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Effect of zinc fertilization on productivity and zinc uptake in Chilli-Finger Millet-Amaranthus system

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Abstract

Crops' response to zinc application may vary under different management systems. The objective of the current investigation was to study the effect of different levels of Zn fertilization on direct and residual availability of zinc in soil, crop yield and uptake of zinc in the chilli-finger millet-amaranthus system on an Alfisol. Field experiments were conducted during 2019-2020 in low zinc soil (0.88 mg kg^{-1}) and treatments were as a one-time application of 5, 10, 15 and 20 kg Zn ha^{-1} through $ZnSO_4.7H_2O$ as basal dose only for chilli; foliar application of 0.5% $ZnSO_4.7H_2O$ (two times for each crop) and control (no Zn fertilization). Extractable Zn content of soil improved from 0.88 to 2.10 mg kg^{-1} by basal application of Zn. It also enhanced Zn concentration in crop produce resulting in higher Zn uptake. The direct effect of Zn fertilization significantly improved chilli yield in all the treatments over the control, however, the significant residual effect of yield enhancement in finger millet and amaranthus was recorded by basal application of Zn from 10 kg ha^{-1} onwards. By increasing the Zn doses from 10 kg to 20 kg per ha, no further significant improvement in yield was noticed with corresponding soil DTPA-Zn of more than 1.5 mg kg^{-1}. From the results, it is obvious that onetime zinc fertilization of 10 kg ha^{-1} y^{-1} through soil could be the best option to correct Zn deficiency and improve the productivity of vegetable-based systems. If DTPA-Zn content of soil reaches 1.5 mg kg^{-1} and above, subsequent Zn application can be avoided.

Key words: Zinc fertilization, residual effect, zinc availability, crop yield, vegetables

Introduction

Vegetable production system is considered as very intensive and exhaustive and requires balanced and optimal doses of fertilizer nutrients for higher crop productivity. Soil is the main source of nutrients and supply required amount of nutrients for crop production. Deficiency of any nutrients in soil affects plant growth and productivity. Zinc deficiency is widespread phenomenon in soils of different production systems across the world and in India, resulting in significant losses of crop yields and nutritional health problems in animals and humans (Shukla and Behera, 2011). Continuous intensive cropping without Zn application decreases the soil Zn (Valenciano *et al.*, 2010). In India, about 44% of soils were deficient in Zn due to exhaustive frequencies of cropping and widespread use of high analysis macronutrient (NPK) fertilizers without micronutrients (Shukla and Behera, 2012; Singh, 2008). Zinc requirement and response of crops to Zn fertilization may vary under different agricultural management systems. However, it differs and depends upon agro-climatic conditions, soil type, extent of deficiency, crops and cultivars, management practices etc. However an enormous response to Zn fertilization in different crops has been elucidated by many researchers (Rattan *et al.*, 2008; Singh *et al.*, 2011; Grija Veni, 2020). Zinc fertilization can increase 15-25% yields of vegetable crops (Patnaik *et al.*, 2011; Gurmani *et al.*, 2012). Residual and cumulative effect of Zn fertilization on crop productivity is reported in maize-wheat (Behra *et al.*, 2008), rice-wheat (Shukla and Behera, 2011), rice-okra (Patnaik *et al.*, 2011), cotton-wheat (Abid *et al.*, 2013), and maize-black gram (Saviour and Stalin, 2013). Further Zn fertilization influences Zn availability and different Zn fractions in soils (Behra *et al.*, 2008; Khadtare *et al.*, 2009; Singh and Shivay, 2013). Though extensive study on direct effect of Zn on individual vegetable crop has been reported, there is little information available on residual Zn utilization potential of different vegetable cropping systems (Ganeshamurthy *et al.*, 2017). Moreover influence of Zn fertilization towards availability and dynamics of Zn under different soils is not clearly understood (Behra *et al.*, 2008; Shukla and Behera, 2011). Considering the above, in this experiment, it was aimed to investigate the effect of various levels of Zn fertilization in direct and residual Zn availability and crop production and uptake of zinc in Chilli-Finger millet- Amaranthus cropping sequence grown on a native soil (Alfisol) with low available Zn content.

Materials and methods

Experimental details: One year field experimentations adopting Chilli (var. Arka Meghana)- Finger millet (var. Indaf 7)- Amaranthus (var. Arka Suguna) cropping sequence were conducted in the experimental field at ICAR-IIHR, Bangalore, India in the year 2019-2020. Experimental soil had sandy loam texture with pH 6.36; electrical conductivity 0.14 dS m^{-1}, with low organic carbon (4.2 g kg^{-1}), mineralizable N (35.4 mg kg^{-1}), available K (49.1 mg kg^{-1}) and DTPA-extractable Zn (0.88 mg kg^{-1}); and high available P (31.1 mg kg^{-1}) and DTPA extractable Mn (2.93 mg kg^{-1}), Fe (5.75 mg kg^{-1}) and Cu (1.24 mg kg^{-1}). Treatments were soil application of 5, 10, 15 and 20 kg Zn ha^{-1} (one time through $ZnSO_4.7H_2O$ as basal dose only to chilli); foliar application of 0.5% $ZnSO_4.7H_2O$ of 250 L ha^{-1} (at 45 and 60 days after planting/sowing (DAP/DAS) for chilli and finger millet, 30 and 45 DAS for amaranthus) and no Zn application.

With three replicates of all the treatments, randomized block design (RBD) was adopted. After harvest of chilli, finger millet was raised and followed by amaranthus in the same plot. The size of the plots was 5 m length and 3 m breadth. Chilli and finger millet seedlings (25 days old) were transplanted on raised beds with spacing of 1 m x 0.5 m; and 20 cm x 15 cm, respectively; sowing of amaranthus seeds was done in rows with 30 cm inter-row spacing. Recommended doses of N, P_2O_5, K_2O (chilli- 120: 80: 80 kg ha^{-1}; finger millet- 60:30:30 kg ha^{-1}; amaranthus- 100: 50:50 kg ha^{-1}) and farm yard manure (15 t ha^{-1} for chill and 10 t ha^{-1} for finger millet and amaranthus) were applied. All the plots within an experimental field were drip irrigated for same length of time considering the soil moisture status and crop water requirement. After maturity, crops were harvested from each plots and fruit or grain and plant biomass yields were recorded.

Soil and plant sampling and analysis: Soils were sampled from all the treatment plots after harvest of each crop. The depth of soil sampling was 0.15 m and samples were collected randomly from about six places from each plot manually, combined, air dried at room temperature 28-30°C, and pulverized using wooden pestle- mortar to pass through a 2.0 mm sieve. Soil Zn was extracted with DTPA and was determined using Atomic Absorption Spectrophotometer (AAS) (Lindsay and Norvell, 1978). Chilli fruits and finger millet grains were sampled. Similarly five whole plants (above ground biomass) were randomly sampled from all the treatments, washed in distilled water, and shade dried. All the plant samples were oven dried at 60°C and weighed. All dried plant samples were ground and homogenized using stainless steel grinder to pass through a 0.5 mm sieve. The plant samples were digested with HNO_3 and $HClO_4$ mixture and extracted with 6 *N* HCl (AOAC, 1990). Plant Zn concentrations were determined using AAS. The Zn uptake of fruit or grain and plant biomass was obtained from the product of their Zn concentration and dry weight. Data on Zn concentration in soil, crop yield, Zn content and uptake by crops were subjected to analysis of variance using the procedure for randomized block design (Gomez and Gomez, 1984) using WASP software version 2.0. Further Duncan's Multiple Range Test (DMRT) was performed for comparison of means at 5% level of significance.

Results and discussion

Zinc fertilization on soil zinc availability: The DTPA extractable Zn content of soil after harvest of Chilli ranged from 0.87 mg kg^{-1} to 2.09 mg kg^{-1}, after harvest of finger millet was 0.85 mg kg^{-1} to 2.09 mg kg^{-1}and after harvest of amaranthus was 0.82 mg kg^{-1} to 1.92 mg kg^{-1} (Fig. 1). The significant increase was noticed in all soil Zn applied treatments. However prominent residual effect was noticed beyond 10 kg Zn application and increasing the doses of Zn significantly improved the soil DTPA extractable Zn (Fig. 1). Reduction in the DTPA Zn content of soil in each treatment was recorded crop after crop. This might be due to crop removal and conversion of Zn from labile to non-labile pool. There was significant variation among the soil applied Zn treatments with respect to DTPA-Zn. Foliar application of 0.5% $ZnSO_4.7H_2O$ did not significantly increase the DTPA-Zn content of soil when compared to control treatment. The increase in DTPA-Zn in soil Zn applied treatments might be due to external supply of high quantity of Zn to soil. The similar results were reported by earlier workers (Behra *et al.*, 2008; Patnaik *et al.*, 2011; Shukla and Behra, 2011; Abid *et al.*, 2013; Kumari *et al.*, 2015).

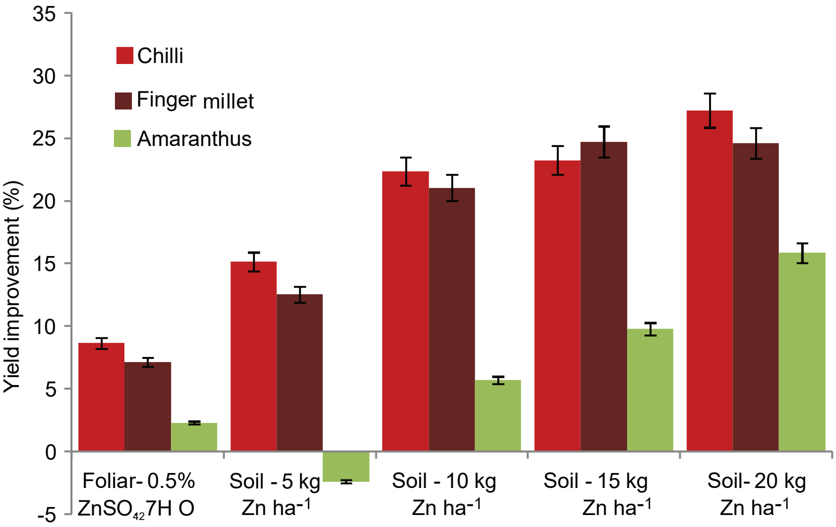

Fig. 1. DTPA Extractable Zn content in soil after harvest of Chilli-Finger Millet-Amaranthus under different levels and methods of Zn Fertilization. (In soil application methods Zn applied only to Chilli as basal dose and finger millet and amaranthus were raised in the same plot with residual Zn)

Direct and residual effect of zinc on crop yield: The direct effect of Zn applications on chilli yield and dry biomass yield revealed that foliar and soil application of Zn improved these parameters over the control (Table 1). The chilli and dry biomass yield ranged from 18.5-23.5 t ha^{-1} and from 5.39-6.31 t ha^{-1}, respectively. The highest and significant fruit yield was observed from 10 kg Zn soil application per ha, but there was no dry biomass yield difference between the method of Zn application. The residual effect of Zn application on finger millet grain and dry biomass yield was also significant from 10 kg soil Zn application onwards, further increasing the doses there was no significant changes in the yield. The finger millet grain and dry biomass yields ranged from 2.87-3.62 t ha^{-1} and 3.66-4.65 t ha^{-1}, respectively. Amaranthus yield ranged from 9.29-10.8 t ha^{-1} (Table 1). In case of amaranthus, also the yield increment was significant from 10 kg Zn ha^{-1}. Soil application Zn beyond 10 kg Zn ha^{-1} did not significantly improved fruit yields and DMYs of finger millet and amaranthus. The enhanced yield in soil Zn applied treatments might be due

Table 1. Economic yield and dry biomass yield of different crops under various levels and methods of Zn fertilization

Treatment	Chilli		Finger millet		Amaranthus
	Fruit yield (t ha^{-1})	Dry biomass yield (t ha^{-1})	Grain yield (t ha^{-1})	Dry biomass yield (t ha^{-1})	Fresh biomass yield (t ha^{-1})
Control	18.5±1.42d	5.39±0.17b	2.87±0.09d	3.66±0.07d	9.29±0.76c
Foliar- 0.5% $ZnSO_4$	20.1±1.20c	6.07±0.10a	3.11±0.16cd	4.00±0.21cd	9.51±0.36bc
Soil- 5 kg Zn ha^{-1}	21.3±0.53bc	6.15±0.04a	3.26±0.15bc	4.20±0.19bc	9.08±0.36bc
Soil- 10 kg Zn ha^{-1}	22.6±0.57ab	6.18±0.06a	3.51±0.29ab	4.52±0.37ab	9.83±0.65bc
Soil- 15 kg Zn ha^{-1}	22.8±1.05ab	6.27±0.29a	3.62±0.35a	4.66±0.45a	10.2±0.51ab
Soil- 20 kg Zn ha^{-1}	23.5±0.50a	6.31±0.04a	3.61±0.24a	4.65±0.31a	10.8±0.41a
CD (P=0.05)	1.53	0.29	0.28	0.37	0.76

Means followed by similar lowercase letter within a column are not significantly different (at $P< 0.05$)

to improvement in availability of Zn in soil through external supply of Zn to soil. The percent improvement in fruit yield of chilli, finger millet and amaranthus in 10 kg Zn ha^{-1} over control was 23, 22 and 6%, respectively (Fig. 2). Increase in fruit yield and DMY due to zinc application was mainly a function of enhanced growth, translocation of more photosynthates towards sink and accumulation of more dry matter in fruits. The role of Zn as essential nutrient in plant growth, metabolism and development had been reported by many workers (Rattan *et al.*, 2008; Singh, 2008; Shukla and Behera, 2012; Wong *et al.*, 2019)

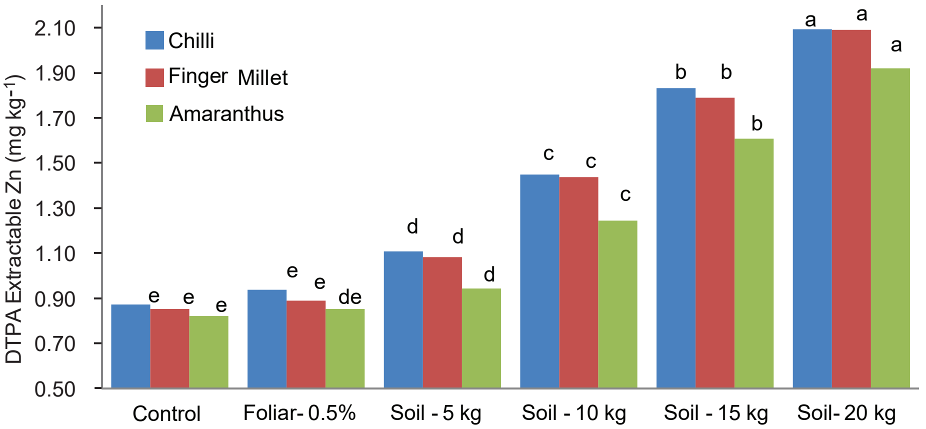

Fig. 2. Yield increment in different Zn fertilization treatments over control (Direct effect on chilli and residual effect on finger millet and amaranthus in soil applied treatments)

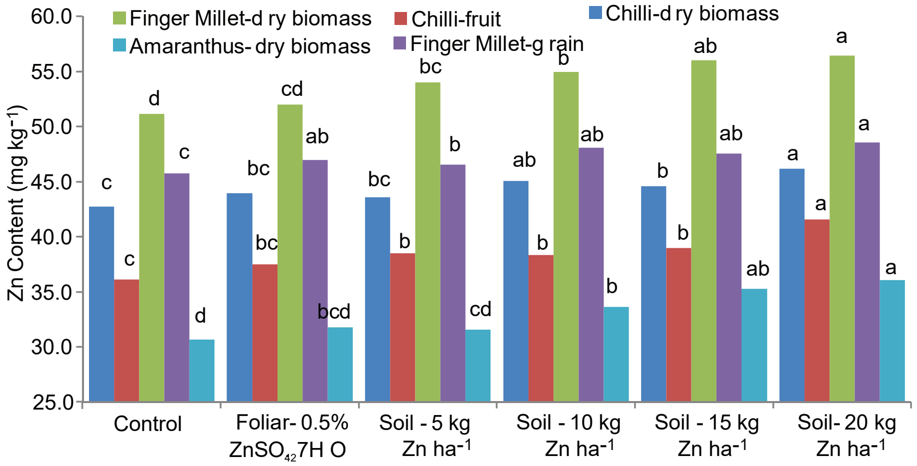

Fig. 3. Zinc concentration in dry biomass and fruits/grains of different crops under different levels and methods of Zn application (Direct effect on chilli and residual effect on finger millet and amaranthus in soil applied treatments)

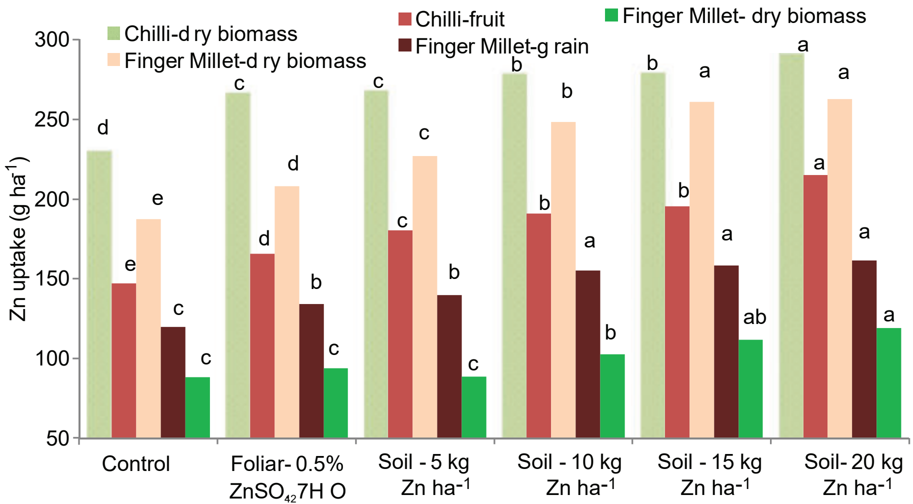

Fig. 4. Direct effect of Zn fertilization on Zn uptake of Chilli and residual effect of Zn fertilization on Zn uptake of finger millet and amaranthus

Direct and residual effect of zinc on zinc content and uptake: The increase in Zn concentration in dry plant biomass, fruit or grain observed due to increasing the level of application of Zn. The highest Zn content in plant was recorded in plants grown in 20 kg Zn applied soils. The Zn content in dry biomass varied from 30.7- 36.1 mg kg^{-1} (amaranthus), 51.1-56.5 mg kg^{-1} (finger millet) and 42.7-46.2 mg kg^{-1}(chilli), similarly in finger millet grain (45.7-48.6 mg kg^{-1}) and chilli fruit 36.1- 41.6 mg kg^{-1} (Fig. 3).

Increasing the doses of application of Zn had significantly increased the Zn uptake by the crops. From the control treatment, it was found that majority of the Zn was supplied from native soil Zn, but in the other treatments, external supply of Zn balanced the large quantity of Zn being mined and exported from the system. Soil application of Zn significantly improved the Zn concentration in plant tissues compared to control and foliar application. Further there were significant differences observed among the different levels of Zn application with respect to Zn concentration in plant tissues. Increasing the doses of Zn in soil recorded the increasing trend in Zn concentration in plant tissues. Foliar application of Zn did not significantly improved Zn concentration in plant tissues when compared to control. Total Zn uptake of the cropping system varied from 773-1050 g ha^{-1}. Foliar and soil application of Zn significantly improved the uptake than that of control (Fig. 4). Moreover, increasing trend in Zn uptake was observed in increasing the levels of Zn application. There was significant difference existed in Zn uptake between soil and foliar Zn application methods and also among different soil Zn application doses. Application of Zn enhanced the Zn availability in soil which was easily utilized by the crops (Raghav and Sharma, 2003; Wong *et al.*, 2019). Since, the nutrient uptake is a function of dry matter and nutrient content, application of Zn in soil increased dry matter yields of crops and enriched Zn content in plant tissues resulted in greater Zn uptake (Singh and Singh, 2017). Increasing the level of Zn had decresaed the yield improvement. This might be due to the existence of law of diminishing return relationship between Zn and yield. The similar results were reported by Singh and Singh (2017).

The application of 10 kg Zn per hectare demonstrated the most effective results in enhancing soil zinc availability and crop yield and zinc uptake when compared to other treatment levels. The results indicated that soil application demonstrated superior effectiveness compared to foliar spraying because it both improved soil zinc availability and plant tissue zinc concentration while increasing overall zinc uptake. Chilli, finger millet and amaranthus demonstrated better development with increased nutritional value and improved harvest output through improved zinc accessibility in the soil. The study highlights the need to establish proper zinc application levels which optimize production outcomes while maintaining sustainable nutrient practices.

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