

Conventional irrigation

Micronutrient application did not show significant variation in P content during initial stages (30DAS) under conventional irrigation (Table 4.9). Boron application showed significantly higher P content (0.33%) at 60 DAS which was statistically on par with KAU multi mix application (0.30%) and treatment without foliar application (0.29%). Zinc applied plants showed lowest P content (0.21%) at this stage. P content was significantly influenced by micronutrient application at 90 DAS. Highest P content was observed for boron applied plants (0.33%) and lowest was for control (0.23%).

4.3.3. Potassium content

Drip irrigation

The treatments showed significant influence on K content only at initial stages (30DAS). Boron applied plants showed significantly higher K content (4.91%) and lowest K content was recorded for KAU multi mix applied plants (1.53%). At 60 DAS and 90 DAS micronutrient application did not showed any influence on potassium content (Table 4.10).

Conventional irrigation

The treatments showed significant variation in K content at initial and harvesting stage of okra (30 DAS and 90 DAS) (Table 4.10). At 30 DAS combined application of zinc and boron showed highest P content (3.72%) which was statistically on par with boron application (3.01%). Lowest K content was recorded for KAU multi mix application. Treatments did not show significant variation in K content at 60 DAS. At 90 DAS boron applied plant recorded significantly higher K content (3.04%). Lowest K content was recorded for plants applied with zinc and boron together (1.81%).

Table 4.8. Effect of micronutrient application on nitrogen content (%) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (%)	60 DAS (%)	90 DAS (%)	30 DAS (%)	60 DAS (%)	90 DAS (%)
T_1-Zn (0.5%)	3.72	2.49	2.10	3.72	2.63	2.10
T_2-B (0.5%)	4.60	2.19	1.88	4.20	2.89	2.10
T_3-Zn (0.5%) + B (0.5%)	3.81	2.67	2.19	4.07	2.67	2.10
T_4-KAU multi mix	3.63	1.88	1.66	4.11	3.02	1.66
T_5-Without foliar application (Control)	4.07	2.04	2.45	3.41	3.02	1.14
CD (0.05)	NS	0.55	NS	NS	NS	0.45

Table 4.9. Effect of micronutrient application on phosphorus content (%) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (%)	60 DAS (%)	90 DAS (%)	30 DAS (%)	60 DAS (%)	90 DAS (%)
T_1-Zn (0.5%)	0.20	0.47	0.44	0.15	0.21	0.26
T_2-B (0.5%)	0.28	0.45	0.52	0.13	0.33	0.33
T_3-Zn (0.5%) + B (0.5%)	0.13	0.69	0.48	0.13	0.26	0.24
T_4- KAU multi mix	0.30	0.41	0.40	0.09	0.30	0.28
T_5- Without foliar application (Control)	0.27	0.52	0.48	0.14	0.29	0.23
CD (0.05)	0.061	0.12	0.06	NS	0.05	0.05

Table 4.10. Effect of micronutrient application on potassium content (%) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (%)	60 DAS (%)	90 DAS (%)	30 DAS (%)	60 DAS (%)	90 DAS (%)
T_1-Zn (0.5%)	1.89	1.93	1.42	2.17	1.74	1.93
T_2-B (0.5%)	4.91	1.44	1.61	3.01	1.81	3.04
T_3-Zn (0.5%) + B (0.5%)	1.55	1.55	1.79	3.72	1.68	1.81
T_4- KAU multi mix	1.53	1.51	1.64	1.59	1.70	2.01
T_5- Without foliar application (Control)	1.62	1.57	2.16	1.97	1.65	1.81
CD (0.05)	0.965	NS	NS	0.87	NS	0.70

Table 4.11. Effect of micronutrient application on calcium content (%) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (%)	60 DAS (%)	90 DAS (%)	30 DAS (%)	60 DAS (%)	90 DAS (%)
T_1-Zn (0.5%)	0.95	2.42	2.12	0.75	1.92	1.80
T_2-B (0.5%)	1.51	1.87	2.52	0.57	1.54	0.76
T_3-Zn (0.5%) + B (0.5%)	0.77	2.19	2.28	1.41	2.16	1.44
T_4- KAU multi mix	1.33	2.15	1.97	1.21	1.79	1.70
T_5- Without foliar application (Control)	1.08	1.97	0.52	0.77	2.00	1.90
CD (0.05)	0.20	0.20	0.32	0.21	0.21	0.22

4.3.4. Calcium content

Drip irrigation

The calcium content was significantly affected by micronutrient application under drip irrigation in all stages (Table 4.11). It was found highest in boron applied plants (1.51%) which was statistically on par with KAU multi mix application at 30 DAS. Lowest calcium content was found in plants applied with zinc and boron together (0.77%). AT 60 DAS calcium was significantly higher in zinc applied plants (2.42%) and was lowest in boron applied plants (1.87%). Boron applied plants showed significantly higher calcium content (2.52%) at 90 DAS which is statistically on par with combined application of zinc and boron (2.28%). Lowest calcium content was found in control at this stage (0.52%).

Conventional irrigation

Micronutrient application significantly influenced the calcium content in okra under conventional irrigation in all stages of growth (Table 4.11). Combined application of zinc and boron recorded significantly higher content of calcium (1.41%) which was statistically on par with KAU multi mix application (1.21%) at 30 DAS. Lowest calcium content was shown by plants applied with boron. At 60 DAS, significantly higher calcium content was recorded by combined application of zinc and boron (2.16%) and lowest calcium content was shown by boron applied plants (1.54%). control plants showed significantly higher calcium content (1.90%) which is statistically on par with zinc application (1.80%) and KAU multi mix application (1.70%) at 90 DAS. Here also lowest calcium content was recorded by boron applied plants (0.76%).

4.3.5. Magnesium content

Drip irrigation

Magnesium content was significantly influenced by micronutrient application at initial stages of crop growth (30 and 60 DAS), but at the harvest stage it did not showed any significant influence (Table 4.12). At 30 DAS and 60 DAS, magnesium content was significantly higher in plants receiving combined application of zinc and boron (0.38% and 0.37% respectively). The lowest Mg content was recorded by Zn applied plants in both stages (0.26% and 0.24% respectively).

Conventional irrigation

Micronutrient application showed significant variation in Mg content only at the later stages (90DAS) (Table 4.12). It did not show any significant influence at the early stages of growth (30 DAS and 60 DAS). At 90 DAS KAU multi mix application showed significantly higher Mg content (0.49%) which was statistically on par with Mg content of zinc applied plants (0.48%).

4.3.6. Sulphur content

Drip irrigation

Sulphur content was significantly influenced by micronutrient application only at the initial stages (30 and 60 DAS). At 30 DAS, KAU multi mix application showed significantly higher S content (0.57%) which was on par with S content of boron applied plants (0.54%) and control plants (0.46%). Lowest S content at this stage was shown by plants applied with combination of zinc and boron (0.37%). Plants applied with boron showed significantly higher S content (0.60%) at 60 DAS and lowest S content was shown by plants applied with KAU multi mix (0.35%). Sulphur content was not significantly varied with micronutrient application at 90 DAS (Table 4.13).

Conventional irrigation

Micronutrient application showed significant effect in S content of okra only at 60DAS. At 30 DAS and 90 DAS, no significant variation in S content with micronutrient application was noticed (Table 4.13). At 60 DAS, S content was significantly higher for plants applied with combination of zinc and boron (0.55%) which is on par with treatment without foliar application (0.45%). Lowest S content at this stage was recorded for plants applied with KAU micronutrient mix (0.36%).

Table 4.12. Effect of micronutrient application on magnesium content (%) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (%)	60 DAS (%)	90 DAS (%)	30 DAS (%)	60 DAS (%)	90 DAS (%)
T_1-Zn (0.5%)	0.26	0.24	0.31	0.42	0.43	0.48
T_2-B (0.5%)	0.31	0.32	0.30	0.37	0.43	0.37
T_3-Zn (0.5%) + B (0.5%)	0.38	0.37	0.32	0.48	0.45	0.40
T_4- KAU multi mix	0.36	0.27	0.33	0.43	0.44	0.49
T_5- Without foliar application (Control)	0.27	0.27	0.30	0.40	0.46	0.30
CD (0.05)	0.05	0.03	NS	NS	NS	0.05

Table 4.13. Effect of micronutrient application on Sulphur content (%) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (%)	60 DAS (%)	90 DAS (%)	30 DAS (%)	60 DAS (%)	90 DAS (%)
T_1-Zn (0.5%)	0.41	0.44	0.45	0.41	0.41	0.41
T_2-B (0.5%)	0.54	0.60	0.27	0.37	0.40	0.44
T_3-Zn (0.5%) + B (0.5%)	0.37	0.47	0.55	0.36	0.55	0.34
T_4- KAU multi mix	0.57	0.35	0.59	0.45	0.36	0.32
T_5- Without foliar application (Control)	0.46	0.37	0.57	0.31	0.45	0.40
CD (0.05)	0.14	0.13	NS	NS	0.11	NS

4.3.7. Iron content

Drip irrigation

Iron content showed significant variation with micronutrient application in all stages of crop growth (Table 4.14). Significantly higher iron content was recorded by okra plants applied with combination of zinc and boron (1759 mg/kg) and lowest was for KAU multi mix applied plants (781 mg/kg) at 30 DAS. At 60 DAS, iron content was significantly higher for plants receiving combination of zinc and boron (855 mg/kg) which was statistically on par with KAU multi mix applied plants (824 mg/kg). Zinc applied plants (705 mg/kg) and boron applied plants (638 mg/kg). At 90 DAS control showed significantly higher iron content (694 mg/kg) which was statistically on par with iron content of boron applied plants (649 mg/kg) and zinc applied plants (632 mg/kg). Lowest iron content was recorded by plants applied with KAU multi mix (492 mg/kg).

Conventional irrigation

Micronutrient application significantly influenced the iron content of okra plants at all stages of growth (Table 4.14). Control plants showed significantly higher iron content at 30 DAS (1405 mg/kg), and the lowest iron content was recorded for plants receiving combined application of zinc and boron (598 mg/kg) which was statistically on par with iron content of boron applied plants (610 mg/kg), zinc applied plants (694 mg/kg) and KAU multi mix applied plants (862 mg/kg). At 60 DAS, plants receiving combined application of zinc and boron recorded significantly higher iron content (881 mg/kg) which was statistically on par with iron content of plants receiving zinc application (757 mg/kg). Lowest iron content was recorded in plants receiving boron at this stage. At 90 DAS, KAU multi mix applied plants recorded significantly higher iron content (1579 mg/kg) which was statistically on par with iron content of control plants (1375 mg/kg) and plants receiving zinc (1359 mg/kg). At this stage lowest Fe content was recorded for plants applied with boron (932 mg/kg).

Table 4.14. Effect of micronutrient application on iron content (mg/kg) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)
T_1-Zn (0.5%)	1134	705	632	694	757	1359
T_2-B (0.5%)	1181	638	649	610	552	932
T_3-Zn (0.5%) + B (0.5%)	1759	855	491	598	881	1043
T_4- KAU multi mix	781	824	492	862	608	1579
T_5- Without foliar application (Control)	1203	467	694	1405	597	1375
CD (0.05)	270	221	132	382	153	419

Table 4.15. Effect of micronutrient application on manganese content (mg/kg) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)
T_1-Zn (0.5%)	204	343	278	649	1233	1787
T_2-B (0.5%)	240	316	429	726	1435	1263
T_3-Zn (0.5%) + B (0.5%)	351	287	234	709	1455	1350
T_4- KAU multi mix	180	374	204	837	2407	1594
T_5- STB POP recommendation (Control)	146	230	157	507	1368	2048
CD (0.05)	51	55	50	120	247	337

4.3.8. Manganese content

Drip irrigation

Manganese content showed significant variation with micronutrient application at all the stages of growth (Table 4.15). Okra plants receiving combined application of zinc and boron showed significantly higher Mn content (351 mg/kg) and lowest was in control (146 mg/kg) at 30 DAS. At 60 DAS Mn content was significantly higher for KAU multi mix applied plants (374 mg/kg) which was statistically on par with Mn content of zinc applied plants (343 mg/kg). The lowest Mn content was recorded for treatment without foliar application (230 mg/kg) at this stage. Significantly higher Mn content was recorded by plants receiving boron (430 mg/kg) and lowest for control (157 mg/kg) at 90 DAS.

Conventional irrigation

Micronutrient application significantly influenced Mn content of okra plants at all stages of growth (Table 4.15). At 30 DAS, KAU multi mix applied plants showed significantly higher Mn content (837 mg/kg) which was statistically on par with Mn content of plants receiving boron (726 mg/kg) Lowest Mn content at this stage was recorded by control plants. Mn content was significantly higher for KAU multi mix applied plants (2407 mg/kg) at 60 DAS. Lowest Mn content was recorded by zinc applied plants (1233 mg/kg) at this stage. Significantly higher Mn content was recorded by zinc applied plants (1787 mg/kg) and lowest was for boron applied plants (1262 mg/kg) at 90 DAS.

4.3.9. Copper content

Drip irrigation

Copper content showed significant variation with micronutrient application at initial stages of growth of okra (30DAS and 60 DAS) (Table 4.16). At 30 DAS plants receiving combined application of zinc and boron recorded significantly higher copper content (64 mg/kg) and lowest was shown treatment without foliar application (9 mg/kg). Okra plants receiving application of boron recorded significantly higher Cu content (64 mg/kg) which was statistically on par with boron content of plants receiving KAU multi mix (49 mg/kg) and zinc applied plants (41 mg/kg) at 60 DAS. Lowest Cu content at this stage was recorded for control plants (12 mg/kg). No significant influence of micronutrient application was observed in Cu content at 90 DAS.

Conventional irrigation

Significant influence of micronutrient application was observed in Cu content of okra plants in all the growth stages (Table 4.16). Plants receiving KAU multi mix application showed significantly higher copper content at 60 DAS (53 mg/kg) and lowest was observed in boron applied plants. At 60 DAS significantly higher Cu content was recorded for plants receiving KAU multi nutrient mix (81 mg/kg) and lowest for zinc applied plants (14 mg/kg). At 90 DAS control plants recorded significantly higher Cu content which was statistically on par with Cu content of KAU multi mix applied plants (15 mg/kg) and zinc applied plants (14 mg/kg). Lowest Cu content at this stage was recorded in boron applied plants (11 mg/kg).

4.3.10. Zinc content

Drip irrigation

Micronutrient application significantly influenced zinc content of okra plants at all stages of crop growth (Table 4.17). Plants receiving combined application of zinc and boron recorded significantly higher boron content (913.06 mg/kg) and lowest by treatment without foliar application (41.13 mg/kg) at 30 DAS. Zinc content was significantly higher in plants receiving zinc application at 60 DAS (816.50 mg/kg) and lowest zinc content was recorded by treatment without foliar application (92.50 mg/kg). Significantly higher zinc content was recorded for plants receiving zinc application (175.50 mg/kg) and lowest was for treatment without foliar application (55.31 mg/kg) at 90 DAS.

Conventional irrigation

Significant variation in zinc content with micronutrient application was observed in all stages of growth of okra plants (Table 4.17). At 30 DAS, plant receiving zinc application recorded significantly higher zinc content (509 mg/kg). At 60 DAS, zinc content was significantly higher for plants receiving zinc application (325 mg/kg) which was statistically on par with zinc content of plants receiving combined application of zinc and boron (298 mg/kg) and KAU multi mix application (243 mg/kg). Zinc content was significantly higher for KAU multi mix application (183 mg/kg) which was statistically on par with zinc content of plants receiving zinc application (140 mg/kg) at 90DAS. The lowest zinc content at all this stages was recorded by treatment without foliar application (66 mg/kg, 83.56 mg/kg, and 92 mg/kg at 30, 60 and 90 DAS respectively)).

4.3.11. Boron content

Drip irrigation

Micronutrient application significantly influenced boron content of okra plants under drip irrigation only at initial stage (30DAS) (Table 4.18). AT 30 DAS, plats receiving boron application recorded significantly higher boron content (136 mg/kg) which was statistically on par with boron content of okra plants receiving combined application of zinc and boron (122 mg/kg). The lowest boron content at this stage was recorded by treatment without foliar application (67 mg/kg). Significant variation in boron content with micronutrient application is not observed at 60 DAS and 90 DAS.

Conventional irrigation

Micronutrient application did not had any significant influence on boron content of okra plants at initial stages (30 DAS and 60 DAS) (Table 4.18). At 90 DAS, micronutrient application significantly influenced boron content. Plants receiving combination of zinc and boron showed significantly higher boron content (142 mg/kg) which was statistically on par with boron content of plants receiving boron (106 mg/kg) and KAU multi mix (102 mg/kg). The lowest boron content at this stage was showed by treatment without foliar application (58 mg/kg).

Table 4.16. Effect of micronutrient application on copper content (mg/kg) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)
T_1-Zn (0.5%)	21	15	15	33	14	14
T_2-B (0.5%)	24	64	16	17	16	11
T_3-Zn (0.5%) + B (0.5%)	64	41	18	16	22	13
T_4- KAU multi mix	26	49	16	53	82	15
T_5- Without foliar application (Control)	9	13	16	24	17	17
CD (0.05)	10	26	NS	13	14	4

Table 4.17. Effect of micronutrient application on zinc content (mg/kg) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)
T_1-Zn (0.5%)	629	817	176	509	325	140
T_2-B (0.5%)	68	131	82	72	158	102
T_3-Zn (0.5%) + B (0.5%)	913	590	135	487	298	111
T_4- KAU multi mix	154	333	95	234	243	183
T_5- Without foliar application (Control)	41	93	55	66	84	92
CD (0.05)	139	142	13	72	127	58

Table 4.18. Effect of micronutrient application on boron content (mg/kg) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)	30 DAS (mg/kg)	60 DAS (mg/kg)	90 DAS (mg/kg)
T_1-Zn (0.5%)	79	91	95	90	94	71
T_2-B (0.5%)	136	139	134	120	120	107
T_3-Zn (0.5%) + B (0.5%)	122	150	128	120	116	142
T_4- KAU multi mix	105	87	142	87	102	102
T_5- Without foliar application (Control)	68	83	127	81.77	100	58
CD (0.05)	32	NS	NS	NS	NS	42

4.4. Nutrient uptake

4.4.1. Nitrogen uptake

Drip irrigation

Significant variation in nitrogen uptake was shown by plants treated with micronutrients at all stages of growth (Table 4.19). At 30 DAS, nitrogen uptake was significantly higher for zinc applied plants (9.76 kg/ha) which was statistically on par with nitrogen uptake of control (8.81 kg/ha), KAU multi mix applied plants (8.14 kg/ha) and boron applied plants (7.64 kg/ha). Lowest nitrogen uptake was shown by plants receiving combined application of zinc and boron (4.95 kg/ha). At 60 DAS, significantly higher nitrogen uptake was observed in plants applied with combined application of zinc and boron (18.63 kg/ha) and lowest nitrogen uptake was shown by plants receiving boron (9.13 kg/ha). At 90 DAS, nitrogen uptake significantly varied with micronutrient application. Highest nitrogen uptake at this stage was shown by control plants (26.71 kg/ha) which was statistically on par with nitrogen uptake of plants receiving combined application of zinc and boron (21.26 kg/ha) and zinc applied plants (20.27 kg/ha). Lowest nitrogen uptake was shown by plants applied with boron (13.88 kg/ha).

Conventional irrigation

Micronutrient application significantly influenced the nitrogen uptake of okra plants under conventional irrigation only at harvesting stage (90DAS) (Table 4.19). At 90 DAS, plants receiving KAU multi mix application showed significantly higher nitrogen uptake (15.28 kg/ha) which was statistically on par with nitrogen uptake of zinc applied plants (12.91 kg/ha). Lowest nitrogen uptake at this stage was recorded by plants receiving combined application of zinc and boron (10.88 kg/ha).

4.4.2. Phosphorus uptake

Drip irrigation

Phosphorus uptake showed significant variation with micronutrient application in all the stages of growth of okra under drip irrigation (Table 4.20).

Plants receiving KAU multi mix showed significantly higher P uptake (0.68 kg/ha) and the lowest uptake was shown by combined application of zinc and boron (0.17 kg/ha) at 30DAS. Plants receiving combined application of zinc and boron showed significantly higher P uptake (4.74 kg/ha) at 60 DAS, and lowest uptake at this stage was shown by boron applied plants (1.77 kg/ha) which was statistically on par with P uptake of treatment without foliar application (1.83 kg/ha). At 90DAS, control showed significantly higher P uptake (5.23 kg/ha) and lowest P uptake was shown by plants applied with KAU multi mix (3.29 kg/ha).

Conventional irrigation

Micronutrient application significantly affected the P uptake of okra crop under conventional irrigation at initial and final stage (30 DAS and 90DAS) and was found to be non-significant at 60 DAS. At 30 DAS control plants showed significantly higher P uptake (0.44 kg/ha) which was statistically on par with P uptake of plants receiving boron (0.42 kg/ha), and combination of zinc and boron (0.34 kg/ha). Lowest P uptake at this stage was recorded for plants receiving KAU multi mix (0.27 kg/ha). Treatment without foliar application showed significantly higher P uptake (2.53 kg/ha) at 90 DAS which is statistically on par with P uptake of KAU multi mix applied plants (2.52 kg/ha). Lowest P uptake at this stage was noted for plants receiving combined application of zinc and boron (1.27 kg/ha) (Table 4.20).

4.4.3. Potassium uptake

Drip irrigation

Potassium uptake showed significant variation with micronutrient application under drip irrigation at all stages (Table 4.21). Plants receiving boron application showed significantly higher K uptake (7.60 kg/ha) at 30 DAS. The lowest uptake at this stage was showed by plants treated with combination of zinc and boron (1.92 kg/ha). At 60 DAS, combined application of zinc and boron gave significantly higher K uptake (10.95 kg/ha) which was statistically on par with K uptake of plants receiving zinc application (10.15 kg/ha) and KAU multi mix application (8.32 kg/ha). Lowest P uptake at this stage was shown by treatment without foliar application (5.54 kg/ha). Significantly higher K uptake at 90DAS was shown by control plants (23.60 kg/ha) and lowest K uptake was shown by plants receiving combined application of boron (11.92 kg/ha).

Conventional irrigation

Micronutrient application significantly influenced K uptake of okra plants under conventional irrigation only at the initial stage (30 DAS). In all other stages it was found non-significant (Table 4.21). At 30 DAS, plants receiving boron showed significantly higher K uptake (9.87 kg/ha) which was statistically on par with K uptake of plants receiving combined application of zinc and boron (9.59 kg/ha). Lowest K uptake at this stage was recorded for KAU multi mix applied plants (4.49 kg/ha).

4.4.4. Calcium uptake

Drip irrigation

Significant variation in Ca uptake was shown by micronutrient application to okra under drip irrigation at all growth stages (Table 4.22). At 30 DAS, plants applied with KAU multi mix showed significantly higher Ca uptake (3.05 kg/ha) which was statistically on par with Ca uptake of treatment without foliar application (2.29 kg/ha), zinc applied plants (2.54 kg/ha) and boron applied plants (2.47 kg/ha). Lowest Ca uptake at this stage was shown by combined application of zinc and boron (1.08 kg/ha). At 60 DAS, significantly higher Ca uptake was shown by plants receiving combined application of zinc and boron (15.35 kg/ha) which was statistically on par with Ca uptake of zinc applied plants (12.82 kg/ha) and KAU multi mix applied plants (11.87 kg/ha). Lowest Ca uptake at this stage was shown by plants applied with boron (8.02 kg/ha). At 90 DAS, plants receiving combined application of zinc and boron showed significantly higher Ca uptake (22.36 kg/ha) which was statistically on par with Ca uptake of zinc applied plants (20.49 kg/ha) and boron applied plants (18.66 kg/ha). Lowest Ca content was shown by treatment without foliar application (5.85 kg/ha) at this stage.

Conventional irrigation

Micronutrient application significantly influenced Ca uptake of plants at all stages of growth of okra plants under conventional irrigation (Table 4.22). At 30 DAS, plants receiving combined application of zinc and boron showed significantly higher Ca uptake (3.72 kg/ha) which was on par with Ca uptake of plants treated with KAU multi mix. Lowest Ca uptake at this stage was shown by plants applied with zinc (1.67 kg/ha). Plants receiving combined application of zinc and boron showed significantly higher Ca uptake (11.70 kg/ha) at 60 DAS which was statistically on par with Ca uptake of zinc applied plants. (10.55 kg/ha). Lowest Ca uptake at this stage was observed for boron applied plants. Control plants recorded highest Ca uptake at 90DAS (22.31 kg/ha) and lowest Ca uptake at this stage was recorded for plants receiving boron application (4.50 kg/ha).

4.4.5. Magnesium uptake

Drip irrigation

Significant variation in magnesium uptake was shown by okra plants only at 60 DAS. At 30 DAS and 90 DAS, micronutrient application did not showed any significant influence on Mg uptake (Table 4.23). Combined application of zinc and boron showed significantly higher Mg uptake (2.60 kg/ha) and lowest was shown by control (0.96 kg/ha) at 60 DAS.

Conventional irrigation

Micronutrient application significantly influenced Mg uptake of conventionally irrigated okra plants only at 90 DAS. At initial stages no significant influence on Mg uptake was observed (Table 4.23). Control plants showed significantly higher Mg uptake (4.64 kg/ha) at 90 DAS and lowest Mg uptake at this stage was shown by KAU micronutrient mix application (2.09 kg/ha).

Table 4.19. Effect of micronutrient application on nitrogen uptake (kg/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)
T_1-Zn (0.5%)	9.76	13.25	20.27	8.57	14.51	12.91
T_2-B (0.5%)	7.64	9.13	13.88	14.18	14.15	12.02
T_3-Zn (0.5%) + B (0.5%)	4.95	18.63	21.26	10.87	14.38	10.88
T_4-KAU multi mix	8.14	10.00	14.12	12.18	13.19	15.28
T_5-Without foliar application (Control)	8.81	7.21	26.71	10.33	12.68	13.15
CD (0.05)	2.84	3.57	8.25	NS	NS	2.5

Table 4.20. Effect of micronutrient application on phosphorus uptake (kg/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)
T_1-Zn (0.5%)	0.52	2.41	4.23	0.33	1.15	1.62
T_2-B (0.5%)	0.44	1.77	3.84	0.42	1.56	1.88
T_3-Zn (0.5%) + B (0.5%)	0.17	4.74	4.59	0.34	1.41	1.27
T_4- KAU multi mix	0.68	2.09	3.29	0.27	1.30	2.52
T_5- Without foliar application (Control)	0.55	1.83	5.23	0.44	1.23	2.53
CD (0.05)	0.09	0.44	0.53	0.10	NS	0.32

Table 4.21. Effect of micronutrient application on potassium uptake (kg/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)
T_1-Zn (0.5%)	5.02	10.15	13.51	4.73	9.58	11.81
T_2-B (0.5%)	7.60	6.21	11.93	9.87	8.74	17.87
T_3-Zn (0.5%) + B (0.5%)	1.92	10.95	17.47	9.59	9.12	9.54
T_4- KAU multi mix	3.43	8.32	13.69	4.49	7.42	18.55
T_5- Without foliar application (Control)	3.40	5.54	23.60	6.01	6.94	21.30
CD (0.05)	0.76	3.42	7.99	1.77	NS	NS

Table 4.22. Effect of micronutrient application on calcium uptake (kg/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)
T_1-Zn (0.5%)	2.54	12.82	20.49	1.67	10.55	11.14
T_2-B (0.5%)	2.47	8.02	18.66	1.86	7.31	4.50
T_3-Zn (0.5%) + B (0.5%)	1.08	15.35	22.36	3.72	11.70	7.54
T_4- KAU multi mix	3.05	11.87	16.41	3.45	7.92	15.49
T_5- Without foliar application (Control)	2.29	6.97	5.85	2.33	8.51	22.31
CD (0.05)	0.82	4.52	3.90	0.79	2.70	5.41

4.4.6. Sulphur uptake

Drip irrigation

Sulphur uptake was significantly influenced by micronutrient application at 30 DAS and 60 DAS (Table 4.24). At 30 DAS, plants receiving KAU multi mix application showed significantly higher S uptake (1.31 kg/ha) which was statistically on par with S uptake of zinc applied plants (1.20 kg/ha), treatment without foliar application (0.98 kg/ha) and boron applied plants (0.91 kg/ha). Sulphur uptake was lowest for plants receiving combined application of zinc and boron (0.47 kg/ha). At 60 DAS, plants applied with combination of zinc and boron showed significantly higher S uptake (3.27 kg/ha) which was statistically on par with S uptake of boron applied plants (2.63 kg/ha) and zinc applied plants (2.37 kg/ha). Lowest S uptake at this stage was recorded for treatment without foliar application (1.29 kg/ha). At 90 DAS, S uptake was not significantly influenced by micronutrient application.

Conventional irrigation

Micronutrient application did not have any significant effect on S uptake of okra plants under conventional irrigation at 30 DAS and 90 DAS (Table 4.24). Significant variation in S uptake was shown by plants receiving micronutrient application at 60 DAS. At this stage, plants applied with combined application of zinc and boron showed significantly higher S uptake (2.95 kg/ha) which was statistically on par with S uptake of zinc applied plants (2.26 kg/ha).

Table 4.23. Effect of micronutrient application on magnesium uptake (kg/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)
T_1-Zn (0.5%)	0.69	1.28	2.98	0.93	2.37	3.25
T_2-B (0.5%)	0.53	1.33	2.54	1.21	2.08	2.09
T_3-Zn (0.5%) + B (0.5%)	0.50	2.60	2.72	1.27	2.45	2.16
T_4- KAU multi mix	0.82	1.43	3.10	1.26	1.95	2.09
T_5- S Without foliar application (Control)	0.59	0.96	2.68	1.22	1.96	4.64
CD (0.05)	NS	0.49	NS	NS	NS	0.53

Table 4.24. Effect of micronutrient application on Sulphur uptake (kg/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)	30 DAS (kg/ha)	60 DAS (kg/ha)	90 DAS (kg/ha)
T_1-Zn (0.5%)	1.20	2.37	4.13	0.93	2.26	2.73
T_2-B (0.5%)	0.91	2.63	2.13	1.25	1.92	2.36
T_3-Zn (0.5%) + B (0.5%)	0.47	3.27	4.74	1.97	2.95	1.96
T_4- KAU multi mix	1.31	2.00	5.54	1.29	1.57	1.66
T_5- Without foliar application (Control)	0.98	1.29	5.03	0.95	1.92	3.65
CD (0.05)	0.45	1.20	NS	NS	0.74	NS

4.4.7 Iron uptake

Drip irrigation

Iron uptake by okra plants was significantly influenced by micronutrient application only at 60 DAS, on the other two stages it had no significant influence (Table 4.25). At 60 DAS, plants receiving combined application of zinc and boron recorded significantly higher iron uptake (605 g/ha) which was statistically on par with iron content of plants receiving KAU multi mix application (469 g/ha) and zinc application (374 g/ha). Lowest iron uptake at this stage was recorded by control (165 g/ha).

Conventional irrigation

Significant variation in iron uptake was shown by plants receiving micronutrient application under conventional irrigation at all stages of growth (Table 4.25). Control plants showed significantly higher iron uptake (432 g/ha) at 30 DAS and lowest at this stage was recorded for plants receiving zinc application (156 g/ha). At 60 DAS, plants receiving combined application of zinc and boron recorded significantly higher Fe uptake (473 g/ha) which was statistically on par with iron uptake zinc applied plants (415 g/ha). Control showed lowest iron uptake (251 g/ha) at this stage. Iron uptake of control plants were significantly higher (1267 g/ha) at 90 DAS and lowest uptake at this stage was recorded by plants receiving boron application (505 g/ha).

4.4.8. Manganese uptake

Drip irrigation

Manganese uptake was significantly influenced by micronutrient application only at 60 and 90 DAS. At 30 DAS no significant variation in iron uptake is noticed (Table 4.26). At 60 DAS, plants receiving combined application of zinc and boron recorded significantly higher Mn uptake (202 g/ha) which was statistically on par with Mn uptake of okra plants receiving KAU micronutrient mix application (201 g/ha), zinc application (181 g/ha) and boron application (138 g/ha).

Lowest Mn uptake at this stage was shown by control (82 g/ha). At 90 DAS, boron applied plants showed significantly higher Mn uptake (318 g/ha) which was statistically on par with Mn uptake of plants receiving zinc application (269 g/ha). Lowest Mn uptake at this stage was recorded by KAU multi mix application (173 g/ha).

Conventional irrigation

Significant variation in Mn uptake with micronutrient application was shown by okra plants at all stages of growth (Table 4.26). At 30 DAS, boron applied plants showed significantly higher Mn uptake (242 g/ha) which was statistically on par with Mn uptake of KAU multi mix applied plants (241 g/ha) and plants receiving combined application of zinc and boron (186 g/ha). Lowest Mn uptake at this stage was shown by plants applied with zinc (142 g/ha). Plants receiving KAU multi mix showed significantly higher Mn uptake (1041 g/ha) and lowest Mn uptake at this stage was shown by treatment without foliar application (584 g/ha). Mn uptake was significantly higher for treatment without foliar application (2316 g/ha) at 90 DAS, and lowest Mn uptake at this stage was recorded by plants receiving combined application of zinc and boron (698 g/ha).

4.4.9. Copper uptake

Drip irrigation

Copper uptake was significantly influenced by micronutrient application at initial stages of crop growth (30 DAS and 60 DAS) (Table 4.27). At 30 DAS, plants receiving combined application of zinc and boron recorded significantly higher copper uptake (9 g/ha) which was statistically on par with Cu uptake of KAU multi mix applied plants (6 g/ha) and zinc applied plants (6 g/ha). Lowest Cu uptake at this stage was recorded by treatment without foliar application (2 g/ha). At 60 DAS significantly higher Cu uptake (29 g/ha) was shown by plants receiving combined application of zinc and boron which was statistically on par with Cu uptake of plants receiving KAU multi mix application and boron application (28 g/ha for both). Lowest Cu uptake at this stage was shown by treatment without foliar application (5 g/ha). No significant variation in Cu uptake with micronutrient application was shown by okra plants at 90 DAS.

Conventional irrigation

Significant variation in copper uptake was shown by okra plants with micronutrient application at all stages of crop growth (Table 4.27). KAU multi mix applied plants showed significantly higher Cu uptake (17 g/ha) at 30 DAS. Lowest Cu uptake at this stage was for plants receiving combined application of zinc and boron. At 60 DAS also, KAU multi mix applied plants showed significantly higher Cu uptake (35 g/ha) and lowest was shown by treatment without foliar application (7 g/ha). Control plants showed significantly higher Cu uptake at 90 DAS (15 g/ha) and lowest uptake was shown by boron applied plants (6 g/ha).

4.4.10. Zinc uptake

Drip irrigation

Zinc uptake was significantly influenced by micronutrient application at all growth stages (Table 4.28). Zinc applied plants showed significantly higher zinc uptake (171 g/ha) at 30 DAS which is followed by plants receiving combined application of zinc and boron (118 g/ha). Lowest zinc uptake at this stage was shown by control plants (9 g/ha). At 60 DAS, plants receiving zinc application showed significantly higher zinc uptake (441 g/ha) which was statistically on par with plants receiving combined application of zinc and boron (416 g/ha). Lowest zinc uptake at this stage was shown by treatment without foliar application (33 g/ha). Zinc applied plants recorded significantly higher zinc uptake at this stage (170 g/ha) and lowest zinc uptake was shown by treatment without foliar application (61 g/ha).

Conventional irrigation

Micronutrient application significantly influenced the zinc uptake at initial stages of growth (30 DAS and 60 DAS) (Table 4.28). Combined application of zinc and boron recorded significantly higher zinc uptake at 30 DAS (128 g/ha) which was statistically on par with zinc uptake of plants receiving zinc application (111 g/ha). The lowest zinc uptake at this stage was recorded by treatment without foliar application (20 g/ha). At 60 DAS, plants receiving zinc application recorded significantly higher zinc uptake (173 g/ha) which was statistically on par with zinc uptake of plants applied with combination of zinc and boron (165 g/ha) and KAU multi mix (106 g/ha). The lowest zinc uptake at this stage was recorded by control plants (35 g/ha). At 90 DAS micronutrient application did not significantly influenced the zinc uptake of okra plants.

4.4.11. Boron uptake

Drip irrigation

No significant variation in boron uptake was shown by plants with micronutrient application at any of the stages (Table 4.29).

Conventional irrigation

Micronutrient application had no significant influence on boron uptake of okra plants under conventional irrigation at any of the growth stages (Table 4.29).

Table 4.25. Effect of micronutrient application on iron uptake (g/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)
T_1-Zn (0.5%)	308	374	596	156	415	908
T_2-B (0.5%)	191	272	534	209	260	505
T_3-Zn (0.5%) + B (0.5%)	228	605	422	157	473	583
T_4- KAU multi mix	177	469	457	251	263	824
T_5- Without foliar application (Control)	2612	165	615	432	251	1267
CD (0.05)	NS	243	NS	153	80	322

Table 4.26. Effect of micronutrient application on manganese uptake (g/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)
T_1-Zn (0.5%)	55	181	269	142	675	1105
T_2-B (0.5%)	40	138	318	242	678	736
T_3-Zn (0.5%) + B (0.5%)	46	202	228	186	791	698
T_4- KAU multi mix	40	201	173	241	1041	1455
T_5- Without foliar application (Control)	32	82	174	155	584	2316
CD (0.05)	NS	68	58	58	192	262

Table 4.27. Effect of micronutrient application on copper uptake (g/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)
T_1-Zn (0.5%)	6	8	15	8	8	10
T_2-B (0.5%)	4	28	13	6	8	6
T_3-Zn (0.5%) + B (0.5%)	9	29	16	4	12	7
T_4- KAU multi mix	6	28	15	17	35	8
T_5- STB POP recommendation(Control)	2	5	14	7	7	15
CD (0.05)	4	17	NS	5	7	3

Table 4.28. Effect of micronutrient application on zinc uptake (g/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)
T_1-Zn (0.5%)	171	441	170	112	173	95
T_2-B (0.5%)	12	57	61	24	80	54
T_3-Zn (0.5%) + B (0.5%)	118	416	131	129	165	62
T_4- KAU multi mix	35	180	79	67	106	95
T_5- STB POP recommendation (Control)	9	33	61	20	35	87
CD (0.05)	44	137	21	27	74	NS

Table 4.29. Effect of micronutrient application on boron uptake (g/ha) of okra under different irrigation methods

Treatments	Drip irrigation			Conventional irrigation		
	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)	30 DAS (g/ha)	60 DAS (g/ha)	90 DAS (g/ha)
T_1-Zn (0.5%)	21	44	91	20	54	49
T_2-B (0.5%)	23	50	106	38	63	60
T_3-Zn (0.5%) + B (0.5%)	16	83	109	40	50	79
T_4- KAU multi mix	24	63	132	21	59	54
T_5- STB POP recommendation (Control)	14	49	113	24	47	53
CD (0.05)	NS	NS	NS	NS	NS	NS

4.5. Soil analysis

4.5.1. pH

Drip irrigation

Micronutrient application to okra under drip irrigation showed no significant influence on pH content of soil after the experiment (Table 4.30). When compared to initial soil pH, a slight decrease in pH is noticed after the experiment.

Conventional irrigation

pH content of the soil is not significantly influenced by micronutrient application in okra under conventional irrigation (Table 4.30). A slight increase in pH is noticed after the experiment.

4.5.2. Organic carbon (%)

Drip irrigation

No significant influence were noticed in organic carbon content of soil due to micronutrient application (Table 4.30). A slight increase in organic carbon content was noticed after the experiment compared to initial value.

Conventional irrigation

Micronutrient application in okra had no significant influence on organic carbon content of soil under conventional irrigation (Table 4.30). Organic carbon content was found to be increased in soil after the experiment.

Table 4.30. Effect of micronutrient application for okra under different irrigation methods on available pH and organic carbon content

Treatments	Drip irrigation		Conventional irrigation	
	pH	OC (%)	pH	OC (%)
T_1-Zn (0.5%)	6.18	1.83	5.39	1.73
T_2-B (0.5%)	6.16	1.92	5.40	1.69
T_3-Zn (0.5%) + B (0.5%)	5.57	1.95	5.82	1.73
T_4-KAU multi mix	6.10	1.92	5.09	1.75
T_5- Without foliar application (Control)	6.01	1.96	5.08	1.73
CD (0.05)	NS	NS	NS	NS
Pre experimental value	5.86	1.69	5.23	1.353

Table 4.31. Effect of micronutrient application for okra under different irrigation methods on available N, P and K in soil

Treatments	Drip irrigation			Conventional irrigation		
	N(kg/ha)	P(kg/ha)	K(kg/ha)	N(kg/ha)	P(kg/ha)	K(kg/ha)
T_1-Zn (0.5%)	263.42	40.38	114.80	257.15	159.80	332.92
T_2-B (0.5%)	238.34	46.57	142.80	294.78	117.98	340.48
T_3-Zn (0.5%) + B (0.5%)	263.42	41.89	66.89	294.78	165.27	416.64
T_4-KAU multi mix	294.78	35.41	115.36	260.29	160.08	294.56
T_5- Without foliar application (Control)	244.61	62.70	125.44	288.51	149.65	362.60
CD (0.05)	20.88	14.78	NS	25.93	26.24	NS
Pre experimental value	156.8	43.35	186.10	194.43	108.04	381.17

4.5.3. Available Nitrogen

Drip irrigation

Micronutrient application significantly influenced the available nitrogen in soil which was under drip irrigation (Table 4.31). Foliar application of KAU multi mix gave significantly higher available nitrogen (294.78 kg/ha). Lowest available nitrogen was observed for the boron treated plots (238.34 kg/ha). There was an increase in available nitrogen content was noticed after the experiment.

Conventional irrigation

Available nitrogen was significantly higher for boron application and combined application of zinc and boron (294.78 kg/ha) which was statistically on par with treatment without foliar application (288.51 kg/ha). Lowest available nitrogen was recorded for zinc applied plots (257.15 kg/ha) (Table 4.31). Increase in available N content was noticed after the experiment.

4.5.4. Available Phosphorus

Drip irrigation

Significant variation in available P was observed with micronutrient application (Table 4.31). Control recorded significantly higher amount of available P (62.70 kg/ha) and least amount of available P was found in treatment KAU multi mix application (35.41 kg/ha). No significant increase in available P is noticed after the experiment.

Conventional irrigation

Combined application of zinc and boron recorded significantly higher amount of available P (165.27 kg/ha) which was statistically on par with available P of plots treated with KAU multi mix (160.08 kg/ha), zinc (159.80 kg/ha) and treatment without foliar application (149.65 kg/ha). Lowest available P was observed in boron applied plots (149.65 kg/ha) (Table 4.31). Increase in available P content was noticed after the experiment.

4.5.5. Available potassium

Drip irrigation

Micronutrient application had no significant influence on available potassium in soil under drip irrigated condition (Table 4.31). Highest value for available potassium was noticed in boron applied plots (142.80 kg/ha) and lowest was observed in plots receiving combined application of zinc and boron (66.89 kg/ha). Available K content decreased in soil after the experiment.

Conventional irrigation

Micronutrient application had no significant influence on available K content in soil (Table 4.31). Highest available K was observed for plots applied with combined application of zinc and boron (146.64 kg/ha) and lowest was for KAU multi mix application (294.56 kg/ha). Content of available K decreased in all treatments except in combined application of zinc and boron after the experiment.

4.5.6. Secondary nutrients

Drip irrigation

Calcium content in soil was significantly influenced by micronutrient application to okra (Table 4.32). Boron application significantly increased the calcium content (1021.04 mg/kg). The lowest calcium content in soil was observed for the plots receiving combined application of zinc and boron (736.38 mg/kg).

Micronutrient application had no significant influence on Mg content of soil. Sulphur content in soil was significantly influenced by the micronutrient application to okra (Table 31). KAU multi mix application significantly increased S content of soil (2.59 mg/kg) which was statistically on par with treatment without foliar application (1.81 mg/kg) (Table 4.32).

Conventional irrigation

Micronutrient application to okra had no significant influence on Ca content of soil under conventional irrigation (Table 4.32).

Mg content in soil was significantly influenced by micronutrient application under conventional irrigation (Table 4.32). Plots treated with combination of zinc and boron recorded highest amount of available Mg (104.83 mg/kg) and lowest amount was found in treatment without foliar application (74.31 mg/kg).

Significant variation in amount of available S was observed with micronutrient application to okra (Table 4.32). Zinc application recorded significantly higher amount of available S (21.20 mg/kg). Lowest S content was found in control plots (2.31 mg/kg).

4.5.7. Micronutrients in soil

Drip irrigation

Micronutrient application significantly influenced iron content in soil under drip irrigation (Table 4.33). Plots receiving combination of Zn and B recorded significantly higher Fe content in soil (16.37 mg/kg) which was statistically on par with treatment without foliar application (14.00 mg/kg). Lowest Fe content in soil was noted for boron applied plots (12.70 mg/kg).

Mn, Zn, and Cu uptake in soil was not significantly influenced by micronutrient application under drip irrigation (Table 4.33).

Boron application resulted in significantly higher boron content in soil (0.77 mg/kg). The lowest boron content in soil was observed for zinc applied plots (0.11 mg/kg) (Table 4.33).

Conventional irrigation

Fe, Mn and Cu content in soil was not significantly influenced by micronutrient application to okra under conventional irrigation (Table 4.34).

Zinc content in soil was significantly higher for zinc applied plots (9.15 mg/kg) and lowest for treatment without foliar application (2.27 mg/kg) (Table 4.34).. Plots receiving zinc application also showed significantly higher amount of boron in soil (0.710 mg/kg) (Table 4.34). Lowest boron content was observed for treatment without foliar application (0.14 mg/kg).

Table 4.32. Effect of micronutrient application for okra under different irrigation methods on available secondary nutrients (Ca, Mg and S) in soil

Treatments	Drip irrigation			Conventional irrigation		
	Ca (mg/kg)	Mg (mg/kg)	S (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	S (mg/kg)
T_1-Zn (0.5%)	920.88	59.19	1.02	429.23	82.88	21.20
T_2-B (0.5%)	1021.04	61.29	1.33	344.73	75.11	11.08
T_3-Zn (0.5%) + B (0.5%)	736.38	47.00	1.02	441.81	104.83	8.91
T_4-KAU multi mix	963.75	67.04	2.59	443.21	76.13	8.25
T_5- Without foliar application (Control)	864.25	67.70	1.81	379.70	74.31	6.32
CD (0.05)	145.21	NS	0.84	NS	6.27	2.31
Pre experimental value	520.5	40.85	2.89	329.15	86.4	6.74

Table 4.33. Effect of micronutrient application for okra under drip irrigation on available micronutrients (Fe, Mn, Zn, Cu and B) in soil

Treatments	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	B (mg/kg)
T_1-Zn (0.5%)	13.15	43.78	2.67	4.92	0.11
T_2-B (0.5%)	12.70	45.95	1.76	5.73	0.77
T_3-Zn (0.5%) + B (0.5%)	16.37	50.54	2.86	5.80	0.42
T_4-KAU multi mix	12.85	47.43	2.26	5.70	0.42
T_5- Without foliar application (Control)	14.01	50.86	2.26	6.18	0.30
CD (0.05)	2.40	NS	NS	NS	0.34
Pre experimental value	9.74	46.65	1.79	4.70	0.28

Table 4.34. Effect of micronutrient application for okra under conventional irrigation on available micronutrients (Fe, Mn, Zn, Cu and B) in soil

Treatments	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	B (mg/kg)
T_1-Zn (0.5%)	12.91	55.00	9.15	4.39	0.71
T_2-B (0.5%)	13.71	57.84	2.41	4.13	0.43
T_3-Zn (0.5%) + B (0.5%)	12.50	56.67	4.50	4.48	0.32
T_4-KAU multi mix	13.78	55.09	3.40	4.23	0.16
T_5-Without foliar application (Control)	11.92	46.84	2.27	3.99	0.14
CD (0.05)	NS	NS	1.25	NS	0.07
Pre experimental value	13.11	77.99	2.34	4.06	0.18

4.4. Economics (Drip irrigation)

4.4.1. Gross return

Micronutrient application had significant influence on gross return from okra under drip irrigated condition (Table 4.35). KAU multi mix application gave significantly higher gross returns (Rs. 328197). Lowest gross return was recorded for combined application of zinc and boron (Rs. 221520) which was statistically on par with treatment without foliar application (Rs. 241098) and boron application (255787).

4.4.2. Net return

Net return from okra under drip irrigation was significantly influenced by micronutrient application (Table 4.35). Significantly higher net return was observed for KAU multi mix application (Rs. 219872). Lowest net return was for combined application of zinc and boron (Rs.97819) which was statistically on par with boron application (Rs. 135197)

4.4.3. Benefit: Cost Ratio

Micronutrient application had significant influence on B: C ratio of cultivation of okra under drip irrigation (Table 4.35). Foliar application of KAU multi mix recorded significantly higher B: C ratio (3.03). Lowest B: C ratio was recorded for combined application of zinc and boron (1.79) which is statistically on par with boron application (2.12).

4.5. Economics (Conventional irrigation)

4.5.1. Gross return

Micronutrient application significantly influenced the gross return from okra plants under conventional irrigation (Table 4.36). Zinc application gave significantly higher gross return (Rs. 238717) which was statistically on par with gross return from treatment without foliar application (Rs. 230499) and combined application of zinc and boron (Rs. 204777). Lowest gross return was obtained from plants treated with KAU multi mix application (Rs. 174299) which was statistically on par with gross return from boron application (Rs. 187603) and combined application of zinc and boron (Rs. 204777).

4.5.2. Net return

Net return from okra plants under conventional irrigation was significantly influenced by micronutrient application (Table 4.36). Application of zinc gave significantly higher net return (Rs. 134342) which is statistically on par with control (Rs. 133435). Lowest net return was obtained from combined application of zinc and boron (Rs. 61982) which is statistically on par with KAU multi mix application (Rs. 63180) and boron application (Rs. 64119).

4.5.3. Benefit: Cost Ratio

Micronutrient application significantly influenced the B: C ratio of okra cultivation under conventional irrigation (Table 4.36). Control gave significantly higher B: C ratio (2.38) which is statistically on par with zinc application (2.29). Lowest B: C ratio was for combined application of zinc and boron (1.43) which is statistically on par with B: C ratio of boron application (1.52) and KAU multi mix application (1.57)

Table 4.35. Effect of micronutrient application on economics of cultivation of okra under drip irrigation

Treatments	Cost of cultivation	Gross return	Net return	B:C ratio
T_1-Zn (0.5%)	101481	269539	168058	2.66
T_2-B (0.5%)	120590	255787	135197	2.12
T_3-Zn (0.5%) + B (0.5%)	123701	221520	97819	1.79
T_4-KAU multi mix	108325	328197	21987	3.03
T_5-Without foliar application (Control)	94170	241098	146928	2.56
CD (0.05)		40826	40826	0.381

Table 4.36. Effect of micronutrient application on economics of cultivation of okra under conventional irrigation

Treatments	Cost of cultivation	Gross return	Net return	B:C ratio
T_1-Zn (0.5%)	104375	238717	134342	2.29
T_2-B (0.5%)	123484	187603	64119	1.52
T_3-Zn (0.5%) + B (0.5%)	142795	204777	61982	1.43
T_4-KAU multi mix	111119	174299	63180	1.57
T_5- Without foliar application (Control)	97064	230499	133435	2.38
CD (0.05)		35315	35315	0.302

Discussion

5. DISCUSSION

Deficiency of micronutrients, especially deficiency of zinc and boron is very prominent in Kerala soils. Even though addition of organic manures at the recommended dose supplies micronutrients to soil, it is found to be insufficient for meeting the requirement of crop plants and this can result in yield reduction. In this context an experiment entitled micronutrient management of okra under different irrigation methods was conducted during 2018 December to 2019 March at Water Management Research Unit, Vellanikkara with the objective to study the effect of foliar application of micronutrients on okra under conventional and drip irrigated conditions.

To study the effect of micronutrients on performance of okra, foliar sprays of zinc, boron, combination of zinc and boron and KAU multi nutrient mix (Sampoorna) were given at three times at three weeks interval and these treatments were tested against the treatment without micronutrient application. All the treatments were supplied along with soil test based nutrient application and FYM at 20 t/ha. The results obtained from the experiment are discussed in this chapter under the following sections.

1. Foliar application of micronutrients on growth and yield of okra under drip and conventional irrigation
2. Foliar application of micronutrients on content and uptake of nutrients by okra under conventional and drip irrigation
3. Foliar application of micronutrients on soil nutrient status under drip and conventional irrigation
4. Economics

5.1. Foliar application of micronutrients on growth and yield of okra under drip and conventional irrigation

Foliar application of micronutrients at three times at three week intervals showed significant variation in the growth, yield and yield attributes of okra under both drip and conventional irrigation.

Drip irrigation

Under drip irrigated condition foliar application of KAU multi mix (0.5%) given in three splits at three weeks interval significantly enhanced the yield of okra plants. Among the five treatments, KAU multi mix application gave 36 per cent yield increase compared to treatment without foliar application (Figure 5.1). This may be due to the significantly higher fruit length, fruit weight and per plant yield obtained with the application of KAU multi mix (0.5%). The plants receiving KAU multi nutrient mix application showed improved growth characters, like plant height, number of leaves and leaf area during initial stages of growth of okra crop (Figure 5.3. & 5.4). This may have improved the yield attributing characters and finally led to significantly higher yield. Sampoorna is a multi-nutrient mixture developed by KAU which contain both secondary and micronutrients. Foliar application of micronutrient mix might have provided both secondary and micronutrients in adequate quantity in addition to the nutrients provided by soil application of fertilizers and FYM. KAU multi mix applied plants showed significantly higher uptake of magnesium, sulphur and boron under drip irrigated condition (Figure 5.13, 5.14 & 5.16). Similar results were obtained by Baloch *et al.* (2008) in chilli. They observed that HiGrow, a compound fertilizer containing macro and micronutrients, when given as foliar spray significantly increased plant height, number of branches, number of fruits, fruit length, fruit weight and fresh fruit yield of chilli. As per Mehraj *et al.* (2015), all the micronutrients have significant influence in plant physiology. Balanced application of these nutrients might have resulted in stimulation of enzymatic activities which led to higher rate of photosynthesis, respiration and photosynthesis and finally led to a higher vegetative growth and yield in okra. Polara *et al.* (2017) observed significant increase in vegetative growth as well as yield and yield attributes in okra plants applied with multi micronutrient mix either as foliar spray or by soil application based on soil test values. So they concluded that increased yield and yield attributes in okra can be attributed to higher photosynthetic rate and increase in production and accumulation of carbohydrates. Similarly increased growth parameters such as plant height and leaf area resulted in higher photosynthetic rate and resulted in higher yield attributing characters and fruit yield.

Under drip irrigated condition foliar application of zinc alone three times at three weeks interval produced 11.77 per cent yield increase compared to soil test based application of fertilizers alone without foliar application (Figure 5.1). Initial soil test data revealed that there was no deficiency of zinc in soil. Even though there was no deficiency of zinc, foliar application of zinc resulted in high yield compared to application of fertilizers in soil alone.

Boron when applied alone or in combination with zinc caused phytotoxicity symptom during the initial period. This resulted in reduced leaf area and dry matter production during the initial period which may have affected the productivity of okra. The yield reduction of okra in boron applied treatments may be due to the lower content and uptake of nitrogen and potassium (Figure 5.9 & 5.11). El- Feky *et al* (2012) obtained similar results in barley. They observed that foliar application of boron as boric acid above 3 mg/L concentration to barley significantly reduced growth as well as yield of barley. Phytotoxicity caused due to boron application resulted in reduction in leaf area, chlorophyll content as well as yield parameters in barley.

The result indicated that B application showed no significant increase in the yield of okra compared to soil application of nutrients alone even though the soil of the experimental site was deficient in B. Hence okra may be a low responsive crop to boron. Bennett (1993) reported that low response crops showed no response to foliar application of nutrients even though the soil is deficient in a particular nutrient.

Foliar application of zinc and boron in combination recorded lowest yield under drip irrigation which can be attributed to the lowest yield attributes resulting from the poor growth during the initial stage of growth of okra which received this treatment (Figure. 5.3, 5.4 &5.5). Reduction in plant height, leaf area and dry matter production during initial stages of growth may be due to the phytotoxicity developed from application of boron in higher concentration (0.5%) along with zinc. Even though this treatment showed highest nutrient uptake, it was not reflected in yield. Lowest fruit length, number of fruits per plant and per plant yield recorded in this treatment can be attributed to poor vegetative growth of okra plants during the initial stages.

Conventional irrigation

Under conventional irrigation foliar application of zinc as zinc sulphate (0.5%) in three splits to okra plants recorded significantly higher fruit yield (Figure. 5.2). This was on par with fruit yield of treatment receiving soil test based application of NPK fertilizers without micronutrient application. The plants receiving this treatment showed greater plant height compared to other treatments (Figure.5.6). Sharma *et al.* (2017) opined that zinc application enhances cell division, meristematic activity of tissues, expansion of cells and formation of cell wall. The increase in plant height of okra plants due to zinc application might have been due to the increased cell division and cell expansion as well as enhanced meristematic activity of tissues.

Higher yield attributing characters like higher fruit length, fruit weight, number of fruits per plant and per plant yield in zinc applied field may be due to enhanced carbohydrate metabolism, protein synthesis and photosynthesis due to zinc application. This enhancement in yield attributes resulted in higher yield of okra receiving zinc application under conventional irrigation. As Marschner *et al.* (1995) reported, zinc plays a major role in activation of enzymes which are involved in carbohydrate metabolism, maintenance of integrity of cellular membrane, protein synthesis, regulation of auxin synthesis and pollen formation.

The yield obtained from zinc treatment was statistically on par with the yield from treatment receiving soil test based application of NPK fertilizers without micronutrient application (Figure 5.2). Yield increase in this treatment may be attributed to the higher vegetative growth of plants. These plants recorded highest

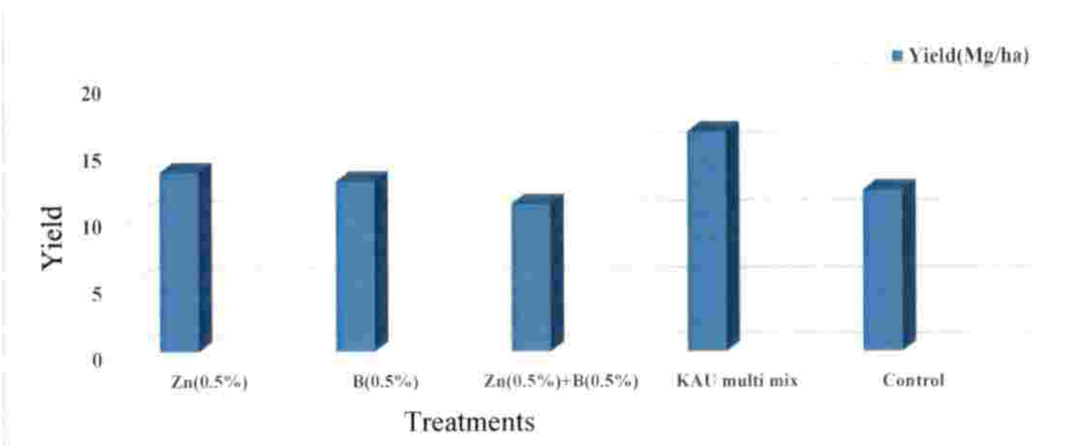

Figure 5.1. Effect of foliar application of micronutrients on yield (Mg/ha) of okra under drip irrigation

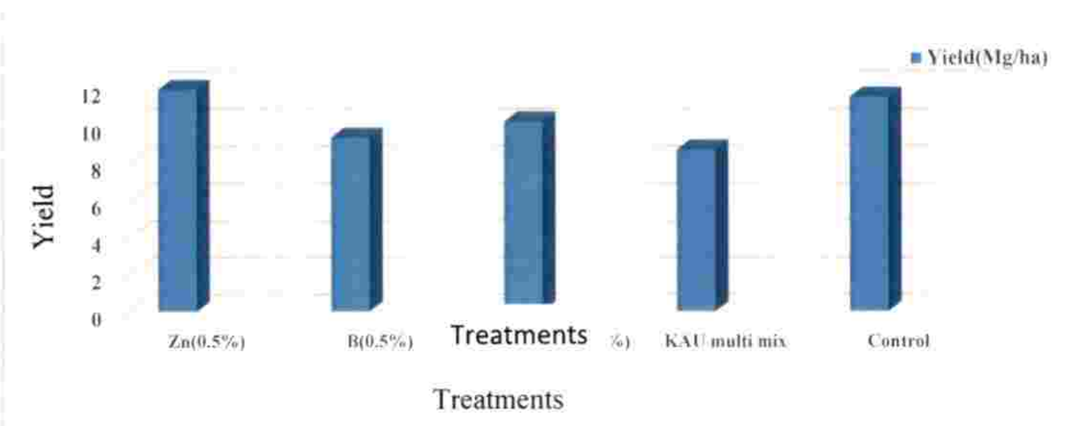

Figure 5.2. Effect of foliar application of micronutrients on yield (Mg/ha) of okra under conventional irrigation

leaf area and highest number of leaves (Table 4.2 & 4.4) which resulted in an increase in yield attributing characters like fruit weight and per plant yield. Higher growth as well as yield in soil test based application of fertilizers can be attributed to the sufficient supply of macro as well as micronutrients from the soil test based application of primary nutrients and FYM as per recommendation. The plants receiving this treatment recorded significantly higher uptake of P, K, secondary and micronutrients except zinc and boron since the application of NPK fertilizers and FYM supplied the essential nutrients for plant growth, micronutrient application could not produce significant yield response in okra under conventional irrigation. As per Kanaujia (2015) yield of rice wheat cropping system was significantly improved by application of recommended dose of NPK fertilizer along with FYM. They also observed an increase in uptake of N, P and K as a result of this treatment.

Foliar application of zinc, boron and their combination showed no significant increase in yield compared to treatments without foliar application. This may be due to the fact that all the treatments received recommended dose of FYM @ 20 t/ha and soil test based NPK recommendation. Due to sufficient application of organic manure, plants could receive enough micronutrients from soil even though the soil showed deficiency of boron. Increase in the micronutrient content of soil after the experiment indicated that there is sufficient supply of micronutrients due to the application of FYM @ 20 t/ha.

Foliar application of KAU multi mix recorded lowest yield in okra under conventional irrigation (Figure 5.2). Lowest yield obtained from this treatment may be attributed to the lowest yield attributing characters in this treatment. KAU multi nutrient mix application recorded lowest fruit weight, number of fruits per plant and per plant yield. This treatment showed a higher number of branches and dry matter production. The balanced supply of macro and micronutrients from KAU multi nutrient mix might have improved the vegetative growth of this plants and the vigorous vegetative growth at the expense of reproductive growth might be the reason for the reduced yield in these treatment.

Under drip irrigated condition KAU multi mix application significantly increased the yield. But this treatment showed no response under conventional irrigation. Result of the study indicated that, foliar application of micronutrients showed differential response under drip and conventional irrigated conditions.

Response to foliar application of micronutrients was more pronounced under drip irrigated conditions. Under conventional irrigated condition, performance of okra was higher even without micronutrient application.

5.2.Foliar application of micronutrients on content and uptake of nutrients by okra under conventional and drip irrigation

Drip irrigation

Content and uptake of both micro and macronutrients of okra under drip irrigation showed significant variation among treatments. Content and uptake of N, P, and K were significantly higher for treatment receiving soil test based application of nutrients and FYM at recommended dose (Figure 5.9, 5.10 & 5.11). NPK fertilizers as well as FYM might have supplied the primary nutrients to the crop in sufficient quantity and this might have led to a higher uptake of these nutrients. Kanaujia *et al*. (2016) found similar result, and observed that application of 100% recommended dose of N, P and K along with FYM recorded maximum uptake of N, P, and K in rice and wheat.

Content and uptake of nitrogen and potassium were found to be the lowest in boron applied plants. Lowest P uptake was found in KAU micronutrient mix applied plants which was statistically on par with P uptake of boron applied plants (Figure 5.8). Similar results were obtained by Leece (1978). He observed that increase in concentration of soil applied boron caused reduction in the content of N, P and K in maize. Aduayi (1978) reported that increase in boron concentration from 0 to 4 ppm given as foliar spray to tomato resulted in decrease in the leaf concentration of nitrogen and phosphorus. Content and uptake of N and P increased from vegetative growth stage to harvest stage, but a decrease in K content was noticed at the harvesting stage.

Uptake of secondary nutrients was found to be increased from vegetative growth stage to the harvesting stage (Figure 5.12, 5.13 & 5.14). Plants receiving boron application either as boron alone or in combination with zinc recorded highest calcium content. It may be due to the synergestic interaction between boron

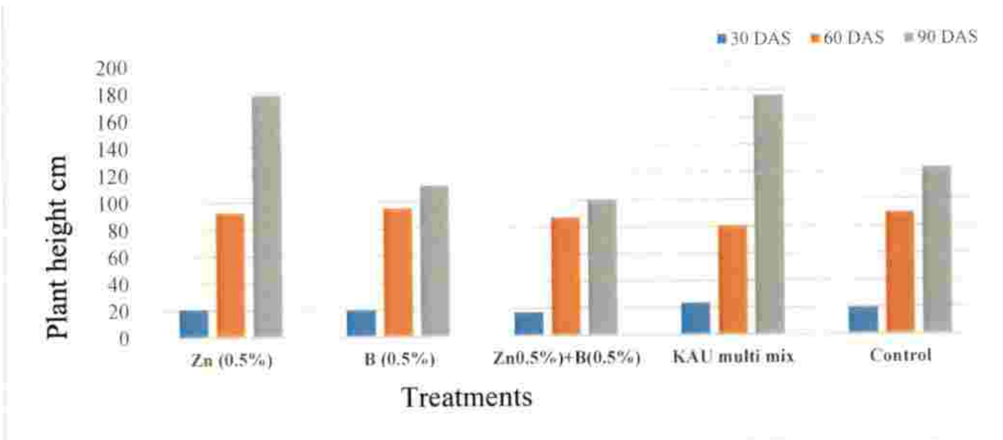

Figure 5.3. Effect of foliar application of micronutrients on plant height of okra under drip irrigation

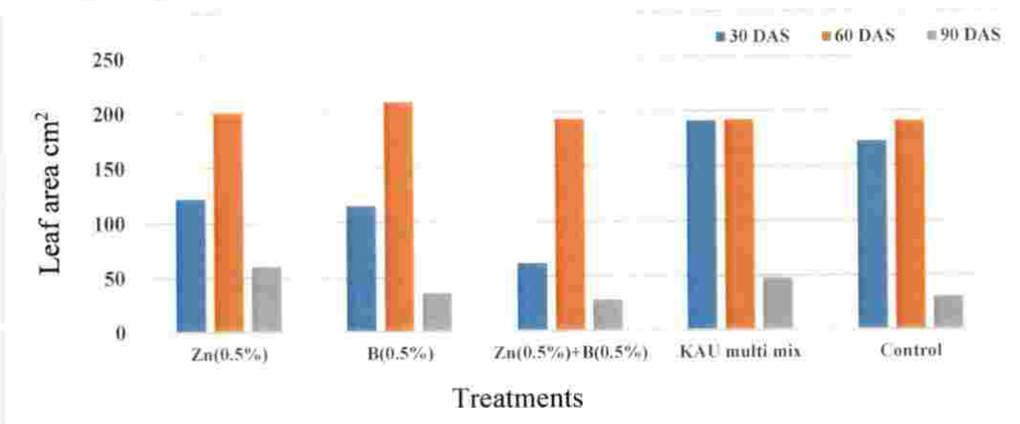

Figure 5.4. Effect of foliar application of micronutrients on leaf area of okra under drip irrigation

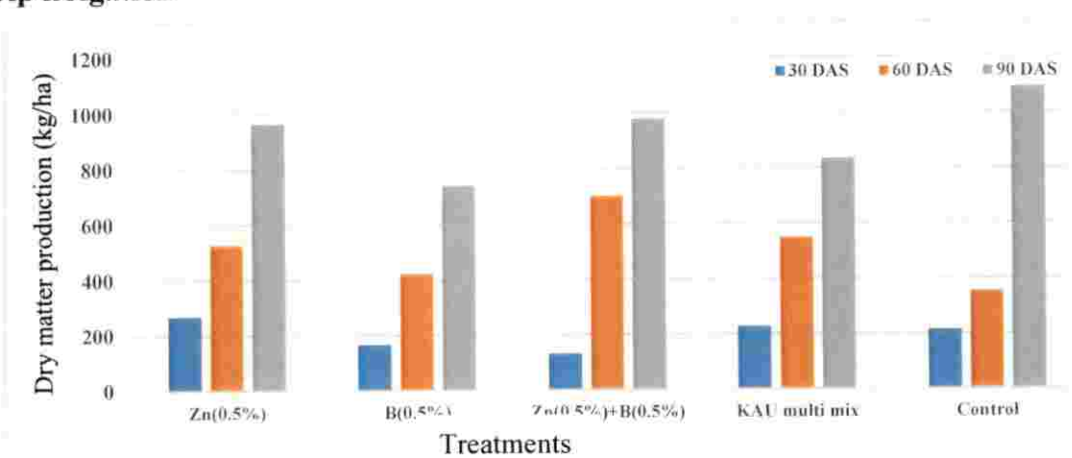

Figure 5.5. Effect of foliar application of micronutrients on dry matter production of okra under drip irrigation

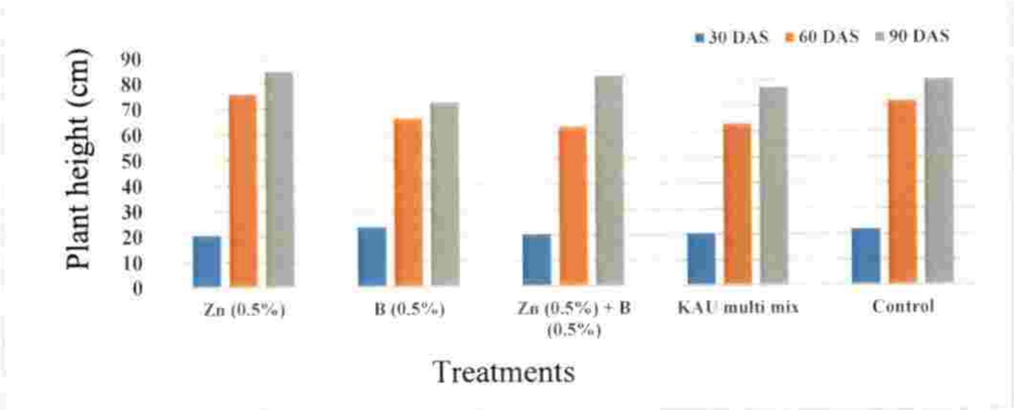

Figure 5.6. Effect of foliar application of micronutrients on plant height of okra under conventional irrigation

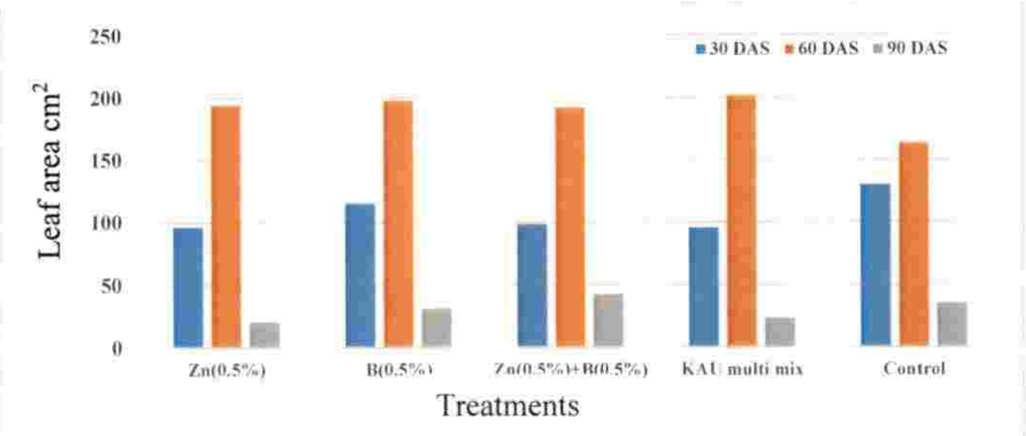

Figure 5.7. Effect of foliar application of micronutrients on leaf area of okra under conventional irrigation

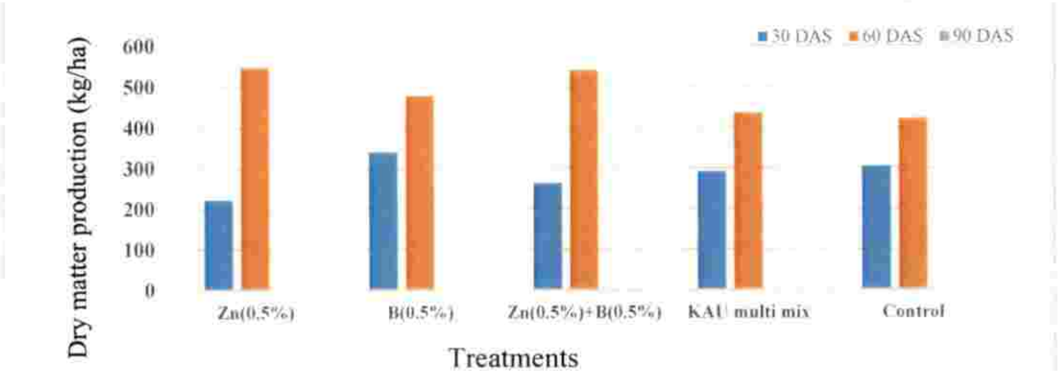

Figure 5.8. Effect of foliar application of micronutrients on dry matter production of okra under conventional irrigation

and calcium. Minarik and Shive (1939) reported that toxic concentration of boron (2.5 ppm) when given to soybean plants through sand culture increased the calcium content in soybean plants. Highest concentration as well as uptake of magnesium and sulphur in plants receiving KAU multi nutrient mix might be due to the adequate supply of these nutrients from this KAU multi mix.

Foliar application of boron significantly reduced the magnesium and sulphur uptake of plants. The okra plants receiving this treatment recorded lowest magnesium and Sulphur uptake at harvesting stage. Tolgyesi and Kozma (1974) reported a negative correlation between calcium and magnesium with boron content in grasses at flowering stage.

Foliar application of micronutrients showed significant variation in the content and uptake of micronutrients by okra plants under drip irrigation. An increase in the uptake of micronutrients was observed from initial to harvesting stage. Control plants recorded higher iron content. Individual application of zinc and boron lead to a higher manganese uptake, but this trend was not observed in their combined application. Application of zinc alone or in combination with boron increased the content and uptake of boron (Figure 5.16). McIlrath *et al.* (1960) reported similar results in Setaria. They found that boron application at higher concentration increased the content of copper iron and manganese in setaria. Kandoliya and Kunjadia (2018) reported that application of zinc either as soil or foliar application improve the uptake of copper by wheat. Zinc uptake was higher when zinc was applied alone or in combination with boron. Higher uptake of zinc by zinc applied plants may be due to the supply of zinc through foliar application of zinc sulphate at regular intervals. But the plants receiving KAU multi nutrient mix showed the highest content and uptake of boron.

Iron uptake was higher for treatments receiving soil test based application of NPK fertilizers (Table 4.25). Manganese uptake was found significantly higher in all treatments receiving foliar application of micronutrients (Table 4.26). Copper uptake was high for foliar applied treatments during the initial growth period but showed no significant difference during the harvesting stage (Table 4.27).

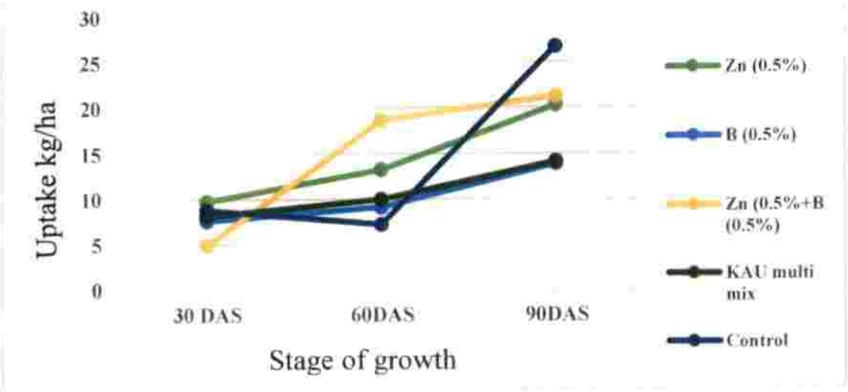

Figure. 5.9. Effect of foliar application of micronutrients on N uptake of okra under drip irrigation

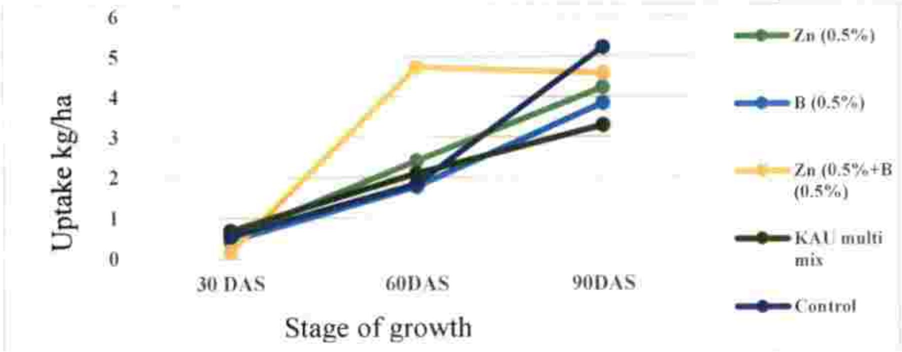

Figure. 5.10. Effect of foliar application of micronutrients on P uptake of okra under drip irrigation

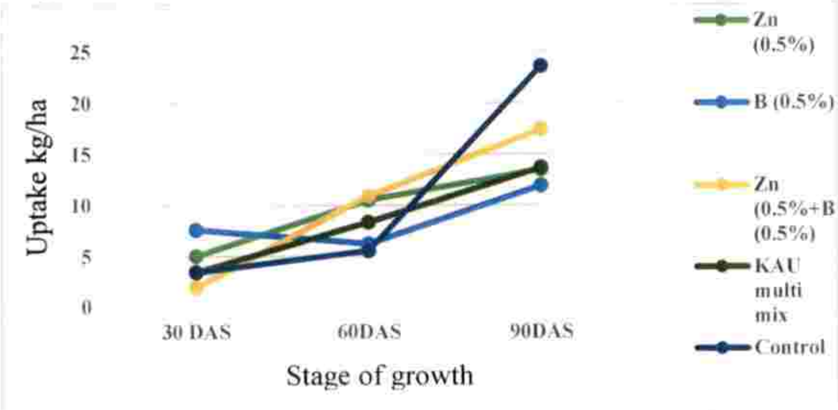

Figure. 5.11. Effect of foliar application of micronutrients on K uptake of okra under drip irrigation

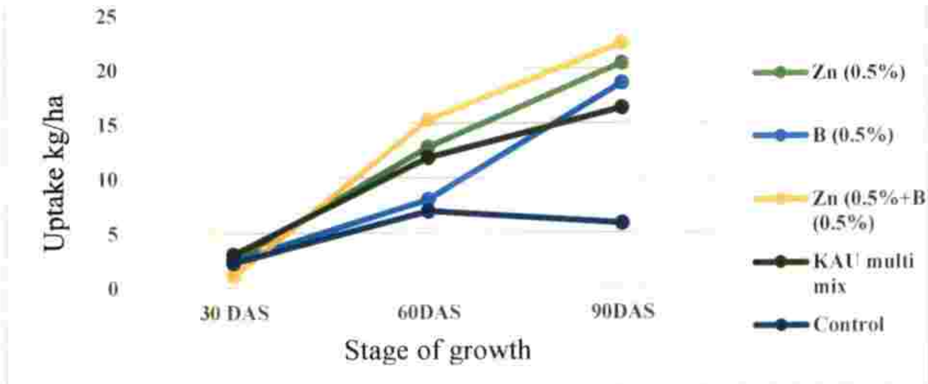

Figure. 5.12. Effect of foliar application of micronutrients on Ca uptake of okra under drip irrigation

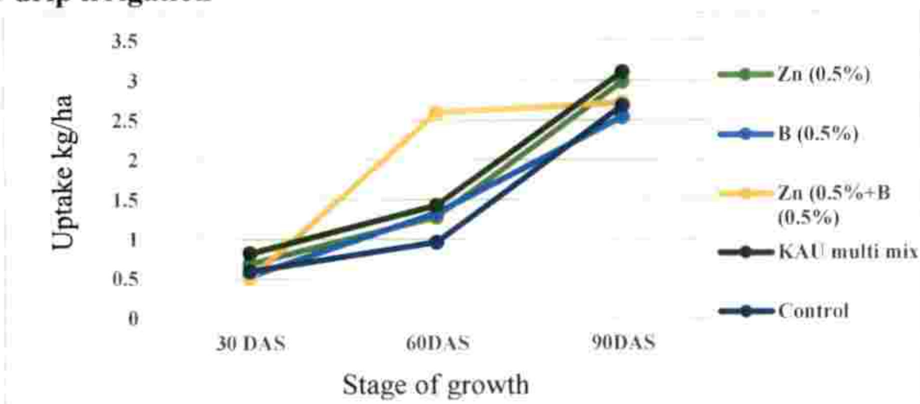

Figure. 5.13. Effect of foliar application of micronutrients on Mg uptake of okra under drip irrigation

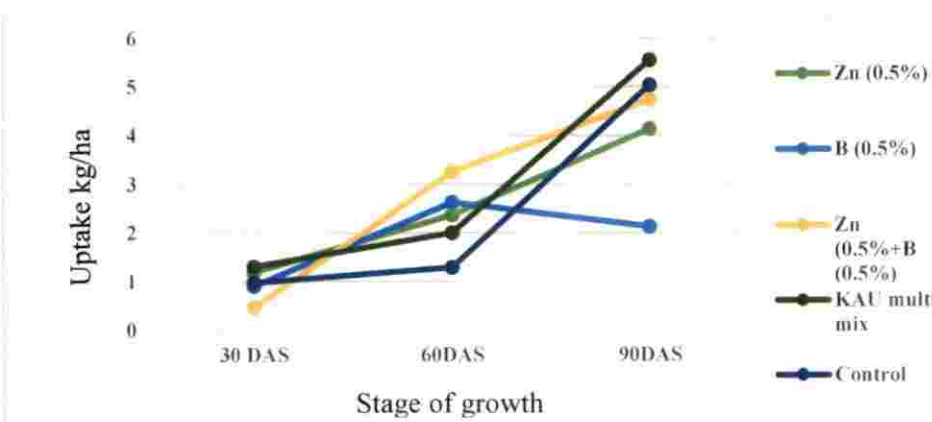

Figure. 5.14. Effect of foliar application of micronutrients on S uptake of okra under drip irrigation

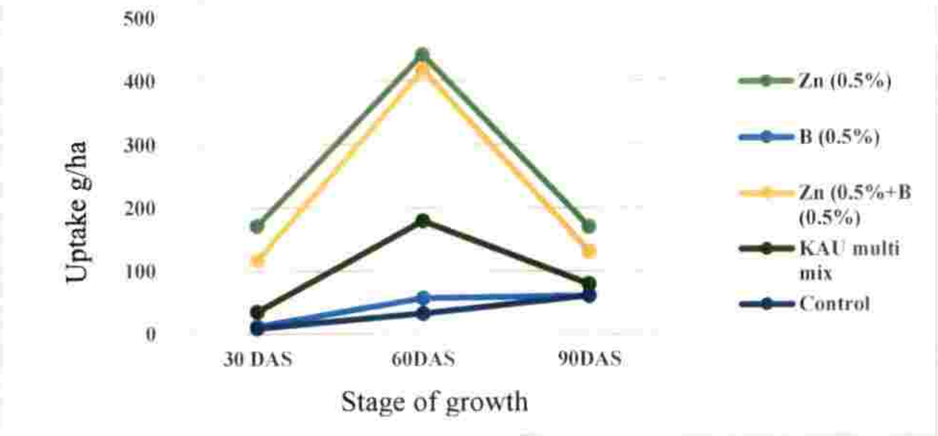

Figure. 5.15. Effect of foliar application of micronutrients on Zn uptake of okra under drip irrigation

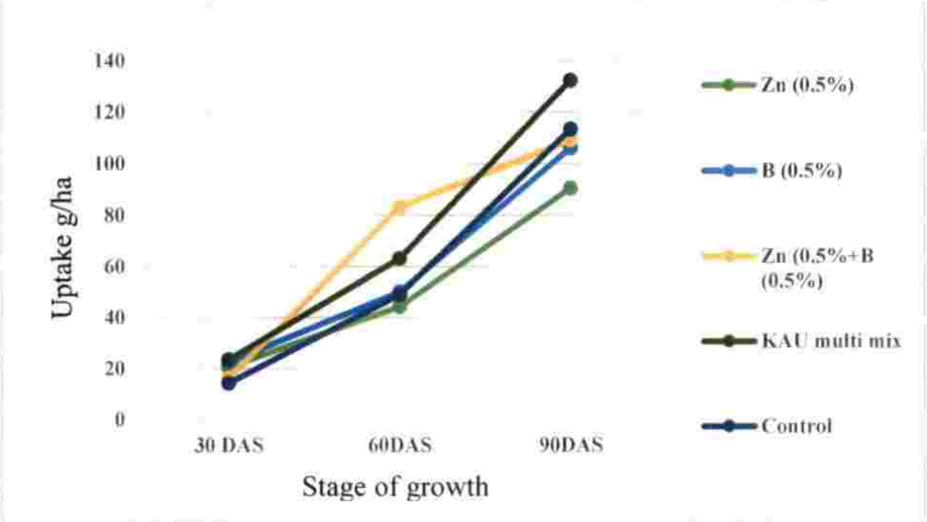

Figure. 5.16. Effect of foliar application of micronutrients on B uptake of okra under drip irrigation

Boron uptake showed no significant variation due to different treatments under drip irrigated condition. The pre experimental status of soil showed that the soil was deficient in boron. The low uptake of boron by okra plants may be due to the low responsive nature of okra plants.

Content and uptake of iron, manganese and boron were increased from vegetative growth stage to harvesting stage. Zinc and copper uptake increased in vegetative growth stage (30 DAS to 60 DAS), but decreased in harvesting stage.

Conventional irrigation

Under conventional irrigation system, nitrogen uptake was highest for KAU multi mix applied treatment which was on par with treatment without foliar application (Figure 5.17). In case of P and K highest uptake was noticed for treatments receiving soil test based application of NPK fertilizers without micronutrient application (Figure 5.18 & 5.19). Compared to drip irrigation the pre experimental nutrient status of soil under conventional irrigation showed high NPK content. Combined with high soil nutrient status, application of NPK fertilizers along with FYM could supply sufficient nutrients to plants. That may be the reason for reduced response to micronutrient foliar spray. Meena *et al.* (2013) reported that 100 percent recommended dose of NPK fertilizers and 10 t/ha of FYM application significantly increased the content and uptake of N, P and K in green gram.

Lowest uptake of N, P and K in plants receiving combined application of zinc and boron can be attributed to the reduction in the dry matter content of these plants due to the phytotoxicity developed from higher concentration of boron.

Uptake of N and P increased from vegetative growth stage to harvesting stage, but K uptake showed increase in vegetative growth stage only. At harvesting stage it decreased significantly.

Uptake of secondary nutrients such as calcium, magnesium and sulphur were also higher for treatment without foliar application of micronutrients (Figure 5.20, 5.21 and 5.22). Significantly higher content and uptake of secondary nutrients by plants receiving control treatment can be attributed to the supply of these nutrients in sufficient quantity from FYM and lime applied. FYM is a good source of Ca (2.3%), Mg (0.92%) and S (0.44%) (Anand *et al*., 2019). Kanaujia (2016) reported that application of FYM along with NPK fertilizer can improve the secondary and micronutrient supply to the crop. This treatments showed an increasing trend in the uptake of calcium, magnesium and sulphur from initial growth stage to harvesting stage (Figure 5.20, 5.21 and 5.22). Because of this continuous supply of nutrients higher growth parameters and dry matter production was observed in okra plants receiving treatments without foliar application.

Lowest calcium uptake in boron applied plants can be attributed to the toxic effect of excess boron applied as foliar spray. Abdulnour *et al*. (2014) reported that higher concentration of boron in propagation media reduced the calcium uptake of micro propagated plantlets of potato. Uptake of magnesium and sulphur was found lowest in plants receiving KAU multi nutrient mix application.

Uptake of Fe, Mn and Cu was found highest in plants receiving control treatments (Table 4.25, 4.26 and 4.27). This might be due to the availability of these nutrients from FYM. Even though the content of zinc was high in plants receiving zinc application, the uptake was found highest in plants receiving KAU multi nutrient mix application because of the higher dry matter production along with supply of sufficient quantity of zinc by this treatment. Highest uptake of boron was found in combined application of zinc and boron followed by boron applied treatments. Similar results were reported by Kumar *et al*. (2017) in guava. They found that combined foliar application of 0.75 per cent $ZnSO_4$ and 1per cent H_3BO_3 resulted in highest boron uptake in guava leaves. Boron uptake was less in control plots.

Zinc uptake showed an increase in foliar applied treatments upto 60 DAS and then showed a decline in zinc uptake (Figure 5.23). But treatment without foliar application showed a steady increase from initial growth to harvest stage.

The lowest uptake of Fe, Cu and Zn was observed in boron applied plants and lowest manganese uptake was found in plants applied with combination of zinc and boron. Boron content and uptake was the lowest in control plants.

Under conventional irrigation, treatments receiving soil test based application of NPK fertilizers along with FYM without foliar application resulted

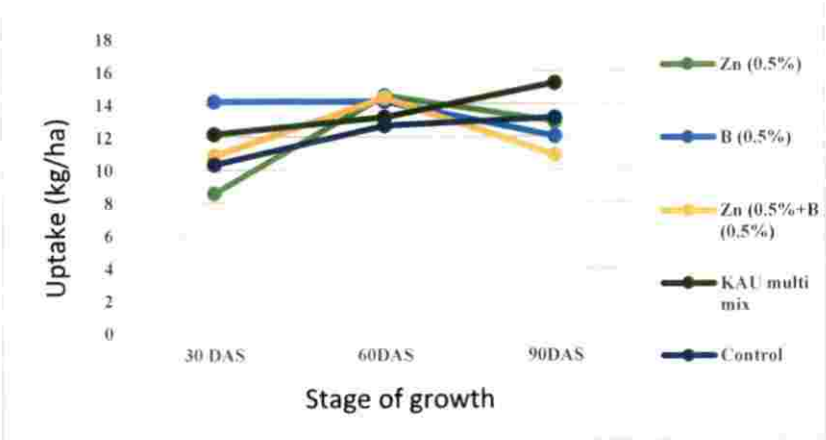

Figure. 5.17. Effect of micronutrient application on N uptake of okra under conventional irrigation

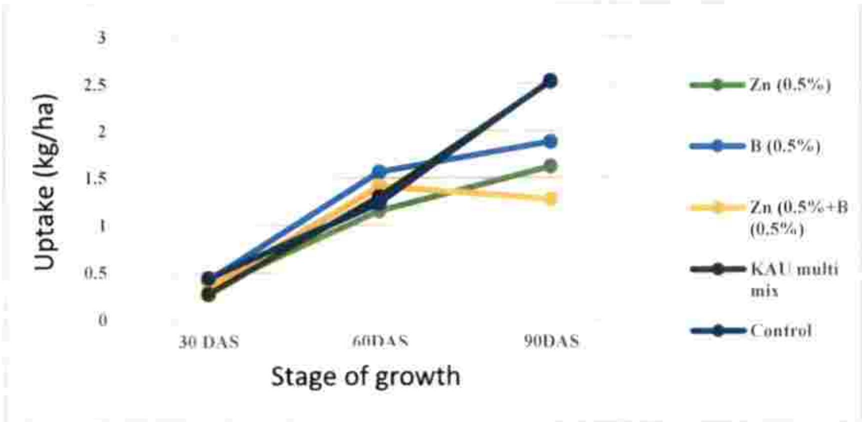

Figure. 5.18. Effect of micronutrient application on P uptake of okra under conventional irrigation

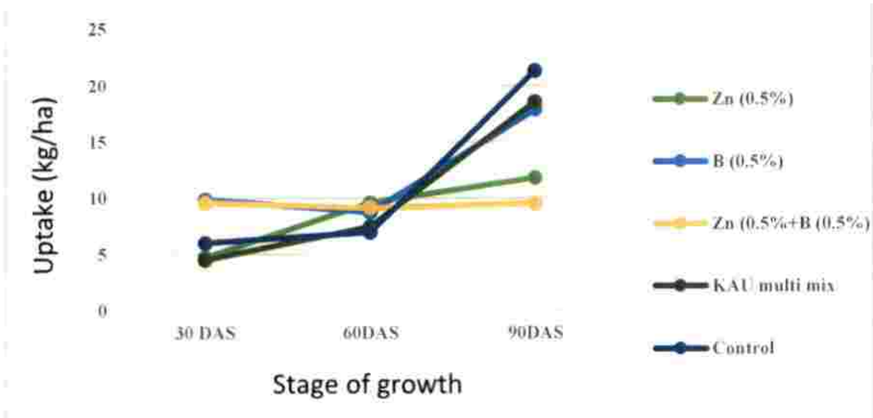

Figure. 5.19. Effect of micronutrient application on K uptake of okra under conventional irrigation

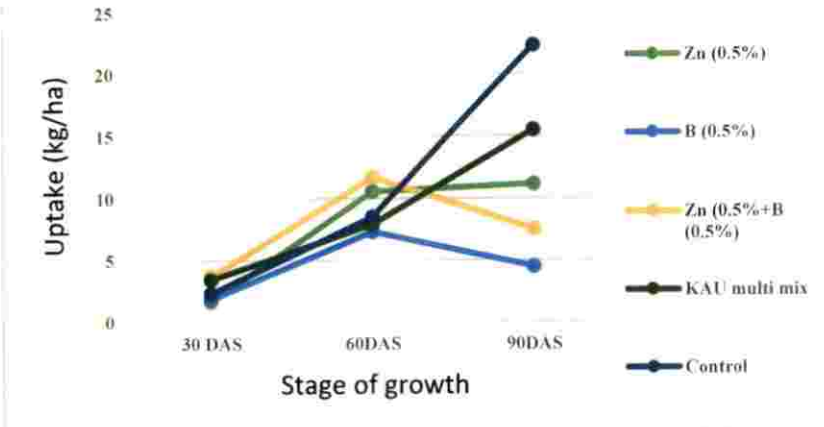

Figure. 5.20. Effect of micronutrient application on Ca uptake of okra under conventional irrigation

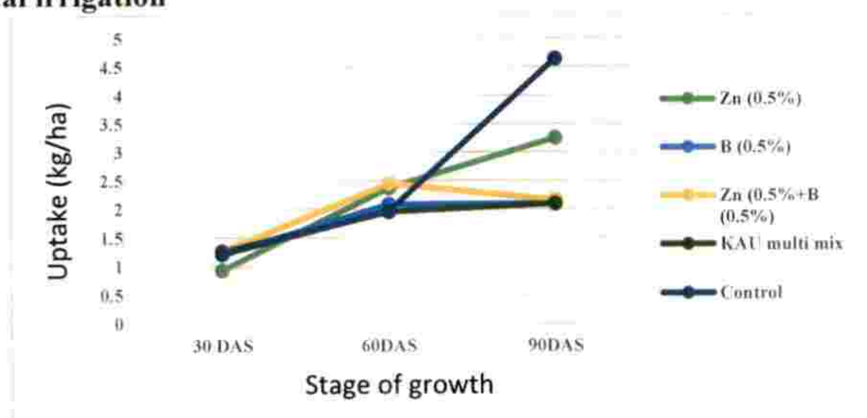

Figure. 5.21. Effect of micronutrient application on Mg uptake of okra under conventional irrigation

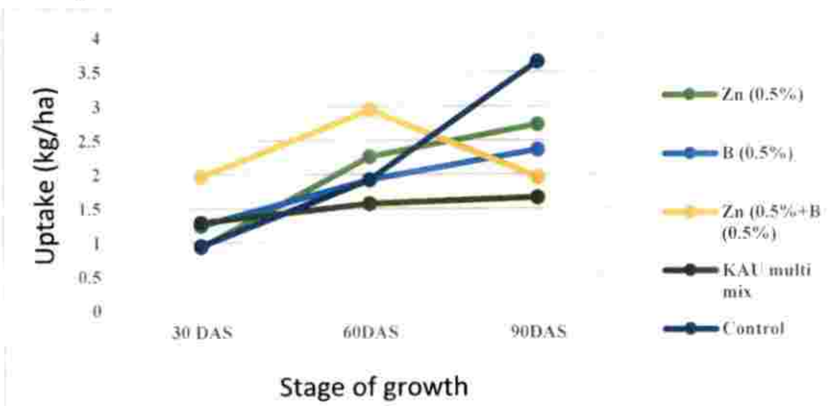

Figure. 5.22. Effect of micronutrient application on S uptake of okra under conventional irrigation

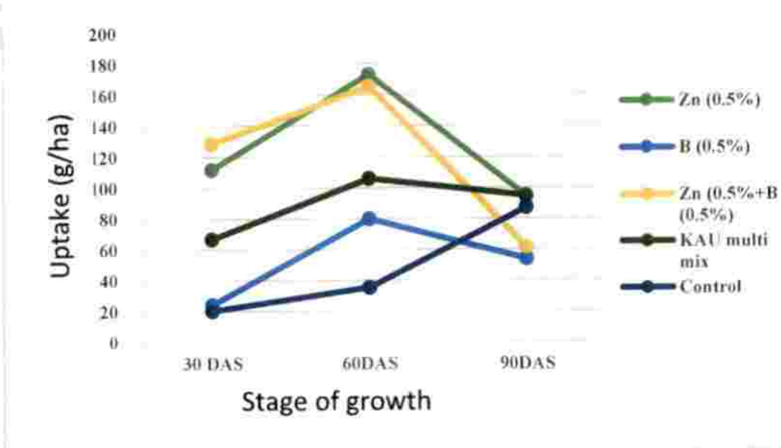

Figure. 5.23. Effect of micronutrient application on Zn uptake of okra under conventional irrigation

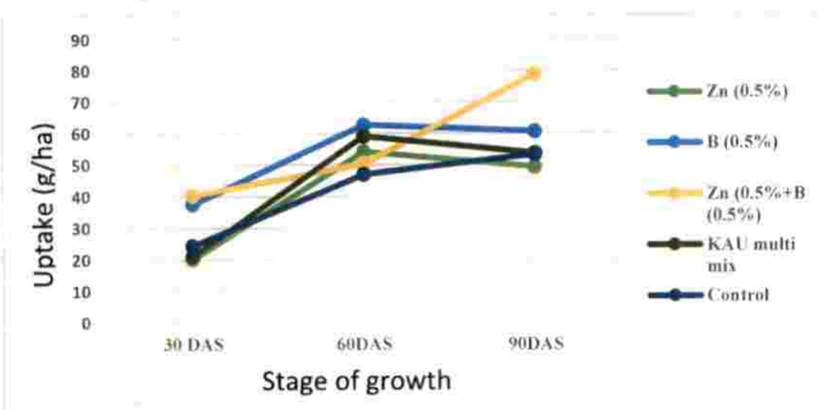

Figure. 5.24. Effect of micronutrient application on B uptake of okra under conventional irrigation

in high uptake of most of the plant nutrients and was finally reflected in the better development of growth and yield parameters and there by higher yield. Foliar application showed no significant influence on the nutrient uptake.

5.3. Foliar application of micronutrients to okra on soil nutrient status under drip and conventional irrigation

Foliar application of micronutrients did not cause any significant changes in the pH and organic carbon content of soil after the experiment.

Drip irrigation

The pre experimental soil was low in available nitrogen, high in available phosphorus and medium in available potassium. Post experimental soil analysis showed that available nitrogen increased in all treatment, but the content of available P decreased in zinc applied treatments, combined application of zinc and boron and KAU micronutrient mix applied treatments (Table 4.31). A reduction in potassium content was observed after the experiment (Table 4.31).

Foliar application of micronutrients significantly influenced the available N, P and K content in soil Plots receiving KAU multi nutrient mix application showed the highest available nitrogen. The highest available P content was observed in control treatment and the highest K content was observed in plots receiving combined application of zinc and boron. Highest soil content of these nutrients in the post experimental soil indicates a lower uptake of these nutrients in the respective treatments (Table 4.31).

Even though the soil was low in nitrogen, soil test based application of nitrogen added resulted in a positive balance of nitrogen after the experiment. But in the case of phosphorus and potassium, the pre experimental soil was high in phosphorus and medium in potassium. Soil test based application of phosphorus and potassium resulted in a negative balance indicating the need for more phosphorus and potassium application from external sources.

Increase in the calcium and magnesium content in post experimental soil may be due to the application of lime as well as FYM which might have supplied calcium to the soil. A reduction in sulphur content in post experimental soil might be due to a higher uptake of sulphur by plants. Foliar application of micronutrients significantly influenced the calcium and sulphur content in soil. Highest calcium in boron applied field can be attributed to the lowest uptake of calcium by this plants due to the boron toxicity. Treatments receiving KAU multi nutrient mix application showed highest sulphur content in soil. Supply of sulphur from the foliar application of KAU multi mix might have reduced the absorption of sulphur from soil and it might have led to a higher sulphur content in plots receiving this treatment (Table 4.32).

Available calcium content in soil was higher in micronutrient treatments except for combined application of zinc and boron compared to the treatment without micronutrient application. There was no significant change in available magnesium content due to micronutrient application. But significant increase in Sulphur content was observed in micronutrient applied treatments compared to treatment without micronutrient application.

Micronutrient content after the experiment indicated that only the iron and boron content in soil was significantly influenced by foliar application of micronutrients. Plots receiving combined application of zinc and boron showed highest iron content in soil. The highest boron content in boron applied field might be due to the lowest absorption of boron from the soil because of supply of boron through foliar application (Table 4.33).

Significant decrease in iron content was observed in micronutrient applied treatments compared to treatment without micronutrient application. Higher boron content was observed in treatments receiving boron application compared to treatment without micronutrient application.

Conventional irrigation

Post experimental soil showed an increase in pH except in KAU multi nutrient mix applied plots and control plots. Significant increase in organic carbon content is noticed after the experiment might be due to the supply of organic matter through FYM addition.

Pre experimental status of soil nutrients in conventionally irrigated plot was low in available N and high in available P and K. Significant increase in the content of N and P was observed in post experimental soil. Increase in available K content was observed only in plots receiving combined application of zinc and boron (Table 4.31).

Micronutrient application significantly influenced the available N, P and K content of soil. Highest content of these primary nutrients was observed in plots receiving combined application of zinc and boron (Table 4.31). This may be due to the lowest uptake of these nutrients by the plants receiving this treatment because of the phytotoxicity developed from excess boron application. Aduayi (1978) reported similar results in maize. He reported that increase boron concentration from 0 to 4 ppm caused reduction in uptake of nitrogen and phosphorus in tomato.

Compared to treatments without foliar application, zinc and KAU multi mix application showed lower available nitrogen in soil, but it showed higher available nitrogen in boron applied and in combined application of zinc and boron. Treatments receiving foliar application of micronutrients showed higher phosphorus content than treatment without foliar application of micronutrients.

The increase in calcium content of soil after the experiment might be due to the application of FYM and lime. The highest calcium content was noticed in KAU multi mix applied treatment. Treatments receiving combined application of zinc and boron showed significantly higher magnesium content and plots receiving zinc application showed significantly higher Sulphur content in soil. Increase in magnesium content after the experiment was observed only in treatments receiving combined application of zinc and boron. Content of magnesium and calcium content was observed to be higher in micronutrient application compared to control. Sulphur content in the soil also increased after the experiment except in control plots (Table 4.32).

Iron content of soil increased in the soil after the experiment except in control. But manganese content was reduced in all treatments. Post experimental soil showed a higher zinc and Cu content except in treatments not receiving micronutrient application. Increase in boron content was observed after the experiment in treatments receiving zinc application, boron application and combined application of zinc and boron (Table 4.33)

Zinc and boron are the only micronutrients whose content on soil was significantly influenced by micronutrient application. Supply of zinc through foliar application might have reduced the absorption of zinc from soil, and this may resulted in significantly higher zinc content in soil. Highest boron content was also observed in plots receiving this treatment.

Foliar application of micronutrients resulted in significant difference in the Zn content of soil after the experiment. Except control all treatments showed an increase in Zn content. Foliar application of Zn, Zn+B, and KAU multi mix resulted in significantly higher zinc content in soil. Among this high zinc content was noticed in zinc application alone followed by combined application of zinc and boron. This may be due to the reduced uptake of zinc from soil as these plants receive zinc from the foliar application. Boron content of the soil after the experiment was higher than pre experimental status. Significantly higher boron content was noticed in Zn, Zn+B and B applied treatments.

Compared to pre experimental soil data there is an increase in the micronutrient content of soil irrespective of the treatment. This indicate that due to the application of FYM, there is sufficient supply of nutrients.

5.4. Economics

Micronutrient application significantly influenced economics of cultivation of okra under drip and conventional irrigation

Drip irrigation

Foliar application of KAU multi nutrient mix to okra under drip irrigation produced higher BC ratio indicating the effect of higher yield (Table 4.35). Similar results were obtained by Polara *et al.* (2017) in okra. They found that foliar application of multi micro nutrient mix gave higher BC ratio. Though there is significant variation in yields between zinc application and KAU multi nutrient mix application, BC ratio of zinc application was statistically on par with BC ratio of KAU multi nutrient mix application due to lesser cost of cultivation for zinc application compared to other micronutrient treatments. Lowest BC ratio in combined application of zinc and boron can be attributed to the lowest yield as well as higher cost of cultivation due to added input cost of $ZnSO_4$ and solubor.

Conventional irrigation

Under conventional irrigation, highest BC ratio was obtained by control treatment (Table 4.36) and this might be due to the higher yield obtained in this treatment. Also cost of cultivation in the control treatment was lowest because of lesser input cost since there is no micronutrient application and lack of application cost of micronutrients. BC ratio of control treatment was on par with BC ratio of zinc application. Rahman *et al.* (2018) similar results. They observed that foliar application of zinc at 560 ppm produced highest BC ratio in potato. Lowest BC ration was observed for KAU multi nutrient mix application because of its lowest yield.

Result of the study indicated that foliar application of KAU multi mix to drip irrigated okra was found to economically beneficial. But under drip irrigated and conventional irrigated condition, foliar application of boron alone or in combination with zinc showed no significant economic benefit.

Summary

6. SUMMARY

An experiment entitled" micronutrient management of okra under different irrigation methods" was conducted during 2018 December to 2019 March at Water Management Research Unit, Vellanikkara with the objective to study the effect of foliar application of micronutrients on okra under conventional and drip irrigated conditions.

To study the effect of micronutrients on performance of okra, foliar sprays of zinc as ZnSO4 (0.5%), boron as solubor (0.5%), combination of zinc and boron (ZnSO4 (0.5%) +Solubor (0.5%)) and KAU multi nutrient mix (Sampoorna) (0.5%) were given at three times at three weeks interval and these treatments were tested against treatment without micronutrient application both under drip irrigation and conventional irrigation. All the treatments were supplied with soil test based application of fertilizers at recommended dose and FYM at 20 t/ha. The results of the study are summarized below.

- Performance of okra under drip and conventional irrigation showed varied response to foliar application of micronutrients.
- Under drip irrigated condition, foliar application of KAU multi mix application showed the highest yield.
- Under drip irrigated condition foliar application of zinc gave 11.77% higher yield than soil test based application of NPK fertilizers without micronutrient application.
- Under conventional irrigation foliar application of zinc gave highest yield, but soil test based application of fertilizers alone without micronutrient application was found to be equally good as this treatment.
- Even though the soil was found to be zinc sufficient, foliar application of zinc gave a good yield response under both conventional and drip irrigated condition.

- Foliar application of boron alone or in combination with zinc at 0.5% can cause phytotoxicity and it can affect the growth and yield of okra under both the irrigated condition.
- Even though the soil was deficient in boron, foliar application of boron either alone or in combination with zinc could not produce significant yield response in okra under both drip and conventional irrigation since okra might be a low responsive crop to boron application.
- Foliar application of micronutrients could not produce any yield or economic advantage than soil test based application of fertilizers and FYM without micronutrient application since this treatment can provide sufficient nutrients for the growth and development of okra.
- Under drip irrigated condition, KAU multi mix application showed higher yield, but did not showed any response under conventional irrigation.
- Foliar application of micronutrients caused significant variation in the content and uptake of primary, secondary and micronutrients of okra plants both under drip and conventional irrigation.
- There was a significant increase in the micronutrient status of soil after the experiment in both the irrigated condition due to application of FYM which supplied sufficient quantity of micronutrients to soil.
- Foliar application of micronutrients like Zn, B, and its combination showed no economic benefit to okra under drip and conventional irrigation.

Okra plants grown under drip irrigated condition was found to be performing better with the foliar application of KAU multi mix. But under conventional irrigation, foliar application of micronutrients could not produce significant yield advantage compared to treatment without foliar application of micronutrients.

Foliar application of KAU multi mix in three times at three weeks interval can be recommended for drip irrigated okra for yield and economic advantage. Foliar application of Zn, B or its combination may not be required for okra under drip and conventional irrigated condition, if the plants are supplied with soil test based application of NPK and FYM at 20 Mg/ha.

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Appendices

APPENDIX -1

Meteriological data during the experimental period

(From 2018 December to 2019 March)

Month	Temprature (^{0}C)		Mean relative humidity (%)	Total rainfall (mm)	No. of rainy days
	Max. ^{0}C	Min. ^{0}C			
December	33.0	22.5	63	0.0	0
January	32.9	20.4	55	0.0	0
February	35.3	23.4	59	0.0	0
March	36.7	24.8	65	0.0	0

APPENDIX 11

Cost of cultivation of foliar application of micronutrients to okra under different irrigation methods

Items	Conventional irrigation					Drip irrigation				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Materials										
Seed	12750	12750	12750	12750	12750	12750	12750	12750	12750	12750
FYM	24000	24000	24000	24000	24000	24000	24000	24000	24000	24000
Lime	3850	3850	3850	3850	3850	3850	3850	3850	3850	3850
Application cost (FYM)	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Application cost (Lime)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Fertilizers										
Urea	1222	1222	1222	1222	1222	1112	1112	1112	1112	1112
Rajphos	872	872	872	872	872	697	697	697	697	697
MOP	1045	1045	1045	1045	1045	1045	1045	1045	1045	1045
$ZnSO_4$	3111		3111			3111		3111		
Solubor		22220	22220				22220	22220		
Sampoorna				9955					9955	
Land preparation										
Tractor	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Men	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Women	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
Earthing up and weeding										
Women	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000
Harvesting										
Women	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000
Irrigation	8400	8400	8400	8400	8400	6000	6000	6000	6000	6000
Spraying	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200
PP chemicals	825	825	825	825	825	825	825	825	825	825
Application cost (PP chemicals)	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Total	104375	123484	142795	111119	97064	101481	120590	123701	108325	94170

Cost of inputs	fertilizers	Labour cost	Price of produce
Okra seeds Rs. 1500 /kg	Urea Rs. 6.55/kg	Men Rs. 600/day	Okra Rs. 20/kg
FYM Rs. 1.0 /kg	Rajphos Rs. 8.3/kg	Women Rs. 600/day	
Lime Rs. 11/ kg	MOP Rs. 19 /kg	Tractor Rs. 350/hr	
	$ZnSO_4$ Rs. 70/kg		
	Solubor Rs. 500 /kg		
	Sampoorns Rs. 224/kg		

Micronutrient management for okra [*Abelmoschus esculentus* (L.) Moench] under different irrigation methods

By

ARYA P

(2017-11-038)

ABSTRACT OF THE THESIS

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ABSTRACT

Intensive cropping and imbalanced use of high analysis fertilizers have induced deficiencies of micronutrients in many part of the country. To achieve high yields and sustain the same over years, it become very pertinent to foresee the emerging nutrient deficiencies and to evolve suitable ameliorating technologies. Deficiency of micronutrients, especially deficiency of zinc and boron, is very prominent in Kerala soils. In this context an experiment entitled 'Micronutrient management for okra [*Abelmoschus esculentus* (L.) Moench] under different irrigation methods' was conducted from December 2018 to March 2019 at Water Management Research Unit, Vellanikkara with the objective to study the effect of foliar application of micronutrients on okra under conventional and drip irrigated conditions.

Treatments consisted of foliar sprays of zinc as $ZnSO_4$ (0.5%), boron as Solubor® (0.5%), combination of zinc and boron ($ZnSO_4$ (0.5%) + Solubor® (0.5%)), and KAU multi nutrient mix (Sampoorna) (0.5%) at three weeks interval and these treatments were tested against treatment without foliar application of micronutrients both under drip irrigation and conventional irrigation. All the treatments were supplied with soil test based application of NPK at recommended dose and FYM at 20 t/ha.

The result of the study indicated that performance of okra under drip and conventional irrigation showed varied response to foliar application of micronutrients. Under drip irrigated condition, foliar application of KAU multi mix application resulted in highest yield (16.41 t/ha). Under conventional irrigation, foliar application of zinc gave highest yield (11.94 t/ha) and soil test based application of NPK alone without micronutrient application was found to be equally good as zinc application (11.53 t/ha). Under drip irrigated condition, foliar application of zinc ($ZnSO_4$ @ 0.5%) gave higher yield than treatment without foliar application of micronutrients. Pre experimental soil analysis data indicated that the

soils at drip and conventional irrigation fields were not deficient in zinc but were deficient in boron. Even then foliar application of zinc ($ZnSO_4$ @ 0.5%) gave good yield response under both drip and conventional irrigation system. Application of boron either alone or in combination with zinc caused the development of phytotoxicity symptoms at the time of spraying, and this may have led to reduced yield performance of okra under both conditions. Under conventional irrigation foliar application of micronutrients could not produce any yield or economic advantage than soil test based application of fertilizers and FYM alone without micronutrient application since this treatment could provide sufficient nutrients for the growth and development of okra. Foliar application of micronutrients caused significant variation in the content and uptake of primary, secondary and micronutrients of okra plants both under drip and conventional irrigation. Under both the irrigated conditions, uptake of N, P and K at harvesting stage were higher for treatment without foliar application of micronutrients. Zinc application led to an increasing trend in zinc uptake during period of application and then reduced subsequently. Boron uptake was found higher in boron applied treatments. The micronutrient status of soil after the experiment in both the irrigated conditions was found to increase compared to pre experimental soil status. This may be due to application of FYM which supplied sufficient quantity of micronutrients to soil. Under drip irrigated condition, foliar application of KAU multi mix was found economically superior with a B: C ratio of 3.03. Under conventional irrigation, the highest B: C ratio (2.38) was obtained for treatment without foliar application of micronutrients. Foliar application of micronutrients showed no economic benefit under conventional irrigation.

Result of the study indicated that foliar application of KAU multi mix to drip irrigated okra was found to economically beneficial. But under drip irrigated and conventional irrigated condition, foliar application of boron alone or in combination with zinc showed no significant economic benefit.