

**SOURCES AND LEVELS OF ZINC FERTILIZATION ON SOIL ZINC  
AVAILABILITY AND ZINC UPTAKE BY SMALL ONION (*Allium cepa* L. var.  
*aggregatum*)**

**ABSTARCT**

Onion, the King of vegetable is one among the oldest cultivated vegetables. The quality and yield of crops are affected by micronutrient deficiencies in soil. Micronutrients which enhance the efficiency of macronutrients are equally important for the growth of a crop. Indian soils are deficient in zinc by an average deficiency of about 50 % at present. It is revealed that the presence of zinc has direct effect on yield and growth parameters of aggregatum onion. To study the Zn uptake and Zn availability to onion, different levels and sources of Zinc was evaluated in a pot culture experiment with onion var. CO(On) 5 in a soil with andy clay loam in texture, non-calcareous and deficient in soil available Zn with 16 treatments comprising different sources of Zn (ZnSO<sub>4</sub>, Zn-EDTA and Zn citrate) and levels of Zn (1,2.5,5.0, 7.5 and 10.0 kg Zn ha<sup>-1</sup> for ZnSO<sub>4</sub> and 0.1,0.25, 0.5, 0.75 and 1.0 kg Zn ha<sup>-1</sup> for Zn-EDTA and Zn citrate).

Significantly highest plant Zn at bulb initiation and harvest stages was observed with ZnSO<sub>4</sub> application 10 kg Zn ha<sup>-1</sup> followed by Zn-EDTA @ 1 kg Zn ha<sup>-1</sup> and both were comparable. Uptake of Zn by onion was significantly higher with Zn-EDTA @ 1 kg Zn ha<sup>-1</sup> and it was comparable with ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> and Zn-EDTA @ 0.75 kg Zn ha<sup>-1</sup>. Regarding the Zn content and uptake by onion at the same level of 1 kg Zn ha<sup>-1</sup>, it was observed that Zn-EDTA performed better than Zn citrate and ZnSO<sub>4</sub>. The soil available Zn at bulb initiation and harvest stages was the highest with the application of ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> followed by ZnSO<sub>4</sub> @ 7.5 kg Zn ha<sup>-1</sup> and ZnSO<sub>4</sub> @ 5 kg Zn ha<sup>-1</sup>. With the application of same level of Zn at 1 kg Zn ha<sup>-1</sup>, Zn-EDTA showed significantly higher soil available Zn which was on par with Zn citrate. From the results obtained, it can be inferred that Zn fertilization had a significant influence on Zn content, Zn uptake and soil available Zn by onion. The performance of 1 kg Zn ha<sup>-1</sup> as Zn-EDTA and 10 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> in improving the Zn uptake of onion was comparable. Hence, it can be concluded that application of either Zn-EDTA @ 1 kg Zn ha<sup>-1</sup> or ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> can be recommended for obtaining higher growth and Zn uptake of onion

**Key words:** Onion, Soil Zn availability, Zn uptake, Zinc- EDTA, Zn-Citrate, ZnSO<sub>4</sub>.

## 1. INTRODUCTION

Onion is most widely used vegetable owing to its flavour, pungency and medicinal value. Onion belonging to the family Alliaceae and native to Asia known as the “Queen of Kitchen (Prohens-Tomás and Nuez, 2007). The pungency of the onion is due to the enzyme allinase in combination with isoalliin which produces an unstable compound and forms thiosulfinates and thiosulfonates while it is disturbed. Onion is a source of antioxidants due the presence of flavanoids such as quercetin and kaempferol which helps avoiding many diseases (Ewald *et al.*, 1999). Also the bulbs of onion contain fructo-oligosaccharides that acts as osmoregulators which helps the plant to overcome drought stress (Shiomi *et al.*, 2005). Understanding the distribution of various zinc fractions in soils help to characterize the dynamics of Zn in soils as well as possible contribution of individual zinc fractions towards plant availability (Ranjan Borah *et al.*, 2022).

“Zinc (Zn) deficiency in crops is a global issue, particularly in plants grown in calcareous soils, where Zn is often adsorbed or precipitated by calcium carbonates” (Sing *et al.*, 2021; Martínez-Ríos *et al.*, 2024). “Zn deficiency is caused by various reasons starting from the prevalence of Zn-deficient soil (30% of world soils) to the Zn malabsorption in humans” (Khan *et al.*, 2022). “Low supply of micronutrients is the main cause of malnutrition in many countries. Understanding the molecular mechanisms of biofortification in crops is challenging” (Krishna *et al.*, 2023). “Zinc found to be a metal of life which play crucial roles in both plant and human physiology. Its requirement ranges from photosynthesis in plants to proper functioning of human brain. Inadequate Zn supply in soil causes lower crop productivity and poor nutritional quality leads to Zn depletion in food chain, ultimately, affecting health and reproductivity in human being. Seriousness of Zinc deficiency understood by claiming millions of lives, especially children, every year. Therefore, in order to maintain the soil nutrients and better crop productivity, the basal application of major nutrients and basal application of Zn @ 5.0 kg ha<sup>-1</sup> is recommended for rice” (Lal *et al.*, 2022).

In India, onion is cultivated in an area of 17.34 lakh hectare with production and productivity of 302.07 lakh MT and 17.36 MT per hectare respectively in the year 2022-2023. Next to China, India occupies second position in world in production of onion. In Tamil Nadu, onion is being produced at about 5,24,880 MT in 2022-23 and productivity of about 11.93 MT per hectare (Indiastat.com).

“Zinc has direct effect on bulb yield and growth of aggregatum onion” (Maurya, 2017). “Zinc plays a vital role to produce good quality onion bulb. Onion is very sensitive to zinc deficient soils” (Tisdale *et al.*, 1995) and also onion responds to zinc fertilizer application. “Zinc favours onion production due to its involvement in cellular functions and physiological processes. Zinc is involved in protein synthesis and it is required for maintenance of the stability of the enzymes. The growth and bulb yield characters enhanced in multiplier onion owing to zinc fertilization” (Acharya *et al.*, 2015).

Varied sources and levels of Zn exerted significant influence on soil available Zn and Zn uptake by onion. With the application of N:P:K:S:Zn - 100:100:100:20:5 kg ha<sup>-1</sup> there was an increase in Zn uptake in onion @ 35, 70 and 110 DAT when compared to other treatments (Nasreen and Hossain, 2004). Application of ZnSO<sub>4</sub>.7H<sub>2</sub>O showed an increase in Zn uptake of onion bulbs when compared to control (Rafique *et al.*, 2008).

Thangasamy (2016) concluded that uptake of zinc was highest at 64 DAT (1.75 g ha<sup>-1</sup>) and the uptake of zinc by onion followed a sigmoid pattern curve. Sarker *et al.* (2018) found that application of ZnSO<sub>4</sub>.7H<sub>2</sub>O @ 3 kg Zn ha<sup>-1</sup> along with other micronutrients (Cu: Mn: Fe – 2: 2: 3 kg ha<sup>-1</sup>) showed maximum total Zn uptake of 395 g ha<sup>-1</sup> in potato.

With the application of increased levels of ZnSO<sub>4</sub>.7H<sub>2</sub>O @ 0, 2, 4, 8 and 16 mg Zn kg<sup>-1</sup> there was an increase in Zn concentration in whole shoots, leaves, tops and bulbs in different cultivars of onion and Zn uptake in tops and bulbs were found highest in ZnSO<sub>4</sub>.7H<sub>2</sub>O application @ 16 mg Zn kg<sup>-1</sup> (Rafique *et al.*, 2008).

## **2.MATERIALS AND METHODS**

A pot culture experiment was conducted in the Department of Soil Science & Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore to investigate the response of onion to different sources and levels of zinc fertilizers. To initiate the experiment, ten kilogram of processed and homogenized soil collected and filled in well cleaned earthen pots individually and two seedlings per pot were planted and maintained. Soil samples were analysed as per the standard procedures (Table 1).

**Table 1. Analytical procedures used in analysis of soil samples**

Parameters	Procedure	Reference
<b>Physical Properties</b>		
Mechanical analysis	Robinson pipette method	Piper (1966)
<b>Physico-chemical properties</b>		
Soil reaction (pH)	Potentiometry (1:2.5 soil:water suspension)	Jackson (1973)
Electrical Conductivity	Conductometry (1:2.5 soil: water suspension)	Jackson (1973)
Free CaCO <sub>3</sub>	Rapid Titration Method	Piper (1931)
<b>Chemical properties</b>		
Soil organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
Cation exchange capacity (CEC)	Neutral normal ammonium acetate (pH- 7.0)	Jackson (1973)
Available Nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
Available Phosphorus	0.5 M NaHCO <sub>3</sub> (pH 8.5)	Olsen (1954)
Available Potassium	Neutral normal ammonium acetate method	Stanford and English (1949)
DTPA extractable micronutrients	Atomic absorption spectrophotometer	Lindsay and Norvell (1978)

The seeds were sown and mulching was given until the seedlings raised to a height of 1-2 cm and watering was done with rose cane periodically. Completely Randomized Block Design was adopted with three replications with 16 treatments.

T <sub>1</sub> : Control	T <sub>9</sub> : 0.50 kg Zn ha <sup>-1</sup> as Zn-EDTA
T <sub>2</sub> : 1.00 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	T <sub>10</sub> : 0.75 kg Zn ha <sup>-1</sup> as Zn-EDTA
T <sub>3</sub> : 2.50 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	T <sub>11</sub> : 1.00 kg Zn ha <sup>-1</sup> as Zn-EDTA
T <sub>4</sub> : 5.00 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	T <sub>12</sub> : 0.10 kg Zn ha <sup>-1</sup> as Zn citrate
T <sub>5</sub> : 7.50 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	T <sub>13</sub> : 0.25 kg Zn ha <sup>-1</sup> as Zn citrate
T <sub>6</sub> : 10.0 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	T <sub>14</sub> : 0.50 kg Zn ha <sup>-1</sup> as Zn citrate

T<sub>7</sub> : 0.10 kg Zn ha<sup>-1</sup> as Zn-EDTA    T15 : 0.75 kg Zn ha<sup>-1</sup> as Zn citrate  
T<sub>8</sub> : 0.25 kg Zn ha<sup>-1</sup> as Zn-EDTA    T16 : 1.00 kg Zn ha<sup>-1</sup> as Zn citrate

STCR based fertilizer prescription was calculated based on the initial soil test values and the NPK requirement was worked out as per equation already developed for onion as furnished below.

**STCR- NPK alone equation for calculating the fertilizer dose:**

$$FN = 0.99 T - 0.37 SN \quad FP_2O_5 = 0.58 T - 1.43 SP \quad FK_2O = 0.67 T - 0.25 SK$$

Where,

FN= Fertilizer N ; FP<sub>2</sub>O<sub>5</sub> = Fertilizer P<sub>2</sub>O<sub>5</sub>; FK<sub>2</sub>O = Fertilizer K<sub>2</sub>O

T= Targetted yield in q ha<sup>-1</sup>; SN, SP and SK = Soil test value of N, P and K in kg ha<sup>-1</sup>

The fertilizer dose for the yield target of 200 q ha<sup>-1</sup> was 120 : 68.2 : 15 kg N : P<sub>2</sub>O<sub>5</sub> : K<sub>2</sub>O ha<sup>-1</sup>. The N, P and K converted into Urea, SSP and MOP. Calculated quantities of SSP and MOP were applied as basal to the pots before transplanting of seedlings. Urea was applied in two splits at basal and 30 days after transplantation of seedlings. The sources and levels of zinc applied basally as per the treatment schedule.

Seedlings of forty days old were transplanted to pots. Two seedlings were maintained in each pot. All the cultivation practices were followed until harvest as per the crop production guide of TNAU.

Soil samples were collected during bulb initiation and harvest stages of the crop from each treatment from the pot. Collected soil samples were dried, processed using 2 mm sieve and were analysed for available zinc contents as per the procedure outlined in Table 1.

The plant samples were collected during bulb initiation and harvest stages of the crop. Plant samples were washed with distilled water air dried in oven at 60°C until constant weight is reached. For harvest stage samples, leaves and bulbs were separated, dry weight was recorded. Dried leaves and bulbs were ground in a wiley mill and stored for further chemical analysis.

A known quantity of the plant samples was digested with 15 ml of the triple acid mixture (Nitric acid: Sulphuric acid: Perchloric acid - 9:2:1) and made to the desired volume. The zinc content in the triacid extract was estimated in Atomic Absorption

Spectrophotometer (Jackson, 1973). Zn uptake was calculated by multiplying the Zn content of the plant with its dry matter production and expressed in  $\text{g plant}^{-1}$ .

The data obtained were statistically analysed for finding out the significance and to draw meaningful conclusions (Panse *et al.*, 1961).

### **3.RESULTS AND DISCUSSION**

#### **3.1 Physico-chemical characteristics of initial soil**

The surface sample (0-15 cm) was collected from the Orchard, TNAU, Coimbatore for conducting pot culture experiment. The experimental soil was sandy clay loam in texture, slightly alkaline in nature (pH 7.81) with permissible amount of soluble salts (EC  $0.23 \text{ dSm}^{-1}$ ). The soil was non-calcareous with a free  $\text{CaCO}_3$  content of 1.51 %. The organic carbon content of the soil was medium ( $5.2 \text{ g kg}^{-1}$ ) and the CEC of the soil was  $28.2 \text{ C mol (p+) kg}^{-1}$ .

The experimental soil was low in available N ( $123 \text{ kg ha}^{-1}$ ), high in available P ( $33.4 \text{ kg ha}^{-1}$ ) and high in available K ( $844 \text{ kg ha}^{-1}$ ). The soil was deficient in DTPA-Zn ( $1.09 \text{ mg kg}^{-1}$ ), DTPA-Cu ( $1.12 \text{ mg kg}^{-1}$ ) and sufficient in DTPA-Fe ( $7.53 \text{ mg kg}^{-1}$ ), DTPA-Mn ( $3.87 \text{ mg kg}^{-1}$ ). Different fractions of Zn in experimental soil were water soluble +exchangeable Zn ( $0.23 \text{ mg kg}^{-1}$ ), organically bound Zn ( $2.56 \text{ mg kg}^{-1}$ ), carbonate bound Zn ( $1.52 \text{ mg kg}^{-1}$ ), Fe-Mn oxide bound Zn ( $13.8 \text{ mg kg}^{-1}$ ), residual Zn ( $79.3 \text{ mg kg}^{-1}$ ) and total Zn ( $97.5 \text{ mg kg}^{-1}$ )

#### **3.2 Dry matter production, Zn content and Zn uptake at bulb initiation stage of onion**

##### **3.2.1 Dry matter production**

The values obtained from the experiment revealed a significant variation in dry matter production with the treatments imposed (Table 2). Dry matter production was significantly highest in the treatment  $1.0 \text{ kg Zn ha}^{-1}$  as Zn- EDTA ( $2.08 \text{ g plant}^{-1}$ ) followed by  $10 \text{ kg Zn ha}^{-1}$  as  $\text{ZnSO}_4$  ( $2.05 \text{ g plant}^{-1}$ ) and  $0.75 \text{ kg Zn ha}^{-1}$  as Zn EDTA ( $2.01 \text{ g plant}^{-1}$ ) respectively. The minimum dry matter was observed in control ( $1.74 \text{ g plant}^{-1}$ ) which was statistically comparable with  $0.1 \text{ kg Zn ha}^{-1}$  as Zn citrate ( $1.78 \text{ g plant}^{-1}$ ). Application of  $\text{ZnSO}_4$  @ 5, 7.5 and  $10 \text{ kg Zn ha}^{-1}$  was on par with Zn-EDTA @ 0.5 and  $0.75 \text{ kg Zn ha}^{-1}$  and Zn- citrate @ 0.75 and  $1 \text{ kg Zn ha}^{-1}$ . At the level of  $1.0 \text{ kg Zn ha}^{-1}$ , Zn-EDTA ( $2.08 \text{ g}$

plant<sup>-1</sup>) documented the highest DMP followed by Zn citrate (1.96 g plant<sup>-1</sup>) and ZnSO<sub>4</sub> (1.84 g plant<sup>-1</sup>). DMP significantly increased with applied Zn levels regardless of the sources used.

This is in close association with the findings of Meena and Singh (1998) who noted a positive relationship with dry matter of the tops and Zn application. In support of this, highly significant and positive correlation was observed between soil available Zn and DMP (0.533\*\* and 0.750\*\* at bulb initiation and harvest stages respectively). Also, the relationship between Zn uptake and DMP was highly significant and positive (0.972\*\* and 0.990\*\* at bulb initiation and harvest stages respectively).

### 3.2.2 Plant Zn content

Significant difference was obtained in plant Zn with different sources and levels of Zn applied (Table 2). ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> (28.3 mg kg<sup>-1</sup>) scored the maximum plant Zn content followed by Zn-EDTA @ 1 kg Zn ha<sup>-1</sup> (27.9 mg kg<sup>-1</sup>). Control recorded the lowest plant Zn (24.1 mg kg<sup>-1</sup>) which was on par with 0.1 and 0.25 kg Zn ha<sup>-1</sup> as Zn-EDTA and Zn citrate. Zn-EDTA @ 0.75 and 1 kg Zn ha<sup>-1</sup> and ZnSO<sub>4</sub> @ 2.5, 5.0 and 7.5 kg Zn ha<sup>-1</sup> were statistically comparable with each other. An increment in plant Zn was seen with increase in Zn levels. With same dosage of fertilization @ 1 kg Zn ha<sup>-1</sup>, Zn-EDTA (27.9 mg kg<sup>-1</sup>) registered the highest plant Zn whereas the lowest being ZnSO<sub>4</sub> (25.7 mg kg<sup>-1</sup>).

The positive effect of Zn on photosynthates and its transportation to various parts of the plant might have improved the Zn content in onion tops (Singh *et al.*, 2017). Tops and bulb Zn increased with increasing levels of Zn application in considering the sources applied. Similar trends were recorded by Rafique *et al.* (2008) and Singh *et al.* (2017). The application of Zn in onion was positively correlated with bulb Zn content as reported by Fouda (2016). Zinc playing a major role in moisture absorption and its role in different enzymes might have increased the bulb Zn upto a certain limit (Singh *et al.*, 2017). The results could be further strengthened by highly significant and positive correlation existed between soil Zn at bulb initiation stage and plant Zn content (0.679\*\*, 0.660\*\* and 0.685\*\* for plant Zn at bulb initiation stage, tops and bulb Zn at harvest stages respectively).

### 3.2.3 Plant Zn uptake

Zn uptake also had a significant influence with different levels and sources of Zn (Table 2). The maximal Zn uptake of plant was noticed in Zn-EDTA @ 1.0 kg Zn ha<sup>-1</sup> (58.6 µg plant<sup>-1</sup>) followed by ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> (57.5 µg plant<sup>-1</sup>) and 0.75 kg Zn ha<sup>-1</sup> as Zn-EDTA (53.7 µg plant<sup>-1</sup>). The least Zn uptake (42.0 µg plant<sup>-1</sup>) was observed in control which was statistically on par with 0.1 kg Zn ha<sup>-1</sup> as Zn citrate (43.1 µg plant<sup>-1</sup>). The treatments containing 5, 7.5 and 10 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> was on par with 0.75 kg Zn ha<sup>-1</sup> as Zn-EDTA and 0.75 and 1.0 kg Zn ha<sup>-1</sup> as Zn citrate. At same level of 1 kg Zn ha<sup>-1</sup>, the maximum Zn uptake was found in Zn-EDTA (58.6 µg plant<sup>-1</sup>) followed by Zn citrate (52.9 µg plant<sup>-1</sup>) and ZnSO<sub>4</sub> (47.6 µg plant<sup>-1</sup>). With increasing levels of Zn, Zn uptake of plants gradually increased.

The increased Zn uptake with Zn-EDTA application could be due to higher available Zn in soil which is again confirmed by the significant and positive correlation between soil available Zn at bulb initiation stage and Zn uptake at different stages of onion (0.616\*\*, 0.605\*\*, 0.619\*\* and 0.614\*\* for Zn uptake in bulb initiation stage, tops, bulbs and total Zn uptake at harvest stage respectively). The application of zinc increased the zinc uptake regardless of the sources which might be due to the availability of Zn in rhizosphere region with Zn addition (Singh *et al.*, 2017). Rafique *et al.* (2008) also observed increased in Zn uptake in tops and bulbs of onion with increasing levels of Zn. Control documented the lowest Zn uptake at bulb initiation and harvest stages of onion which might be due to the low availability of Zn in the rhizosphere region. Zn-EDTA showed highest Zn uptake as compared to other sources of Zn at the level of 1 kg Zn ha<sup>-1</sup> owing to its high availability coefficient and stability in soils. Similar results in rice crop were reported by Karak *et al.* (2005) observed that Zn content and uptake of rice were in the order Zn-EDTA > Zn-DTPA > ZnSO<sub>4</sub>. Chelates are easily absorbed and translocated within the plants (Sekhon, 2003).

### 3.3 Dry matter production, Zn content and Zn uptake at harvest stage of onion

#### 3.3.1 Dry matter production in tops

Marked variation was found in dry matter production of the plant at harvest stage due to the sources and levels of Zn applied (Table 3). Dry matter production in tops was highest when Zn was applied as Zn-EDTA @ 1.0 kg Zn ha<sup>-1</sup> (4.70 g plant<sup>-1</sup>) followed by

0.75 kg Zn ha<sup>-1</sup> as Zn-EDTA (4.65 g plant<sup>-1</sup>) and 10 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> (4.58 g plant<sup>-1</sup>) and all the above mentioned treatments were statistically on par with each other. The minimal DMP was noted in control (3.68 g plant<sup>-1</sup>) and was on par with 0.1 kg Zn ha<sup>-1</sup> as Zn citrate (3.79 g plant<sup>-1</sup>). Zn-EDTA showed the maximal DMP compared to other Zn sources at the same dosage of 1.0 kg Zn ha<sup>-1</sup> application. ZnSO<sub>4</sub> @ 5.0 and 7.5 kg Zn ha<sup>-1</sup> was on par with 0.75 and 1.0 kg Zn ha<sup>-1</sup> as Zn citrate and 0.5 kg Zn ha<sup>-1</sup> as Zn-EDTA. While enhancing Zn levels, there was a rise in DMP.

The increment in dry matter content of leaves with increasing Zn levels was proved with the findings of Meena and Singh (1998) who noted a positive relationship with dry matter of the tops and Zn application. In support of this, highly significant and positive correlation was observed between soil available Zn and DMP (0.533\*\* at bulb initiation stage). Also, the relationship between Zn uptake and DMP was highly significant and positive (0.972\*\* at bulb initiation stage).

### **3.3.2 Dry matter production in bulbs**

Different sources and levels of Zn showed a significant variation in the dry matter production of onion bulbs (Table 3) and the highest DMP noticed in Zn-EDTA @ 1.0 kg Zn ha<sup>-1</sup> (11.4 g plant<sup>-1</sup>) followed by 10 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> (11.1 g plant<sup>-1</sup>) and 0.75 kg Zn ha<sup>-1</sup> as Zn-EDTA (11.1 g plant<sup>-1</sup>) which were on par. ZnSO<sub>4</sub> @ 7.5 and 10 kg Zn ha<sup>-1</sup> and Zn-EDTA @ 0.5 and 0.75 kg Zn ha<sup>-1</sup> and Zn-citrate @ 0.75 and 1.0 kg Zn ha<sup>-1</sup> were comparable with each other. The minimal DMP was found in control (9.4 g plant<sup>-1</sup>). At the level of 1 kg Zn ha<sup>-1</sup>, ZnSO<sub>4</sub> documented the lowest DMP in bulbs compared to other sources. With increasing Zn levels, DMP of bulbs also increased regardless of the sources tried.

Meena and Singh (1998) found a close relationship with dry matter of the tops and Zn application. Highly significant and positive correlation was observed between soil available Zn and DMP (0.750\*\* at harvest stage). Also, the relationship between Zn uptake and DMP was highly significant and positive (0.990\*\* at harvest stage). Lowest dry matter production in both the stages with no Zn application revealed the impact of Zn application in enhancing dry matter production. This is in conformity with the findings of El-Gamili *et al.* (2000) and Assefa *et al.* (2015).

### 3.3.3 Total dry matter production

The values recorded showed a significant variation in DMP due to the treatments investigated (Table 3). Zn-EDTA @ 1.0 kg Zn ha<sup>-1</sup> (16.1 g plant<sup>-1</sup>) registered highest total DMP of onion followed by 0.75 kg Zn ha<sup>-1</sup> as Zn- EDTA (15.8 g plant<sup>-1</sup>) and 10 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> (15.7 g plant<sup>-1</sup>) and they were statistically on par. Control which received no Zn exhibited the minimum DMP of 13.1 g plant<sup>-1</sup>. 0.1 kg Zn ha<sup>-1</sup> as Zn-citrate (13.5 g plant<sup>-1</sup>) was comparable with control. ZnSO<sub>4</sub> exhibited the lowest DMP in onion when same dosage of 1 kg Zn ha<sup>-1</sup> was imposed with different sources of Zn. ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> was statistically comparable with 0.5 and 0.75 kg Zn ha<sup>-1</sup> as Zn- EDTA and 1 kg Zn ha<sup>-1</sup> as Zn- citrate. Total DMP of onion improved with rising levels of Zn. The studies by Meena and Singh (1998), El-Gamili *et al.* (2000) and Assefa *et al.* (2015) confirms the relationship between Zn content, uptake and dry matter production of onion.

### 3.3.4 Zinc content in tops and bulbs

Sources and levels of Zn exerted significant influence on the zinc content in tops at harvest stage (Table 3). ZnSO<sub>4</sub> applied at 10 kg Zn ha<sup>-1</sup> (22.6 mg kg<sup>-1</sup>) registered the highest zinc content in tops followed by Zn-EDTA @ 1.0 kg Zn ha<sup>-1</sup> (22.4 mg kg<sup>-1</sup>) and 0.75 kg Zn ha<sup>-1</sup> as Zn-EDTA (21.9 mg kg<sup>-1</sup>) respectively which were statistically on par. The treatment which received no Zn recorded the minimal Zn content in tops (18.7 mg kg<sup>-1</sup>) which was statistically comparable with 0.1 kg Zn ha<sup>-1</sup> as Zn-EDTA and Zn-citrate. ZnSO<sub>4</sub> @ 5.0 and 7.5 kg Zn ha<sup>-1</sup> and Zn citrate @ 0.75 and 1.0 kg Zn ha<sup>-1</sup> were on par with Zn-EDTA @ 0.75 kg Zn ha<sup>-1</sup>. At 1 kg Zn ha<sup>-1</sup> level, Zn-EDTA recorded significantly the highest Zn content in tops. With increment in Zn levels, Zn content in tops gradually increased.

Bulb content varied markedly with the sources and levels of Zn tried (Table 3). The highest bulb Zn content was registered in ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> (16.5 mg kg<sup>-1</sup>) followed by 1.0 kg Zn ha<sup>-1</sup> as Zn-EDTA (16.4 mg kg<sup>-1</sup>) and both the treatments were statistically comparable. Zn-EDTA @ 1 kg Zn ha<sup>-1</sup> was on par with the same source at 0.75 kg Zn ha<sup>-1</sup>. The minimum bulb Zn content was documented in control (13.0 mg kg<sup>-1</sup>) which was on par with 0.1 kg Zn ha<sup>-1</sup> as Zn citrate (13.7 mg kg<sup>-1</sup>). With Zn dose applied at 1 kg Zn ha<sup>-1</sup>, Zn-EDTA recorded the significantly highest bulb Zn content when compared with other sources.

The application of Zn in onion was positively correlated with bulb Zn content as reported by Fouda (2016). Zinc playing a major role in moisture absorption and its role in different enzymes might have increased the bulb Zn upto a certain limit (Singh *et al.*, 2017). The results could be further strengthened by highly significant and positive correlation existed between soil Zn at bulb initiation stage and plant Zn content (0.679\*\*, 0.660\*\* and 0.685\*\* for plant Zn at bulb initiation stage, tops and bulb Zn at harvest stages respectively).

### **3.3.5 Zinc uptake in tops**

Zinc uptake in tops varied notably with different levels and sources of Zn (Table 3). The highest Zn uptake was noticed in Zn-EDTA @ 1.0 kg Zn ha<sup>-1</sup> (105.3 µg plant<sup>-1</sup>) followed by ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> (103.6 µg plant<sup>-1</sup>) and Zn-EDTA @ 0.75 kg Zn ha<sup>-1</sup> (101.9 µg plant<sup>-1</sup>) which were on par. Control registered the lowest Zn uptake in tops of about 68.9 µg plant<sup>-1</sup>. The treatments with 2.5, 5.0 and 7.5 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> was on par with 0.75 and 1.0 kg Zn ha<sup>-1</sup> as Zn-citrate and 0.5 kg Zn ha<sup>-1</sup> as Zn-EDTA. Amongst the sources, Zn-EDTA documented the significantly highest Zn uptake in tops compared to other sources at equal dosage of Zn application @ 1.0 kg Zn ha<sup>-1</sup>.

### **3.3.6 Zinc uptake in bulbs**

Significant difference was found in the bulb Zn content with the treatments under investigation (Table 3). Zn-EDTA @ 1.0 kg Zn ha<sup>-1</sup> (187 µg plant<sup>-1</sup>) recorded the highest Zn uptake in bulbs followed by ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> (183 µg plant<sup>-1</sup>) and 0.75 kg Zn ha<sup>-1</sup> as Zn-EDTA (174 µg plant<sup>-1</sup>) which were on par with each other. The treatments containing ZnSO<sub>4</sub> @ 5.0 and 7.5 kg Zn ha<sup>-1</sup> were on par with Zn-EDTA @ 0.75 kg Zn ha<sup>-1</sup> and Zn-citrate @ 0.75 and 1.0 kg Zn ha<sup>-1</sup>. The minimum bulb Zn content was noticed in control receiving no Zn (122 µg plant<sup>-1</sup>). The significantly highest Zn uptake in bulbs was noticed in Zn-EDTA over other sources at the level of 1 kg Zn ha<sup>-1</sup> application. Zn uptake in bulbs raised with increment in Zn levels.

### **3.3.7 Total Zn uptake**

Total Zn uptake of onion also varied markedly with different sources and levels of Zn (Table 3). Application of 1.0 kg Zn ha<sup>-1</sup> as Zn-EDTA (292 µg plant<sup>-1</sup>) recorded the maximum Zn uptake in plants followed by ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> (287 µg plant<sup>-1</sup>) and

0.75 kg Zn ha<sup>-1</sup> as Zn citrate (276 µg plant<sup>-1</sup>). Control registered the lowest Zn uptake (191 µg plant<sup>-1</sup>) which was comparable with 0.1 kg Zn ha<sup>-1</sup> as Zn citrate (206 µg plant<sup>-1</sup>). ZnSO<sub>4</sub> @ 5.0 and 7.5 kg Zn ha<sup>-1</sup> was on par with 0.75 and 1.0 kg Zn ha<sup>-1</sup> as Zn-citrate and 0.75 kg Zn ha<sup>-1</sup> as Zn-EDTA. Zn-EDTA showed significantly highest Zn uptake when compared to other sources when Zn was applied at the level of 1.0 kg Zn ha<sup>-1</sup>. Total Zn uptake gradually raised, with rise in Zn levels regardless of the sources imposed.

The application of zinc increased the zinc uptake regardless of the sources which might be due to the availability of Zn in rhizosphere region with Zn addition (Singh *et al.*, 2017). Rafique *et al.* (2008) also observed increased in Zn uptake in tops and bulbs of onion with increasing levels of Zn. Control documented the lowest Zn uptake at bulb initiation and harvest stages of onion which might be due to the low availability of Zn in the rhizosphere region. Zn-EDTA showed highest Zn uptake as compared to other sources of Zn at the level of 1 kg Zn ha<sup>-1</sup> owing to its high availability coefficient and stability in soils. Similar results in rice crop were reported by Karak *et al.* (2005).

### **3.4 Effect of sources and levels of Zn on soil available Zn at different onion growth stages**

At bulb initiation stage, sources and levels of Zn had a significant influence on soil available Zn at bulb initiation stage (Table 4). Significantly highest available Zn was noticed in ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> (2.04 mg kg<sup>-1</sup>) followed by 7.5 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> (1.79 mg kg<sup>-1</sup>) and ZnSO<sub>4</sub> @ 5 kg Zn ha<sup>-1</sup> (1.53 mg kg<sup>-1</sup>) respectively. Soil available Zn was lowest in treatment with no Zn (1.04 mg kg<sup>-1</sup>) which was statistically comparable with 0.1 kg Zn ha<sup>-1</sup> as Zn citrate (1.10 mg kg<sup>-1</sup>). At the same dose of 1 kg Zn ha<sup>-1</sup>, Zn-EDTA (1.27 mg kg<sup>-1</sup>) registered the maximal Zn content followed by Zn citrate (1.24 mg kg<sup>-1</sup>) and the least being ZnSO<sub>4</sub> (1.15 mg kg<sup>-1</sup>). Addition of Zn showed escalation in soil available Zn irrespective of the sources used.

At harvest stage sources and levels of Zn markedly influenced the soil available Zn at harvest stage (Table 4). The soil available Zn was significantly highest in the treatment that received ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> (1.30 mg kg<sup>-1</sup>) followed by 7.5 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> (1.24 mg kg<sup>-1</sup>). Control recorded minimal soil available Zn content of 0.99 mg kg<sup>-1</sup> which was on par with Zn citrate @ 0.1 kg Zn ha<sup>-1</sup> (1.04 mg kg<sup>-1</sup>). Zn-EDTA (1.14 mg kg<sup>-1</sup>) documented the highest available soil Zn followed by Zn citrate (1.11 mg kg<sup>-1</sup>) and

ZnSO<sub>4</sub> (1.09 mg kg<sup>-1</sup>) at equal dosage of Zn application @ 1 kg Zn ha<sup>-1</sup>. ZnSO<sub>4</sub> @ 2.5 and 5 kg Zn ha<sup>-1</sup> was statistically comparable with Zn-EDTA @ 0.75 and 1 kg Zn ha<sup>-1</sup>. Regardless of the sources applied, there was an increment in soil available Zn with increasing Zn levels.

Zn-EDTA performed better than Zn citrate probably due to greater fixation and stability of Zn-EDTA chelates in soil than Zn citrate. Stability constants (Log K values) of Zn-EDTA and Zn citrate complexes were 17.5 and 5.0 respectively (Smith and Martell, 1976). Zinc in soil as a result of application of inorganic sources such as ZnSO<sub>4</sub>, due to the interaction of Zn with soil constituents leads to reduced Zn availability. To reduce Zn fixation in soil, it is recommended to be applied as organic or synthetic chelates which will enhance their availability to plants (Udeigwe *et al.*, 2016). Effectiveness of chelated micronutrient compounds was already reported by Sekhon (2003). Increasing Zn levels, enhanced soil available Zn content which is in line with the findings of Gonzalez *et al.* (2016). At harvest stage, ZnSO<sub>4</sub> @ 2.5 and 5 kg Zn ha<sup>-1</sup> was on par with Zn-EDTA @ 0.75 and kg Zn ha<sup>-1</sup> which indicates that Zn-EDTA is 3.33 to 6.66 times more effective than ZnSO<sub>4</sub> owing to the higher rate of diffusion and extractability of Zn-EDTA than ZnSO<sub>4</sub> (Modaihsh, 1990). Zn chelates were more effective in lesser doses than inorganic ZnSO<sub>4</sub> fertilizer. Similar trends were noticed by Anderson *et al.* (2018).

#### 4. SUMMARY AND CONCLUSIONS

The results of the pot culture experiment indicated that different sources and levels of Zn had significant influence on Zn content, uptake of onion and soil available Zn. A marked variation was noticed in Zn content of onion at bulb initiation and harvest stages. Significantly highest plant Zn at bulb initiation and harvest stages was observed with ZnSO<sub>4</sub> application 10 kg Zn ha<sup>-1</sup> followed by Zn-EDTA @ 1 kg Zn ha<sup>-1</sup> and both were comparable. Uptake of Zn by onion was significantly higher with Zn-EDTA @ 1 kg Zn ha<sup>-1</sup> and it was comparable with ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> and Zn-EDTA @ 0.75 kg Zn ha<sup>-1</sup>. Regarding the Zn content and uptake by onion at the same level of 1 kg Zn ha<sup>-1</sup>, it was observed that Zn-EDTA performed better than Zn citrate and ZnSO<sub>4</sub>. Zn content and uptake by onion was the lowest in no Zn application. The soil available Zn at bulb initiation and harvest stages was the highest with the application of ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> followed by ZnSO<sub>4</sub> @ 7.5 kg Zn ha<sup>-1</sup> and ZnSO<sub>4</sub> @ 5 kg Zn ha<sup>-1</sup>. With the application of same level of Zn at 1 kg Zn ha<sup>-1</sup>, Zn-EDTA showed significantly higher soil available Zn

which was on par with Zn citrate. No Zn application (Control) and Zn citrate @ 0.1 kg Zn ha<sup>-1</sup> registered significantly lowest soil available Zn at both the stages of onion. From the results obtained, it can be inferred that Zn fertilization had a significant influence on Zn content, Zn uptake and soil available Zn by onion. The performance of 1 kg Zn ha<sup>-1</sup> as Zn-EDTA and 10 kg Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> in improving the Zn uptake of onion was comparable. Hence, it can be concluded that application of either Zn-EDTA @ 1 kg Zn ha<sup>-1</sup> or ZnSO<sub>4</sub> @ 10 kg Zn ha<sup>-1</sup> can be recommended for obtaining higher growth and Zn uptake of onion.

#### **DISCLAIMER (ARTIFICIAL INTELLIGENCE)**

Author(s) here by declares that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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#### **COMPETING INTERESTS**

Authors have declared that no competing interests exist.

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**Table 2. Effect of sources and levels of Zn on dry matter production, Zn content and uptake at bulb initiation stage of onion**

Treatments	Dry matter production (g plant <sup>-1</sup> )	Zn content (mg kg <sup>-1</sup> )	Zn uptake (µg plant <sup>-1</sup> )
T <sub>1</sub> -Control (NPK)	1.74	24.1	42.0
T <sub>2</sub> - 1.00 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	1.84	25.7	47.6
T <sub>3</sub> - 2.50 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	1.85	26.6	49.8
T <sub>4</sub> - 5.00 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	1.95	26.7	52.9
T <sub>5</sub> - 7.50 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	1.98	26.8	53.4
T <sub>6</sub> - 10.0 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	2.05	28.3	57.5
T <sub>7</sub> - 0.10 kg Zn ha <sup>-1</sup> as Zn-EDTA	1.85	25.3	47.3
T <sub>8</sub> - 0.25 kg Zn ha <sup>-1</sup> as Zn-EDTA	1.87	25.4	47.8
T <sub>9</sub> - 0.50 kg Zn ha <sup>-1</sup> as Zn-EDTA	1.97	25.8	51.6
T <sub>10</sub> - 0.75 kg Zn ha <sup>-1</sup> as Zn-EDTA	2.01	26.7	53.7
T <sub>11</sub> - 1.00 kg Zn ha <sup>-1</sup> as Zn-EDTA	2.08	27.9	58.6
T <sub>12</sub> - 0.10 kg Zn ha <sup>-1</sup> as Zn citrate	1.78	24.2	43.1
T <sub>13</sub> - 0.25 kg Zn ha <sup>-1</sup> as Zn citrate	1.84	25.4	47.3
T <sub>14</sub> - 0.50 kg Zn ha <sup>-1</sup> as Zn citrate	1.86	25.6	48.2
T <sub>15</sub> - 0.75 kg Zn ha <sup>-1</sup> as Zn citrate	1.95	26.5	52.8
T <sub>16</sub> - 1.00 kg Zn ha <sup>-1</sup> as Zn citrate	1.96	26.6	52.9
SEd	0.04	0.6	2.5
CD (P=0.05)	0.09	1.3	5.1

**Table 3. Effect of sources and levels of Zn on dry matter production, Zn content and uptake at harvest stage of onion**

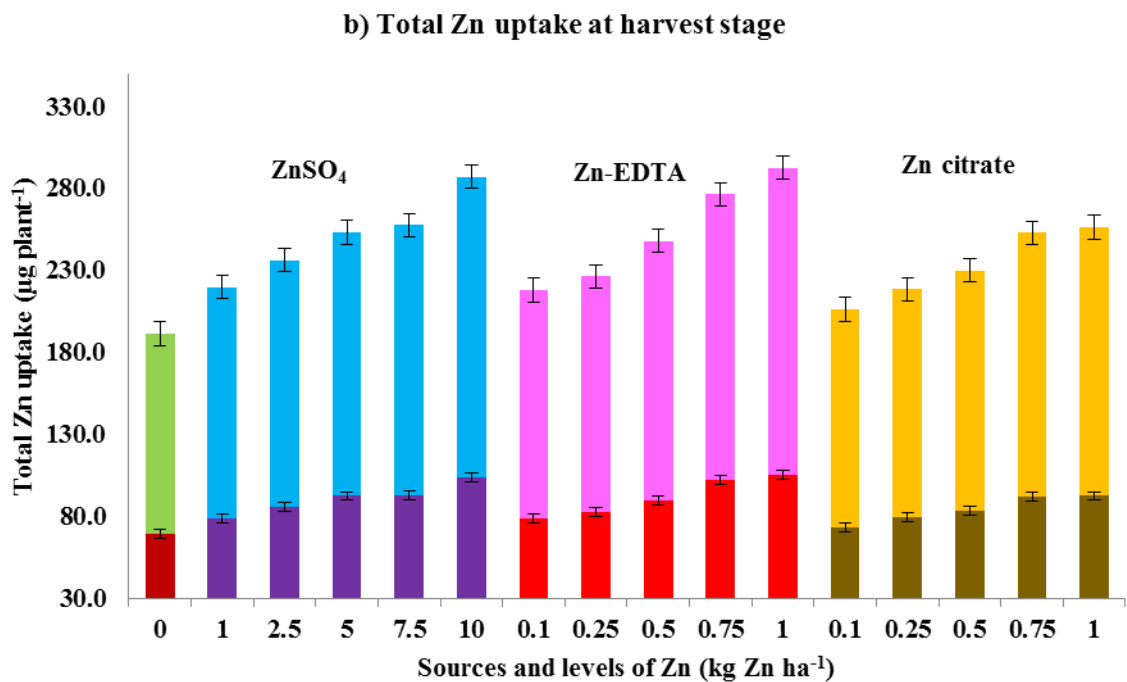
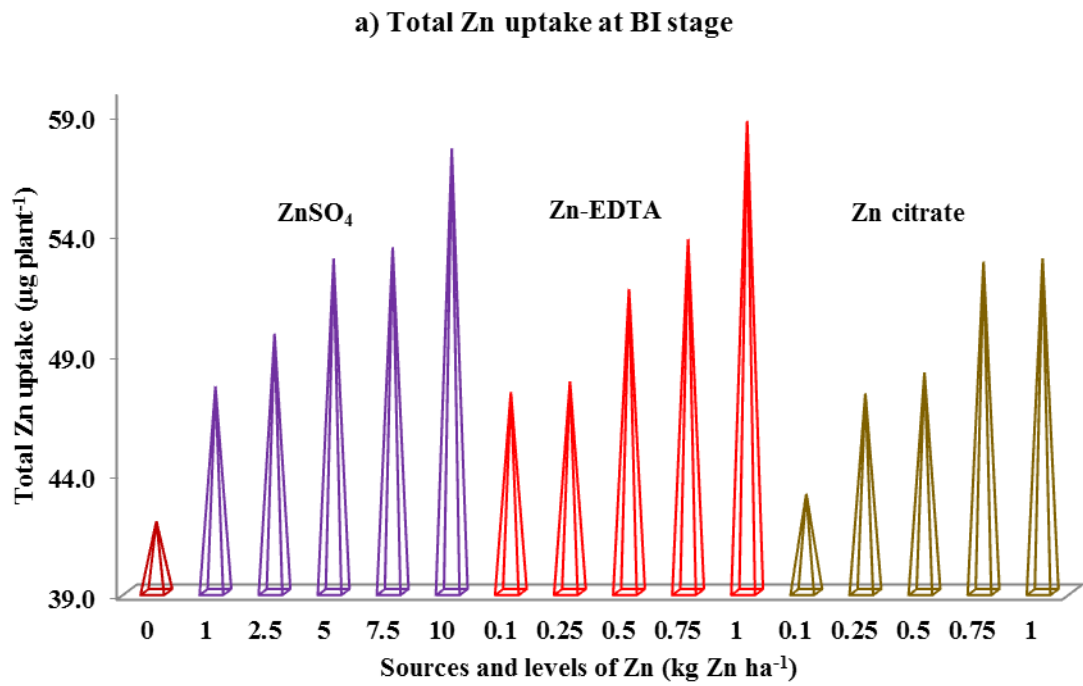
Treatments	Dry matter production (g plant <sup>-1</sup> )			Zn content (mg kg <sup>-1</sup> )		Zn uptake (µg plant <sup>-1</sup> )		
	Tops	Bulbs	Total	Tops	Bulbs	Tops	Bulbs	Total
T <sub>1</sub> -Control (NPK)	3.68	9.4	13.1	18.7	13.0	68.9	122	191
T <sub>2</sub> - 1.00 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	3.95	10.0	14.0	19.9	14.1	78.7	141	220
T <sub>3</sub> - 2.50 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	4.11	10.1	14.2	20.8	14.9	85.5	151	236
T <sub>4</sub> - 5.00 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	4.35	10.5	14.9	21.2	15.3	92.3	161	253
T <sub>5</sub> - 7.50 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	4.36	10.6	15.0	21.3	15.5	92.9	164	257
T <sub>6</sub> - 10.0 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	4.58	11.1	15.7	22.6	16.5	103.6	183	287
T <sub>7</sub> - 0.10 kg Zn ha <sup>-1</sup> as Zn-EDTA	4.00	10.0	14.0	19.7	13.9	78.8	139	218
T <sub>8</sub> - 0.25 kg Zn ha <sup>-1</sup> as Zn-EDTA	4.13	10.1	14.2	20.0	14.2	82.7	144	226
T <sub>9</sub> - 0.50 kg Zn ha <sup>-1</sup> as Zn-EDTA	4.36	10.7	15.1	20.5	14.8	89.4	158	248
T <sub>10</sub> - 0.75 kg Zn ha <sup>-1</sup> as Zn-EDTA	4.65	11.1	15.8	21.9	15.7	101.9	174	276
T <sub>11</sub> - 1.00 kg Zn ha <sup>-1</sup> as Zn-EDTA	4.70	11.4	16.1	22.4	16.4	105.3	187	292
T <sub>12</sub> - 0.10 kg Zn ha <sup>-1</sup> as Zn citrate	3.79	9.7	13.5	19.3	13.7	73.2	133	206
T <sub>13</sub> - 0.25 kg Zn ha <sup>-1</sup> as Zn citrate	3.98	10.0	14.0	19.9	13.9	79.3	139	218
T <sub>14</sub> - 0.50 kg Zn ha <sup>-1</sup> as Zn citrate	4.12	10.1	14.2	20.2	14.5	83.3	147	230
T <sub>15</sub> - 0.75 kg Zn ha <sup>-1</sup> as Zn citrate	4.34	10.6	14.9	21.1	15.2	91.6	161	253
T <sub>16</sub> - 1.00 kg Zn ha <sup>-1</sup> as Zn citrate	4.35	10.7	15.1	21.2	15.3	92.3	164	256
SEd	0.10	0.3	0.4	0.5	0.4	4.3	8	12
CD (P=0.05)	0.21	0.5	0.8	1.0	0.7	8.8	16	24

**Table 4. Effect of sources and levels of Zn on soil available Zn at different growth stages of onion**

Treatments	Soil available Zn (mg kg <sup>-1</sup> )	
	Bulb initiation stage	Harvest stage
T <sub>1</sub> -Control (NPK)	1.04	0.99
T <sub>2</sub> - 1.00 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	1.15	1.09
T <sub>3</sub> - 2.50 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	1.28	1.12
T <sub>4</sub> - 5.00 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	1.53	1.17
T <sub>5</sub> - 7.50 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	1.79	1.24
T <sub>6</sub> - 10.0 kg Zn ha <sup>-1</sup> as ZnSO <sub>4</sub>	2.04	1.30
T <sub>7</sub> - 0.10 kg Zn ha <sup>-1</sup> as Zn-EDTA	1.12	1.07
T <sub>8</sub> - 0.25 kg Zn ha <sup>-1</sup> as Zn-EDTA	1.14	1.09
T <sub>9</sub> - 0.50 kg Zn ha <sup>-1</sup> as Zn-EDTA	1.17	1.11
T <sub>10</sub> - 0.75 kg Zn ha <sup>-1</sup> as Zn-EDTA	1.23	1.12
T <sub>11</sub> - 1.00 kg Zn ha <sup>-1</sup> as Zn-EDTA	1.27	1.14
T <sub>12</sub> - 0.10 kg Zn ha <sup>-1</sup> as Zn citrate	1.10	1.04
T <sub>13</sub> - 0.25 kg Zn ha <sup>-1</sup> as Zn citrate	1.13	1.07
T <sub>14</sub> - 0.50 kg Zn ha <sup>-1</sup> as Zn citrate	1.14	1.08
T <sub>15</sub> - 0.75 kg Zn ha <sup>-1</sup> as Zn citrate	1.19	1.10
T <sub>16</sub> - 1.00 kg Zn ha <sup>-1</sup> as Zn citrate	1.24	1.11
SEd	0.03	0.02
CD (P=0.05)	0.06	0.05

**Table 5. Correlation between soil available Zn at bulb initiation stage and content and uptake of Zn at different stages of onion**

	Zn content			Zn uptake			
	Bulb initiation stage	Harvest stage		Bulb initiation stage	Harvest stage		
		Plant Zn	Tops		Bulbs	Total	Tops
Soil Zn-BI	0.679**	0.660**	0.685**	0.616**	0.605**	0.619**	0.614**



**Fig 1. Effect of different sources (a) and levels of Zn on total Zn uptake (b) at different stages of onion**