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Effect of Traditional Sources of Zn and ZnO-Nano-Particles Foliar Application on Productivity and P-Uptake of Maize Plants Grown on Sandy and Clay Loam Soils

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APPLYING Zn as soil fertilizers might undergo precipitation in presence of phosphate fertilizers; alternatively, this nutrient may be amended through foliar application. Specifically, we hypothesized that the effect of Zn foliar application is quite enough to overcome Zn deficiency beside its synergetic effect on P uptake. To test this hypothesis, a field study was conducted in a split-plot design where Zn-sources, i.e. $ZnSO_4$, Zn-EDTA and ZnO-nano-particles (ZnO-NP) were plotted in main plots while their rates of application (0, 5, 10 and 15 mg L^{-1}) were schemed in sub-plots. Results obtained herein indicate that these three fertilizers not only improved significantly concentrations of both P and Zn in maize during V14-fouteenth leaf and physiological maturity growth stages but also increased significantly the available contents of these nutrients in soil, especially with increasing the level of foliar application. Moreover, these fertilizers improved significantly plant height during the above-mentioned growth stages and raised grain yield and 100-grain weight. The efficiency of these fertilizers could be arranged as follows: ZnO-NP> Zn-EDTA> $ZnSO_4$. In conclusion, Zn foliar application especially in the nano form recorded a synergic effect on P availability and uptake; consequently these applications increased maize production as just mentioned with superiority for ZnO-NP; however, further studies are needed to investigate the residual effects of these nano-particles within the edible plant parts.

Keywords: Zinc foliar application; Phosphorus; Maize productivity; Sandy soil; Clay loam soil

Introduction

Maize is one of the important crops in Egypt (Fahmi and Abbas, 2012; Farid et al., 2014; Elbeltagi et al., 2020). Its production covers approximately 55% of the local marker and the gap between production and consumption is compensated by importation (Noreldin et al., 2016). Thus, increasing maize production has become a national goal to meet the growing demands of human and animal needs (Abd El-Gawad and Morsy, 2017), probably through maintaining balanced nutritional inputs (Souri and Hatamian, 2019) and adopting unconventional procedures to enhance plant productivity (Ouda and Zohry, 2017).

Zinc is an important nutrient for all living organisms (Wieners et al., 2019). It is involved in many physiological functions within plants (Hassan et al., 2019 and Manaf et al., 2019); in spite of that Zn availability seemed to be relatively low (Elshony et al., 2019; Manaf et al., 2019; Pawlowski et al., 2019) especially in calcareous and sandy soils (Abbas, 2013 and Hafeez et al., 2013). Its deficiency may cause retardation of plant growth and development (Aman et al., 2020). Furthermore, Zn insufficient intake by human may cause hair and memory loss, skin problems and weakness in body muscles (Hafeez et al., 2013). Accordingly, there is a need to raise Zn level infood chain components.

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Soil and foliar applications of Zn fertilizers should be consideredto satisfy plant needs for this nutrient (Singh et al., 2019; Stewart et al., 2019; Zachary et al., 2019 and Akter et al., 2020). Appling Zn as soil fertilizers might undergo precipitation in presence of phosphate fertilizers (Abd El- Aziz et al., 2020); yet, lack of this nutrient may be amended through foliar application without being competed with other soil nutrients on uptake by plant. One of the common Zn-fertilizers is $ZnSO_4$ which is a highly soluble salt besides being low in price as compared to synthetic chelates and complexes (Gonzalez et al., 2007). Another choice is to use ZnO nano-particles, at relatively lower concentrations than $ZnSO_4$, to obtain positive results (da Cruz et al., 2019). In this concern, it was found that the effect of ZnO-NP exceeds that of $ZnSO_4$ on improving plant growth and physiology (Rossi et al., 2019). However, its level of application should be considered precisely. This is because ZnO nanoparticles adversely affect plant growth e.g.wheat growth was affected significantly with spraying plants with ZnO nanoparticles at rates of 25-50 mg Zn L^{-1} (Ebrahim and Aly, 2005). Also, the adverse effects of this foliar application appeared on chickpea at only10 mg Zn L^{-1} (Burman et al., 2013). Moreover, ZnO nanofertilizers have negative impacts on the surrounding ecosystem when used at relatively high rates (Ge et al., 2011). Probably, repeated foliar applications of ZnO nano-fertilizers, prepared at relatively low concentrations, can cause the desirable effects of these fertilizers on the grown plants without deteriorating the surrounding environment.

Zn chelates are the third selections of Zn-fertilizers (Montoya et al., 2018 and Zhao et al., 2020). These chelates should be applied at low rates to lessen the costs of Zn fertilizerson one hand and avoid further environmental pollution risks on the other hand (Demetrio et al., 2016; Abbas and Abdelhafez, 2013). It may also decrease the needed amounts of N-fertilizers for grown plants (Almendros et al., 2019).

The Zn-fertilizers do not only increase Zn uptake by plants but also interact with many other essential nutrients to increase their uptake by plants (Pawlowski et al., 2019). Moreover, Znmay induce resistance against pathogens and herbivores (Cabot et al., 2019 and Abdelhafez et al., 2021) and adverse the effects of drought (Ullah et al., 2019) through induction of proline, soluble sugars, and enzyme activities (Sharifi et al., 2020). Such conditions are probably dominant in sandy soils (Abbas et al., 2007; Mulcahy et al., 2013; Farid et al., 2014; Bassouny and Abbas, 2019).

Specifically, we hypothesized that the effect of the foliar application of Zn is synergetic for P because Zn is a structural nutrient in DNA replication and gene expression (Barman et al., 2018) while P is needed for DNA synthesis (McDonald et al., 2017). Accordingly, plants fed on Zn as foliar spray may stimulate more P carriers in plant roots to raise its content in plants. The current study investigated the direct and indirect impacts of spraying maize plants with different Zn fertilizers, i.e. $ZnSO_4$, Zn-EDTA and ZnO nano-particles (ZnO-NP) on P- uptake by plants and hence increases plant growth and productivity.

Materials and Methods

Materials of study

Two field experiments were conducted on a clay soil at the Agricultural Research Center, Giza (Latitude 29° 59′ 55.046″ N and longitude 31° 12″ 49.272″ E) and a sandy soil at El-Ismailia Station, Agric. Res. Center (Latitude 30° 35′ 41.901″ N and longitude32° 16′45.834″ E) during the summer season of 2018. Soil samples were collected from the investigated fields, air dried, and analyzed for their physical and chemical characteristics as outlined by Klute (1986) and Sparks et al. (1996), respectively. The obtained results are presented in Table 1.

Grains of maize (*Zea mays* variety three way cross TWC360) were obtained from Field Crops Research Institute, Giza (Egypt). Nano-Zn oxide (assay> 99.9%, nano-particles≈30nm) containing 70 % Zn and molecular weight= 81.38) was obtained from Sisco Research Laboratories Pvt. Ltd. (UN No.: 3077), Zn-EDTA (13% Zn) was obtained from El-Gomhoria Company and $ZnSO_4.7H_2O$ (24% Zn) was obtained from El-Gomhoria Company. Stock solutions (1000 mg Zn L^{-1}) were then prepared from each of these chemicals to be used later for preparation of different Zn concentrations.

Experimental design

The experimental work was carried out in a split plot design with three replicates where Zn fertilizers (nano ZnO (NP), Zn EDTA and $ZnSO_4$) were applied in the main plots whereas their different rates of application (0, 5, 10 and 15 mg Zn L^{-1}) were schemed in the sub-plots. The area of each soil plot was 10.5 m^2 (3.0 m x 3.5 m).

TABLE 1. Particle size distribution and soil chemical characteristics

Soil characteristic	Giza	El-Ismailia
Particle size distribution%		
Coarse sand	1.45	62.70
Fine sand	24.82	29.68
Silt	34.25	3.40
Clay	39.48	4.22
Soil texture (USDA)	Clay loam	Sand
Chemical characteristics		
pH *	7.88	7.58
EC_e** (dS m^{-1})	1.96	0.92
$CaCO_3$content, g kg^{-1}	16 .3	2 .8
Organic matter, g kg^{-1}	5.8	2.8
Soil bulk density, Mg m^{-3}	1.32	1.64
Available-P, mg kg^{-1}	3.67	2.32
Available-Zn, mg kg^{-1}	0.56	0.20

pH* was determined in 1:2.5 soil: water suspension, while EC** was determined in soil paste extract. Available P and Zn were extracted by AB-DTPA

Seeds of maize were then sown on the 5th of May in the clay loam soil and on the 15th of May in the sandy one. All plots, containing the clayey loam soil, received 480 kg super phosphate (6.7% P) per hectare during soil preparation while those contained the sandy soil received 600 kg per hectare. Ammonium sulphate (15.5 % N) was applied at a rate of 300 kg N ha^{-1} in three equal doses, i.e. 20, 40 and 60 days after planting. Potassium sulphate (40% K) was applied at a rate of 120 kg K ha^{-1} after 60 days from planting. In case of Zn-fertilizers, maize plants were sprayed four times at 10, 20, 40 and 60 days after planting at a rate of approximately one m^3 per hectare (equivalent to 400 L per feddan). After 75 days of planting (V14 growth stage), plant heights were estimated. At the physiological maturity stage, all plants were harvested from both soils to determine the following growth characters: (1) plant height, (2) grain yield per ha (kg ha^{-1}) and (3) 100-grain weight (g).

Soil and plant analyses

Soils (0 – 30 cm) were sampled from the rhizosphere of all plots at 45 (V10-tenth leaf) and 70 (V14-fourteenth leaf) days after planting (DAP)as well as the physiological maturity stage. These samples were air dried, crushed and sieved through a 2 mm sieve then analyzed for their available contents of P and Zn after being extracted by AB-DTPA according to Soltanpour (1985); afterwards' determined using Atomic Absorption Spectrophotometer (Analytikjena Nova 350).

The collected maize samples were dried at 70 ^{o}C, ground in a Willy Mill and digested with H_2SO_4 - H_2O_2 according to Parkinson and Allen (1975). Afterwards, P and Zn were determined in plant digests using Atomic Absorption Spectrophotometer.

Statistical analysis

The obtained data were statistically analyzed using SPSS program according to the analyses of variance (ANOVA) and LSD test at 0.05 probability level to compare the significance of differences among treatments.

Results

Zn-fertilizers and plant growth parameters

Spraying plants with Zn-fertilizers improved significantly plant height during the two studied growth stages, i.e. V14-fourtheenth leaf and physiological maturity (Table 2). Such increases were more noticeable with increasing the concentrations of Zn foliar application. Also, Zn spray raised significantly maize grain yield and 100- grain weight (obtained at the physiological maturity stage) when it was used at rates up to 10 Zn mg L^{-1}; afterwards, no significant increases occurred in yield and yield component, except for the weight of 100 grain (collected from the sandy soil).

TABLE 2. Grand means of the effects of Zn-foliar applications on plant height (during V14-fourteenth leaf and physiological maturity), grain yield and 100 grain weight of maize plants

	Plant height at V14, cm		Plant height at harvest, cm		Grain yield Mg ha^{-1}		Weight of 100 grain, g	
	Clay loam soil	Sandy soil	Clay loam soil	Sandy soil	Clay loam soil	Sandy soil	Clay loam soil	Sandy soil
Zinc source								
ZnO (Nano)	87.50^{a}	73.50^{a}	188.0^{a}	171.17^{a}	9.86^{a}	8.65^{a}	35.53^{a}	31.38a
Zn SO_4	83.33^{b}	68.83^{b}	182.17^{c}	167.75^{b}	9.67^{a}	8.35^{b}	34.63^{a}	29.95a
Zn- EDTA	85.58^{ab}	70.50^{b}	185.50^{b}	171.17^{a}	9.78^{a}	8.54^{ab}	34.96^{a}	30.54a
Zinc applied rates mg L^{-1}								
Control	77.00^{d}	64.00^{d}	172.0^{d}	165.00^{c}	9.23^{b}	7.69^{c}	30.93^{c}	25.80^{c}
5 mg L^{-1}	82.78^{c}	69.33^{c}	185.33^{c}	168.00^{b}	9.50^{b}	7.74^{b}	34.45^{b}	28.10^{c}
10 mg L^{-1}	88.78^{b}	73.44^{b}	189.33^{b}	172.33^{a}	10.02^{a}	8.81^{a}	36.31^{ab}	31.74^{b}
15 mg L^{-1}	93.33^{a}	77.00^{a}	194.22^{a}	173.56^{a}	10.34^{a}	9.82^{a}	38.48^{a}	36.85^{a}

Similar letters within columns indicate no significant variations among treatments.

On the other hand, the effects of different Zn-sources were detectable on plant heights (during the abovementioned growth stages) as well as the grain yield obtained from the sandy soil (Fig 1). These effects could be arranged,according to the capability of Zn source to improve growth and grains yield of maize, as follows: nano ZnO (NP) > Zn EDTA > $ZnSO_4$. In case of maize grain yield (obtained from the clay loam soil) and 100 seed weight, results obtained herein indicate no significant variations among the different Zn-sources.

Effect of spraying plants with Zn-fertilizers on P and Zn availability in soil

The effect of Zn source and rate on availability of P: Figure 2 and Table 3 show that the availability of P increased significantly with application of Zn fertilizers in the two soils under investigation during the different plant growth periods, i.e. V10-tenth leaf, V14-fourteenth leaf and physiological maturity stage. Such increases were more detectable with increasing the rate of Zn foliar application. Generally, the clay loam soil of El-Giza exhibited higher available P-contents than the sandy soil of El-Ismailia and the increase that occurred in available-P contents could be arranged as follows: Nano ZnO (NP) > Zn EDTA > ZnSO4 > control. It seems that Zn-availability increased in soil up to the end of the vegetative growth stage; thereafter this content decreased markedly during the reproductive growth and recorded relatively low contents at the physiological maturity stage.

The effect of Zn sources and rates on Zn-availability in soil: Figure 3 and Table 4 reveals that Zn availability increased significantly in both soils of study owing to application of Zn-fertilizers, especially with increasing the rate of application. Also, significant variations occurred in both soils of study owing to the source of Zn spray, where ZnO-NP and Zn-EDTA recorded higher increases in Zn-availability as compared to $ZnSO_4$ (except for Zn-EDTA in the sandy soil which recorded comparable Zn-availability values with $ZnSO_4$ treatments). Generally, Zn-available contents decreased in soil with increasing the growth stage of plants.

The effect of Zn source and rate on P and Zn-contents within plant shoots and grains

Effect of Zn source and rate on P-content in plants: Foliar application of Zn-fertilizers raised significantly P-content in maize shoot during V14 and physiological maturity growth stages. Also, P-content in grains increased significantly owing to these foliar applications, especially with increasing the concentration of Zn in the applied spray (Table 6). Nano Zn-particles recorded the highest increases in P-content in maize grains,but not in shoots, during the two studied stages of plant growth, followed by Zn-EDTA then $ZnSO_4$. On the other hand, the source of Zn foliar spray was of no significant effect on P-content in shoots during bothV14 or physiological maturity growth stages.Considerable amounts of P transferred from plant shoots to grains during the reproductive growth; consequently, this content decreased in plant shoots at the physiological maturity stage while recorded relatively higher values in grains.

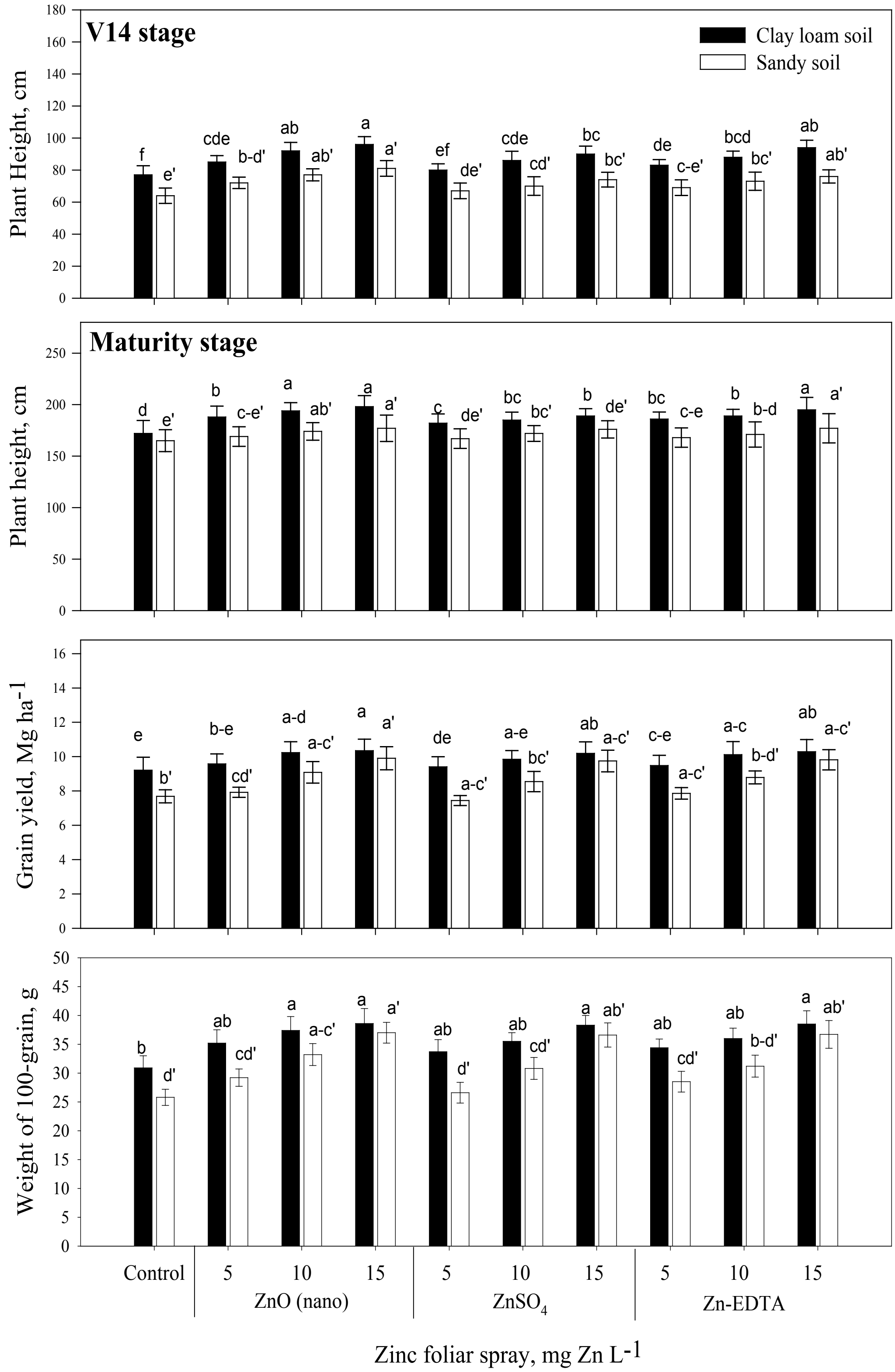

Fig. 1. Plant height (during V14-fourteenth leaf and physiological maturity), grain yield and 100 grain weight of maize plants as affected by application of different Zn-fertilizers. Similar letters indicate no significant variations among treatments

TABLE 3. Grand means of the effects of different zinc sources (S), applied at different rates (R), on available P-content in soil

	Clay loam soil			Sandy soil		
	V10-tenth leaf	V14-fourteenth leaf	Physiological maturity stage	V10-tenth leaf	V14-fourteenth leaf	Physiological maturity stage
Zinc Source						
ZnO (Nano)	12.83[a]	14.40[a]	11.85[a]	5.55[a]	6.31[a]	4.20[a]
Zn SO_4	12.13[b]	14.14[b]	11.31[c]	3.69[c]	4.34[c]	2.18[c]
Zn- EDTA	12.34[ab]	14.43[a]	11.52[b]	4.98[b]	5.53[b]	3.175[b]
Zinc applied rate mg L^{-1} (R)						
Control	12.20[a]	14.03[c]	10.38[d]	2.08[d]	2.42[d]	1.82[d]
5 mg L^{-1}	12.25[a]	14.22[b]	11.60[c]	4.86[c]	5.21[c]	2.76[c]
10 mg L^{-1}	12.49[a]	14.28[b]	11.97[b]	5.55[b]	6.28[b]	3.78[b]
15 mg L^{-1}	12.78[a]	14.75[a]	12.29[a]	6.46[a]	7.67[a]	4.36[a]

Similar letters within columns indicate no significant variations among treatments.

TABLE 4. Grand means of the effects of different zinc sources (S), applied at different rates (R), on available Zn-content in soil

	Clay loam soil			Sandy soil		
	V10-tenth leaf	V14-fourteenth leaf	Physiological maturity stage	V10-tenth leaf	V14-fourteenth leaf	Physiological maturity stage
Zinc Source						
ZnO (Nano)	0.69[a]	0.64[a]	0.49[a]	0.29[a]	0.243[ab]	0.16[a]
Zn SO_4	0.65[b]	0.60[b]	0.39[c]	0.26[b]	0.225[b]	0.12[b]
Zn- EDTA	0.66[b]	0.58[c]	0.43[b]	0.28[b]	0.233[a]	0.15[a]
Zinc applied rate mg L^{-1} (R)						
Control	0.61[d]	0.59[d]	0.32[d]	0.24[c]	0.20[c]	0.12[c]
5 mg L^{-1}	0.66[c]	0.60[c]	0.42[c]	0.27[b]	0.23[b]	0.13[bc]
10 mg L^{-1}	0.69[b]	0.62[b]	0.47[b]	0.29[ab]	0.24[b]	0.14[b]
15 mg L^{-1}	0.72a	0.66[a]	0.53[a]	0.31[a]	0.26[a]	0.17[a]

Similar letters within columns indicate no significant variations among treatments.

Effect of Zn source and rate on Zn-content in plants

Application of Zn-fertilizers raised significantly Zn content within plant shoots (during the two investigated growth stages) as well as Zn content in grains (after plant harvest) (Table 6). Such increases were almost higher with increasing the level of Zn-application. In this concern, the effect of the different Zn-sources on Zn content in plant shoot could be arranged as follows: ZnO-NP>Zn-EDTA>$ZnSO_4$. Generally, Zn-content decreased noticeably in plant shoot from V14-fourteenth leaf up to the physiological maturity stage.

Discussion

Effect of Zn applications on Zn and P availability in soil and their uptake by maize plants

Application of the investigated Zn fertilizers raised significantly Zn content in maize shoots and grains, especially with increasing the rate of Zn application. Likewise, the used fertilizers raised significantly Zn availability in soil. This is because these fertilizers increased significantly the growth of plant roots and their exudates. These exudates could raise significantly Zn availability and uptake by plants (Gupta et al., 2016). Also, root exudates might increase P availability in soil (Dakora and Phillips, 2002; Yang et al., 2018).

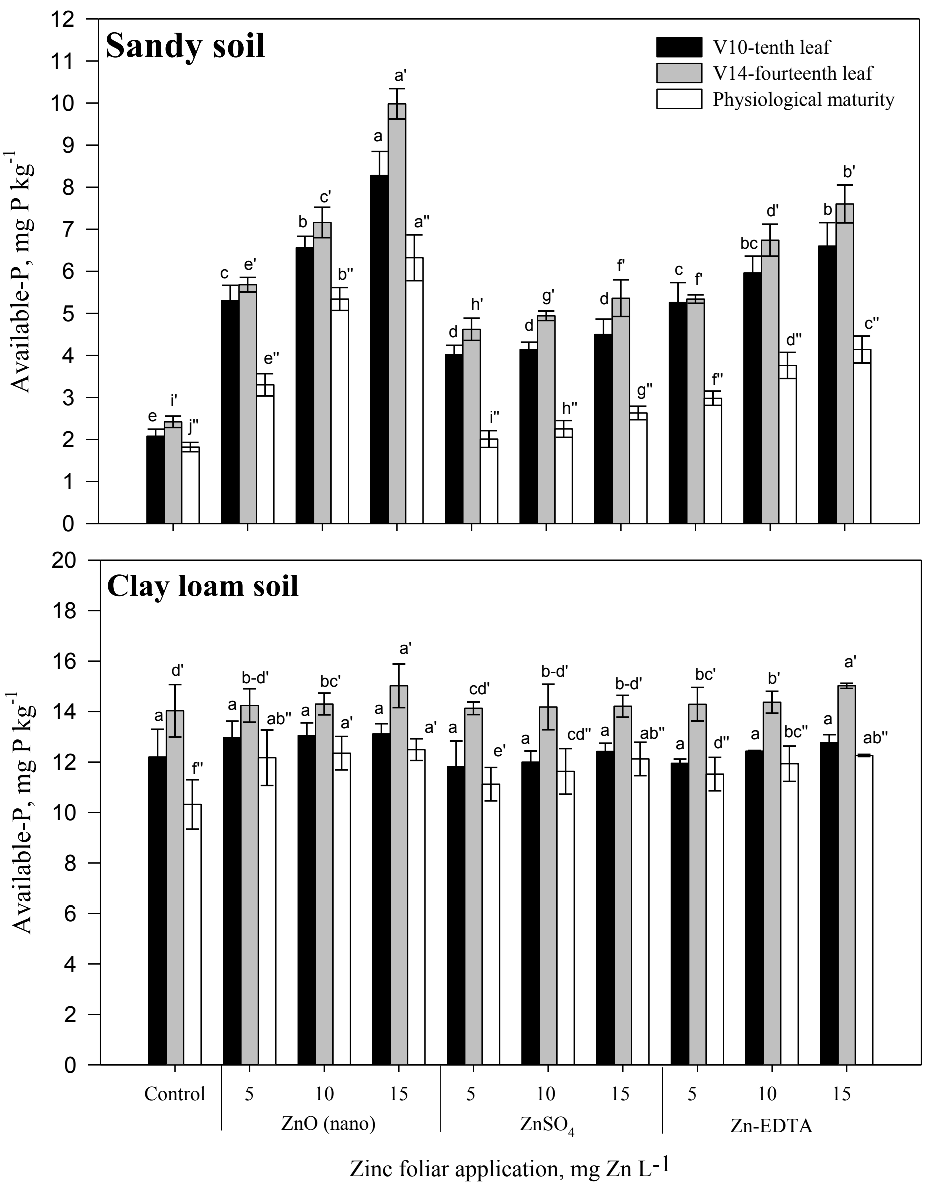

Fig. 2. Effect of different zinc sources (S), applied at different rates (R), on available P-content in soil during the different stages of maize growth. Similar letters indicate no significant variations among treatments

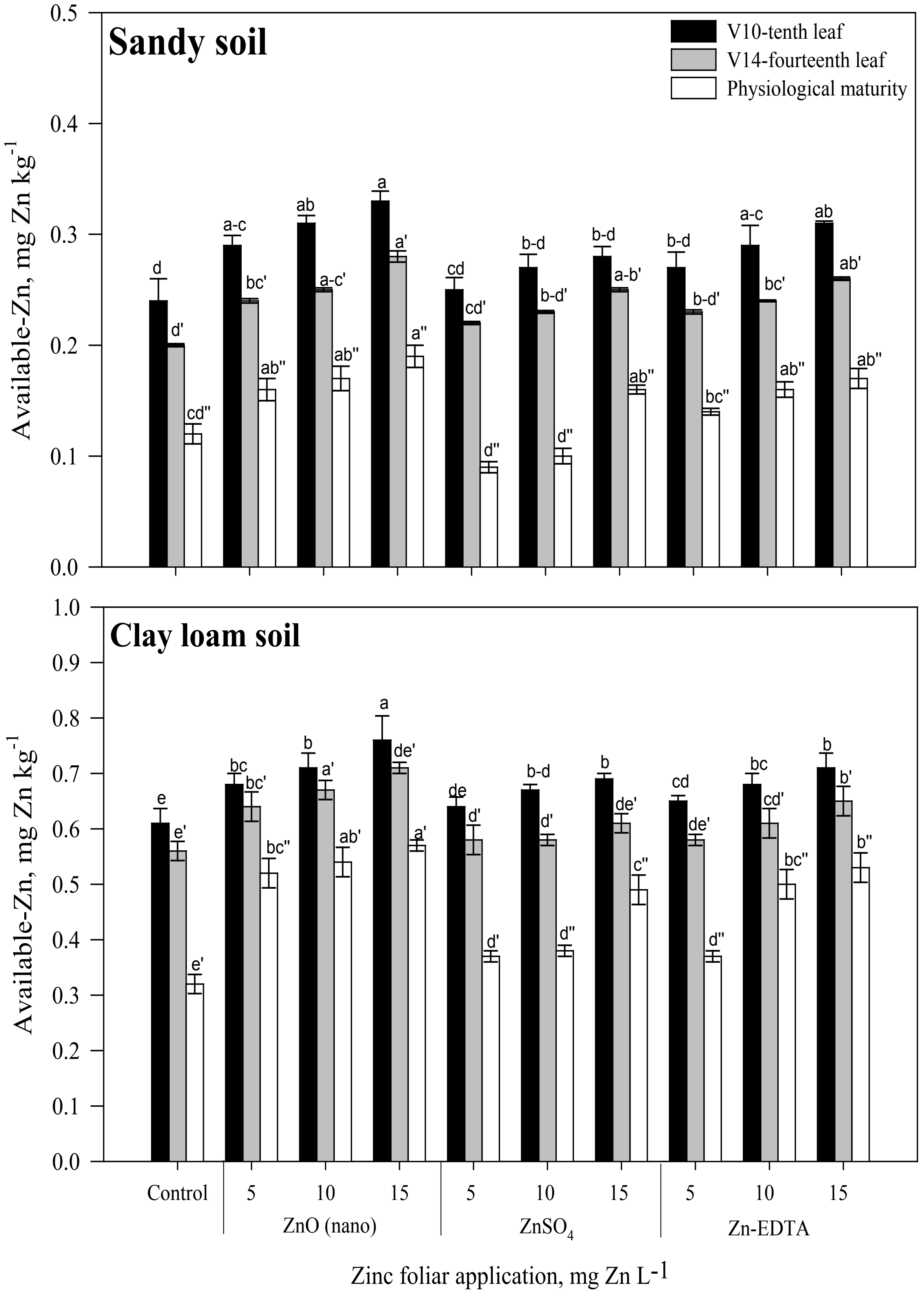

Fig. 3. Effect of different zinc sources (S) applied at different rates (T) on Zn-availability in soils. Similar letters within columns indicate no significant variations among treatments

TABLE 5. Effect of different zinc sources (S) applied at different rates (T) on P-content in plants (g P kg^{-1})

Zinc Source (S)	Rate mg L^{-1} (R)	Clay loam soil			Sandy soil		
			Plant harvest stage			Plant harvest stage	
		Shoot at V14	shoot	grain	Shoot at V14	shoot	grain
ZnO (Nano)	Control	2.21±0.23^{a}	1.91±0.17^{a}	2.43±0.21^{8f}	1.68±0.19^{d}	1.42±0.17^{a}	2.03±0.13^{f}
	5 mg L^{-1}	2.53±0.11^{a}	2020.12±^{a}	3.24±0.23^{de}	1.74±0.23^{b}	1.58±0.21^{a}	2.43±0.11^{de}
	10 mg L^{-1}	2.81±0.15^{a}	2.12±0.22^{a}	3.86±0.34^{bc}	1.77±0.25^{ab}	1.70±0.13^{a}	3.12±0.15^{b}
	15 mg L^{-1}	3.04±1.92^{a}	2.19±0.20^{a}	4.46±0.20^{a}	1.79±0.23^{a}	1.73±0.15^{a}	3.46±0.25^{a}
	Mean	2.65A	2.06A	3.50A	1.75A	1.60.65A	2.76A
Zn SO_4	Control	2.21±0.23^{a}	191±17.1^{a}	2.43±0.21^{f}	1.68±0.19^{d}	1.42±0.17^{a}	2.03±0.13^{f}
	5 mg L^{-1}	2.39±0.25^{a}	1.960.21±^{a}	2.72±0.26^{f}	1.71±0.20^{c}	1.48±0.15^{a}	2.26±0.11^{ef}
	10 mg L^{-1}	2.49±0.12^{a}	2.000.18±^{a}	3.35±0.37^{d}	1.73±0.27^{c}	1.58±0.22^{a}	2.55±0.13^{cd}
	15 mg L^{-1}	2.67±0.18^{a}	2.060.19±^{a}	3.83±0.11^{bc}	1.74±0.26^{bc}	1.65±0.21^{a}	2.72±0.21^{c}
	Mean	2.44A	1.98A	3.08B	1.72A	1.53A	2.39B
Zn- EDTA	Control	2.21±0.23^{a}	1.91±0.17^{a}	2.43±0.21^{f}	1.68±0.19^{d}	1.42±0.17^{a}	2.03±0.13^{f}
	5 mg L^{-1}	2.49±0.10^{a}	1.910.29±^{a}	2.86±0.09^{ef}	1.73±0.27^{c}	1.56±0.22^{a}	2.37±0.11^{de}
	10 mg L^{-1}	2.69±0.21^{a}	2.02±0.27^{a}	3.59±0.17^{cd}	1.74±0.22^{bc}	1.69±0.15^{a}	2.60±0.16^{cd}
	15 mg L^{-1}	2.73±0.16^{a}	2.100.23±^{a}	4.12±0.21^{ab}	1.76±0.17^{b}	1.71±0.16^{a}	2.81±0.14^{c}
	Mean	2.53A	2.00A	324.94B	1.73A	1.60A	2.46B
Grand means of applied Zn-rates	Control	2.21^{c}	1.91^{c}	2.43^{d}	1.68^{c}	1.42^{b}	2.03^{d}
	5 mg L^{-1}	2.47^{bc}	1.99^{b}	2.94^{c}	1.73^{b}	1.54^{ab}	2.35^{c}
	10 mg L^{-1}	2.66^{b}	2.05^{a}	3.60^{b}	1.75^{ab}	1.65^{a}	2.76^{b}
	15 mg L^{-1}	2.81^{a}	2.15^{a}	4.13^{a}	1.76^{a}	1.69^{a}	3.00^{a}

Similar letters within columns indicate no significant variations among treatments.

TABLE 6. Effect of zinc source applied at different rates on Zn content in shoots and grains (mg Zn kg^{-1}).

Zinc Source (S)	**Rates mg L^{-1} (R)**	**Clay loam soil**			**Sandy soil**		
			Plant harvest stage			**Plant harvest stage**	
		Shoot at V14	**shoot**	**Grain**	**Shoot at V14**	**shoot**	**Grain**
ZnO (Nano)	Control	26.50±1.15^{e}	23.33±0.85^{f}	26.30±0.94^{d}	23.45±1.34^{g}	15.56±0.37^{g}	17.41±1.40^{d}
	5 mg L^{-1}	28.75±1.53^{bc}	25.19±1.7^{c-e}	27.78±1.28^{b-c}	25.52±1.04^{ef}	20.37±0.92^{cd}	19.26±0.8^{c}
	10 mg L^{-1}	29.75±1.03^{ab}	26.67±1.3^{a-c}	28.89±1.30^{ab}	27.24±0.93^{bc}	21.85±0.83^{ab}	21.48±1.8^{b}
	15 mg L^{-1}	30.50±2.2^{a}	28.15±0.93^{a}	29.63±1.08^{a}	29.31±0.97^{a}	22.96±0.95^{ab}	23.70±0.90^{a}
	Mean	28.88A	25.83A	28.15A	26.38A	20.19A	20.46A
Zn SO_4	Control	26.50±1.15^{e}	23.33±0.85^{f}	26.30±0.94^{d}	23.45±1.34^{g}	15.56±0.37^{g}	17.41±1.40^{d}
	5 mg L^{-1}	27.50±1.58^{de}	24.07±1.16^{ef}	26.67±1.80^{cd}	24.48±0.63f^{g}	17.41±0.53^{f}	18.15±0.35^{cd}
	10 mg L^{-1}	28.00±1.27^{cd}	25.19±0.98^{c-e}	27.78±1.90^{b-d}	25.86±0.78^{de}	18.15±0.47^{ef}	19.26±0.68^{c}
	15 mg L^{-1}	28.50±1.28^{cd}	26.30±0.76^{b-d}	28.15±1.01^{a-c}	26.90±1.50^{cd}	19.26±0.68^{de}	19.63±0.85^{c}
	Mean	27.63B	24.72B	27.22B	25.17B	17.59C	18.61B
Zn- EDTA	Control	26.50±1.15^{e}	23.33±0.85^{f}	26.30±0.94^{d}	23.45±1.34^{g}	15.56±0.37^{g}	17.41±1.40^{d}
	5 mg L^{-1}	28.00±0.95^{cd}	24.81±0.8^{d-f}	27.41±0.76^{b-d}	25.17±1.8^{ef}	18.89±0.62^{e}	18.52±1.61^{cd}
	10 mg L^{-1}	29.00±0.90^{bc}	25.56±1.9^{b-e}	28.15±1.75^{a-c}	26.21±1.2^{c-e}	20.74±1.2^{bc}	21.11±0.60^{b}
	15 mg L^{-1}	29.75±0.93^{ab}	27.04±1.05^{ab}	28.89±1.82^{ab}	28.28±1.7^{ab}	22.96±0.55^{a}	22.22±0.83^{b}
	Mean	28.31C	25.19AB	27.69AB	25.78BC	19.54B	19.81A
Grand means of applied Zn-rates	Control	26.50^{d}	23.33^{d}	26.30^{c}	23.45^{d}	15.56^{d}	17.41^{d}
	5 mg L^{-1}	28.08^{c}	24.70^{c}	27.30^{b}	25.06^{c}	18.89^{c}	18.63^{c}
	10 mg L^{-1}	28.95^{b}	25.81^{b}	28.26^{a}	26.44^{b}	20.26^{b}	20.63^{b}
	15 mg L^{-1}	29.60^{a}	27.15^{a}	28.89^{a}	28.16^{a}	21.74^{a}	21.74^{a}

Similar letters within columns indicate no significant variations among treatments.

Increasing the concentration of Zn- foliar application led to concurrent significant increases in P-content within maize shoots and grains. This is because Zn stimulated P transporters (Khan et al., 2014) and increased the active loading of Zn^{2+} (metal cations) to apoplastic xylem (Sondergaard et al., 2004). Such a synergy effect did not contradict with the antagonistic effect of P on Zn uptake as found by Watts-Williams et al. (2014). In soil, inorganic phosphate (P_i) interacts with Zn forming $Zn_3(PO4)_2$ (Gupta et al., 2016; Ayeni et al., 2018; Gupta et al., 2020) and/or reaction crystallization (Hutnik et al., 2016), while in plants P-fertilizer induces Zn deficiency symptoms in plants owing to the dilution effect resulted from the induction of plant growth by P fertilizers (Santos et al., 2019). The above results confirm the assumption of the study which indicates that plants fed on Zn as foliar spray increase significantly P-contents within their tissues.The efficiency of Zn- fertilizers could be arranged as follows: ZnO-NP> Zn-EDTA> $ZnSO_4$. Generally, nano-fertilizers are efficient fertilizers to satisfy plant needs for nutirnets (Abdalla et al., 2018; El-Ghamry et al., 2018; Omara et al., 2019; Shams and Abbas, 2019; El-Ramady et al., 2020). Although, P-content within maize shoots varied slightly; however, insignificantly owing to the application of different Zn-sources. On the other hand, these sources affected significantly Zn content in maize grains. Also, their impacts on maize growth and yield were noticeable as will be mentioned hereafter.

Effect of Zn applications on maize growth and yield

Application of Zn fertilizers increased significantly plant growth with superiority for ZnO-NF over the other two Zn-fertilizers (Zn-EDTA and $ZnSO_4$), especially in the poor fertile sandy soil. Also, the effects of Zn-EDTA on grain yield exceeded the corresponding ones of $ZnSO_4$ in the sandy soil under investigation. The positive effects of nano-zinc oxide on plant growth were also reported on *Rosmarinus officinalis* (Mohsenzadeh and Moosavian, 2017), pomegranate (*Punica granatum* cv. Ardestani) (Davarpanah et al., 2016), soy bean (Hashemi et al., 2016), rice (Moazam et al., 2017). On the other hand, high levels of ZnO-NP might be toxic to plants (Mohsenzadeh and Moosavian, 2017) and the surrounding ecology (Rajput et al., 2018). However, it may be safely handled for production of crops for Bioenergy Industry (Ullah et al., 2020). In case of Zn-EDTA, its foliar application increased significantly wheat productivity (Doolette et al., 2018), rice (Anusuya et al., 2019); yet, this salt decreased rice grain yield (Wang et al., 2020). A point to note is that unmanaged spray of EDTA-salts may also have negative impacts on the environment as it may increase the availability of potentially toxic elements found in soil possessing a potential threat to the surroundings (Abbas and Abdelhafez, 2014).

Conclusion

The investigated Zn-fertilizers i.e. ZnO-NP, Zn-EDTA and ZnSO4 recorded significant increases in maize productivity with more obvious effect of ZnO-NP; however, further studies are needed to investigate the residual effects of these nano-particles in edible plant parts on man and animal .

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