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Full Length Article

Efficiency of Zinc and Phosphorus Applied to Open-pollinated and Hybrid Cultivars of Maize

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Abstract

Improving efficiency of applied nutrients is important to produce optimum crop yields with reduced fertilizer inputs. Phosphorous (P) has antagonistic effect on zinc (Zn) uptake by plants and information on the efficiency of these each nutrients in maize cultivars are limited. This study evaluated the response of different levels of Zn (0, 9 mg kg^{-1} soil) and P (0, 40 mg kg^{-1} soil) on growth, nutrient uptake and their utilization efficiency in four maize cultivars differing in their growth behavior (DK–6142, P1543, Neelam and Afghoi) when grown under natural greenhouse conditions. Maize cultivars significantly differed for above given traits and among treatments, combined Zn+P application increased dry matter, nutrient uptake and their efficiency as compared with control. Agronomic, physiological and recovery efficiency of P increased in Neelam, Afghoi and DK–6142 cultivars with Zn applied and vice versa. Afghoi and DK–6142 cultivars were more responsive for agronomic, physiological and apparent Zn and P recovery efficiency than other ones. For P1543 cultivar, Zn and P physiological efficiency decreased while recovery efficiency increased, respectively with combined application of both nutrients. However, for each of the nutrients utilization efficiency, none of these were related to open pollinated or hybrid maize cultivars and rather dependent on genetic makeup for internal higher utilization efficiency. Overall, nutrient efficiency of applied Zn or P are interdependent on each other and maize cultivars had a differential response to their applications.

Keywords: Maize hybrids; Open-pollinated; Phosphorus; Nutrient efficiencies; Zinc

Introduction

Zinc (Zn) and phosphorous (P) are important nutrients for growth of plants and often deficient in calcareous and high pH soils (Gianquinto *et al.,* 2000; Imran *et al.,* 2015; 2016). Soil deficiency of the one nutrient can regulate plant status of the other, as excessive Zn application to soil has been shown to decrease P concentration in plants (Soltangheisi *et al.,* 2013). Under soil Zn deficiency, uptake of P by roots and its accumulation in leaves increases (Cakmak *et al.,* 1986; Huang *et al.,* 2000; Khan *et al.,* 2014). On other hand, excessive application of P fertilizers to soil decreases plant available Zn (Lambert *et al.,* 2007; Zorrig *et al.,* 2010). Zinc and P fertilization has negative interaction for each other with respect to their concentration and uptake by maize plants and individual application of each to soil improves their uptake and concentration. However, P application when combined with Zn increases Zn concentration in plants that might be due to dilution effect of increased shoot growth rather than reduced Zn uptake by roots (Singh *et al.,* 1988). On other hand, some evidences support that interaction of P and Zn occurs within plants and not in soils (Cakmak *et al.,* 1986; Khan *et al.,* 2015).

Maize is an exhaustive crop which requires high P and also sensitive to Zn deficiency (Sattar *et al.,* 2011; Imran and Rehim, 2016). Breeding for nutrient efficient cultivars of maize can be a best approach to manage deficiencies of Zn and P. However, this will require avoiding speculated antagonistic interaction between P and Zn especially for calcareous soils where both P and Zn are widely deficient and recommended for optimum crop growth (Maqsood *et al.,* 2015).

Maize genotypes differ in uptake and efficiency of applied nutrients (Hussain *et al.,* 2012). Nutrient efficiency of crop plants depends on their performance in soils of low nutrient status. The efficiency of a certain nutrient for genotype depends on its higher uptake from a deficient soil, better translocation to aerial parts and better utilization of absorbed nutrients within plant body (Clark, 1990). For example, P–efficient crop cultivars are designed to grow in soils deficient with P and Zn in many cases; hence, interaction between P and Zn uptake efficiency become important when P supply may affect the expression of uptake efficiency of Zn in crop plants (Zhu *et al.,* 2001).

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Hence, it is essential to measure the influence of soil P bioavailability on Zn utilization efficiency in different maize cultivars. Further, improving fertilizer use efficiency by maintaining an appropriate level of each nutrient is of primary importance from economic perspective and for sustainable agriculture (Welch and Graham, 2005). Therefore, P–Zn interaction in maize for improving nutrient utilization efficiency needs particular attention. The present study has been therefore planned with the objectives to study the dependence of nutrient utilization efficiency of applied P and Zn on each other in maize cultivars contrasting in their growth behavior.

Materials and Methods

Soil Physico-chemical Analysis

Bulk soil samples (0–15 cm depth) were collected from Agricultural Research Farm of Bahauddin Zakariya University, Multan. Collected soil was sun dried, thoroughly mixed and crushed to pass through a 2 mm sieve. A subsample of the soil was analyzed for physico-chemical characteristics by following standard methods. Hydrometer method was used for the determination of soil textural class (Gee and Bauder, 1986). Soil EC and pH was measured in 1:1 soil to water suspension. Organic matter (OM) and free lime content ($CaCO_3$) was determined by Walkley-Black (Nelson and Sommer, 1982) and acid dissolution methods (Allison and Moodie, 1965). Zinc was extracted with AB-DTPA (Soltanpour, 1985) and its concentration in the extract was estimated on an atomic absorption spectrophotometer (Perkin Elmer, AAnalyst 100, Waltham, USA). Soil was extracted with sodium bicarbonate (Olsen and Sommers, 1982) and plant available P in soil was determined on spectrophotometer (Biotechnology Medical Services, UV-1602, BMS, Canada).

Experimental Details

Five (5) kg of thoroughly mixed soil was filled each in 48 polyethylene lined plastic pots. Two Zn levels (0 or 9 mg Zn kg^{-1} soil as $ZnSO_4.7H_2O$) and two P rates (0 or 40 mg P kg^{-1} soil as KH_2PO_4) were applied in all possible combinations to four cultivars of maize (open pollinated cultivars Neelam and Afghoi, and hybrid cultivars DK–6142 and P1543). Basal rates of 60 mg N kg^{-1} and 60 mg K kg^{-1} to soil were added respectively as urea and potassium sulphate. Before sowing, soil in all the pots was moistened with distilled water, dried and thoroughly mixed for equilibration. The pots were arranged according to a two factorial completely randomized design in a glasshouse (Steel *et al.*, 1997).

Five seeds of each maize cultivar were sown per pot. Ten days after germination, three plants were maintained in each pot. Distilled water was used to maintain moisture contents at field capacity in all the pots during the experimental period. Two weeks after sowing, a second dose of 30 mg N kg^{-1} soil as urea was applied uniformly to each pot. For plant roots and shoots, seedlings were harvested 30 days after sowing, washed with distilled water and blotted dry with tissue papers. The plant samples were oven dried at 70°C to a constant weight for dry matter yield. Finely ground plant samples were digested in di-acid mixture (2:1 ratio of HNO_3:$HClO_4$). An atomic absorption spectrophotometer was used to measure Zn concentration in the digest. Phosphorous in the digested material was analyzed by metavanadate yellow color method (Chapman and Pratt, 1961). Shoot P and Zn contents were calculated as: Nutrient content (mg pot^{-1}) = shoot dry matter (SDM, g pot^{-1}) × shoot nutrient concentration (mg g^{-1}).

Phosphorus and Zn Utilization Efficiency

Phosphorous and Zn utilization efficiency was calculated as (Siddique and Glass, 1981):

$$\textit{P Utilization Efficiency}\ (g^2\ SDM\ mg^{-1}\ shoot\ P) = \frac{SDM\ (g\ pot^{-1})}{Shoot\ P\ nutrient\ concentration\ (mg\ g^{-1})} \quad \text{(Equation i)}$$

$$\textit{Zn Utilization Efficiency}\ (g^2\ SDM\ mg^{-1}\ shoot\ Zn) = \frac{SDM\ (g\ pot^{-1})}{Shoot\ Zn\ nutrient\ concentration\ (mg\ g^{-1})} \quad \text{(Equation ii)}$$

Agronomic, physiological and recovery efficiencies were calculated as (Gerloff and Gabelman, 1983):

$$\textit{Agronomic Efficiency}\ (g\ g^{-1}) = \frac{SDM\ of\ fertilized\ crop - SDM\ of\ unfertilized\ crop}{Quantity\ of\ fertilizer\ applied} \quad \text{(Equation iii)}$$

$$\textit{Physiological Efficiency}\ (g\ g^{-1}) = \frac{SDM\ of\ fertilized\ crop - SDM\ of\ unfertilized\ crop}{Nutrient\ uptake\ of\ fertilized\ crop - Nutr.\ uptake\ of\ unfertilized\ crop} \quad \text{(Equation iv)}$$

$$\textit{Apparent Recovery Efficiency}\ (\%) = \frac{Nutrient\ uptake\ of\ fertilized\ crop - Nutrient\ uptake\ of\ unfertilized\ crop}{Quantity\ of\ fertilizer\ applied} \times 100 \quad \text{(Equation v)}$$

Statistical Analysis

Analysis of variance (ANOVA) was based on two factorial completely randomized design. Least Significant Difference (LSD) test was used to compare various significantly treatments mean (Steel *et al.,* 1997). Computer based software; *Statistix 9*® was used for statistical analysis.

Results

Effects on Plant Growth

There was significant effect of Zn or P treatments, cultivars and their interaction on shoot fresh and dry matter yield of maize (Table 2). Shoot fresh and dry matter of three cultivars (Afghoi, P1543 and Neelam) was highest for combined Zn and P treatment followed by individual application. However, maximum shoot fresh and dry matter in DK–6142 was recorded for individual P treatment followed by Zn+P treatment (Table 2). Root fresh weight of Afghoi and Neelam was highest for combined Zn+P treatment followed by individual applied P. However, P1543 produced maximum shoot fresh and dry weights by individual applied Zn. Apart from this, root dry weight was highest in all the four cultivars with combined Zn+P followed by individual P treatment.

Nutrients Concentration in Plant Tissues

Zn and P concentrations in shoot and root tissues varied with genotype, nutrient and their interactions (Table 3). In interactive effects, Zn concentration in shoots and roots ranged from 29.8 to 16.9 μg g^{-1} and 30.4 to 17.4 μg g^{-1} in all maize cultivars, respectively. As compared to control, shoot and root Zn concentrations were significantly improved by Zn+P fertilization in DK–6142 followed by P1543, Neelam and Afghoi cultivars. Phosphorous concentration ranged from 1.61 to 2.85 g kg^{-1} in shoots and 1.56 to 2.80 g kg^{-1} in roots (Table 2) and highest was recorded for combined Zn+P treatment followed by individual P and Zn. Among cultivars, P concentration in plant tissues was greater for DK–6142 and P1543 as compared to Neelam and Afghoi.

Highest shoot Zn uptake in all the cultivars was found for combined Zn+P application followed by individual Zn and P treatments (Fig. 1). Similarly, shoot P uptake also increased with combined Zn+P application; however, it was greater for individual P applied following combined Zn+P.

Phosphorus and Zinc Utilization Efficiency

Zinc and P utilization efficiency varied significantly with treatments and their interactions (Fig. 2). Among interactions, Zn utilization efficiency ranged from 399 to 627 g^{-2} of shoot dry weight in all maize cultivars. As compared to control, Zn utilization efficiency increased by individual applied P in Afghoi followed by P1543, Neelam and DK–6142 cultivars for combined Zn+P and individual applied Zn treatments, respectively. Nonetheless, zinc utilization efficiency increased with shoot dry weight and decreased with shoot Zn concentration (Fig. 2A). Phosphorus utilization efficiency was dependent on applied Zn. All the cultivars had maximum P utilization efficiency for Zn application only (5.61 to 4.79 g^{-2} shoot dry matter mg^{-1} of shoot P) followed by combined Zn+P and individual Zn application (Fig. 2B).

Agronomy efficiency for Zn or P signficantly increased either with or without of each nutrient applied and highest of it was observed in Afghoi except for P1543 when recommnded level of both nutrients was applied (Fig. 3A).

Physiological Zn efficeincy was significantly highest for Agfhoi and DK–6142 cultivars at recommended level of P as compared to control (Fig. 4A). Similarly, physiological efficiency for P increased significantly in all maize cultivars from indiviual P to combined Zn+P application except P1543 cultivar with highest efficiency when no Zn applied (Fig. 4B).

Among maize cultivars, highest apparent Zn recovery efficiency was observed in Afghoi at recommended level of P as compared to control (Fig. 5A and 5B). Likely, highest apparent P recovery efficeincy was observed for Afghoi followed by DK–6142, Neelam and P1543 when recommended Zn applied.

Table 1: Physical and chemical properties of soil used in the experiment

Soil Property	Unit	Value
Textural class	---	Loam
Sand	%	42.8
Silt	%	39.3
Clay	%	17.9
pH (1:1 soil to water suspension)	---	8.04
EC (1:1 soil to water suspension)	dS m^{-1}	0.55
$CaCO_3$	%	4.63
Organic matter	%	0.47
AB-DTPA extractable Zn	mg kg^{-1}	0.93
Olsen P	mg kg^{-1}	9.57

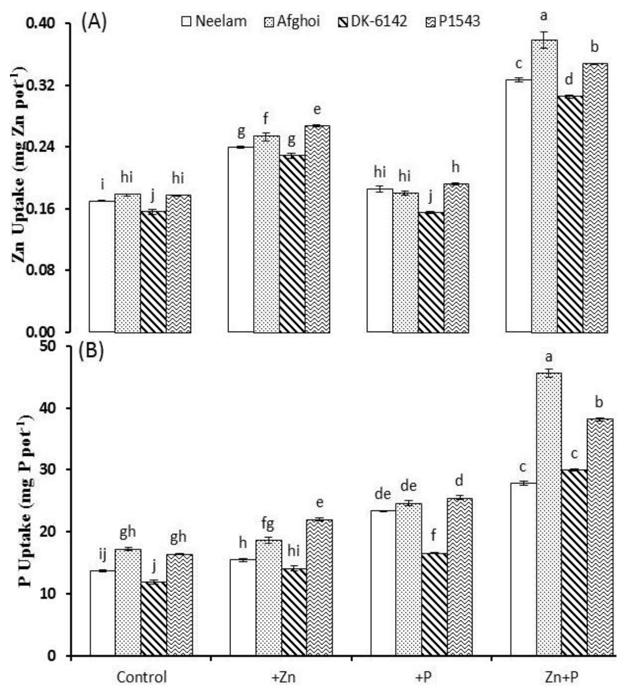

Fig. 1: Effect of Zn and P applications on uptake of Zn and P by maize cultivars

Means not sharing the same letter within a box differ significantly at 5% level of probability by LSD test and error bars indicate ± standard deviation of three replications

Discussion

Due to Zn and P deficiency in calcareous soils (Table 1), combined application of Zn+P improved plant growth attributes in all maize cultivars (Table 2). Shoot concentration of micronutrients may play critical role in accumulation of it in grain (Cakmak *et al.,* 2010). Concentration of Zn in plant tissues was improved by Zn fertilization and decreased with application of P (Table 3). It might be due to possibility of individual applied P to induce Zn deficiency due to higher than adequate shoot P concentration in maize plants or yield dilution due to increased dry matter with P application (Das *et al.,* 2005; Rehim *et al.,* 2014). However, extent of variation in Zn concentration with P application was genotype specific

Table 2: Effect of Zn and P applications on growth attributes of four maize cultivars

Cultivars		Shoot Fresh Weight (g pot^{-1})	Shoot Dry Matter (g pot^{-1})	Root Fresh Weight (g pot^{-1})	Root Dry Matter (g pot^{-1})
P_0Zn_0	Neelam	56.1 ± 0.6 e–g	9.1 ± 0.1 g	25.0 ± 1.4 h	4.5 ± 0.1 k
	Afghoi	59.3 ± 0.8 de	9.8 ± 0.1 f	29.7 ± 2.4 ef	6.0 ± 0.3 h
	DK–6142	55.3 ± 3.1 fg	8.0 ± 0.3 i	27.1 ± 0.8 g	5.3 ± 0.2 j
	P1543	54.8 ± 3.7 g	9.3 ± 0.1 g	38.4 ± 0.5 b	7.4 ± 0.1 f
P_0Zn_9	Neelam	60.8 ± 2.1 d	9.3 ± 0.1 g	30.6 ± 0.4 d–f	6.5 ± 0.2 g
	Afghoi	66.5 ± 2.8 c	10.1 ± 0.4 e	31.4 ± 1.7 c–e	7.3 ± 0.1 f
	DK–6142	59.1 ± 0.9 d–f	8.6 ± 0.2 h	29.0 ± 0.9 f	5.7 ± 0.1 i
	P1543	58.5 ± 1.6 d-g	10.3 ± 0.1 e	38.6 ± 0.1 b	7.5 ± 0.1 ef
$P_{40}Zn_0$	Neelam	61.7 ± 0.9 d	10.7 ± 0.1 d	30.8 ± 0.7 c-f	7.4 ± 0.3 ef
	Afghoi	75.4 ± 1.8 b	10.7 ± 0.3 d	32.7 ± 0.1 c	7.7 ± 0.1 e
	DK–6142	59.8 ± 3.2 de	8.6 ± 0.1 h	30.4 ± 1.5 ef	7.2 ± 0.1 f
	P1543	60.4 ± 0.7 d	10.9 ± 0.1 d	38.5 ± 0.4 b	7.5 ± 0.2 ef
$P_{40}Zn_9$	Neelam	69.0 ± 0.4 c	11.4 ± 0.1 c	32.4 ± 0.2 cd	8.7 ± 0.1 c
	Afghoi	84.8 ± 0.5 a	13.4 ± 0.5 a	38.4 ± 1.2 b	9.2 ± 0.4 b
	DK–6142	67.3 ± 1.7 c	10.3 ± 0.1 e	37.2 ± 0.9 b	8.2 ± 0.1 d
	P1543	75.1 ± 1.4 b	11.9 ± 0.1 b	51.3 ± 2.0 a	9.9 ± 0.2 a

Means not sharing the same letter within a column differ significantly at 5% level of probability by LSD test and ± indicate standard deviation of three replications. The subscript numbers after P and Zn shows their respective application rates in mg kg^{-1} of soil

Table 3: Effect of Zn and P applications on Zn and P concentrations in four maize cultivars

Cultivars		Shoot Zn (µg g^{-1})	Root Zn (µg g^{-1})	Shoot Phosphorous (g kg^{-1})	Root Phosphorous (g kg^{-1})
P_0Zn_0	Neelam	18.79 ± 0.01 j	19.14 ± 0.03 j	1.61 ± 0.04 m	1.58 ± 0.03 m
	Afghoi	18.25 ± 0.05 k	18.61 ± 0.05 k	1.77 ± 0.01 l	1.73 ± 0.01 l
	DK–6142	19.53 ± 0.17 i	19.93 ± 0.07 i	1.86 ± 0.01 jk	1.81 ± 0.02 jk
	P1543	18.98 ± 0.03 j	19.36 ± 0.26 j	1.90 ± 0.01 ij	1.85 ± 0.2 ij
P_0Zn_9	Neelam	25.70 ± 0.07 g	26.20 ± 0.02 g	1.82 ± 0.03 k	1.78 ± 0.03 k
	Afghoi	25.01 ± 0.04 h	25.51 ±0.04 h	1.84 ± 0.03 k	1.80 ± 0.03 k
	DK–6142	26.71 ± 0.03 e	27.25 ± 0.12 e	1.93 ± 0.03 hi	1.89 ± 0.03 hi
	P1543	26.01 ± 0.04 f	26.53 ± 0.04 f	1.97 ± 0.03 h	1.93 ± 0.03 h
$P_{40}Zn_0$	Neelam	17.38 ± 0.41 m	17.72 ± 0.07 m	2.05 ± 0.05 g	2.02 ± 0.06 g
	Afghoi	16.94 ± 0.04 n	17.29 ± 0.07 n	2.13 ± 0.02 f	2.08 ± 0.03 f
	DK–6142	18.05 ± 0.09 k	18.43 ± 0.12 k	2.23 ± 0.03 e	2.19 ± 0.03 e
	P1543	17.62 ± 0.07 l	18.01 ± 0.03 l	2.28 ± 0.03 e	2.23 ± 0.03 e
$P_{40}Zn_9$	Neelam	28.61 ± 0.02 c	29.19 ± 0.27 c	2.44 ± 0.03 d	2.38 ± 0.02 d
	Afghoi	28.15 ± 0.25 d	28.72 ± 0.25 d	2.53 ± 0.02 c	2.47 ± 0.02 c
	DK–6142	29.75 ± 0.05 a	30.35 ± 0.18 a	2.85 ± 0.02 a	2.79 ± 0.03 a
	P1543	29.27 ± 0.09 b	29.91 ± 0.07 b	2.71 ± 0.02 b	2.65 ± 0.03 b

Means not sharing the same letter within a column differ significantly at 5% level of probability by LSD test and ± indicate standard deviation of three replications. The subscript numbers after P and Zn shows their respective application rates in mg kg^{-1} of soil

(Table 3). Hence, it is essential to measure the influence of soil P bioavailability on Zn uptake and utilization efficiency in different maize species. Zinc efficient genotypes can increase its translocation to the shoot and regulate P transport in order to maintain balanced nutrient of Zn (Cayton *et al.*, 1985). The higher Zn uptake in maize plant was associated with a higher grain yield (Fageria *et al.*, 2008; Jamil *et al.*, 2015).

Combined application of both Zn+P caused increase in shoot P concentration (Table 3) that relates with increased soil P supply probably to intensification of root system (Taiz and Zeiger, 2008). Application of P tends to decrease the root Zn concentration and this might be due to formation of insoluble complex with Zn where deficient in soil (Li *et al.*, 2003; Sarwar *et al.*, 2010, 2015).

As compared with control without P or Zn, Zn uptake in the shoots was improved by the Zn and decreased with P application (Fig. 1). Maximum P and Zn uptake in maize shoot was found by Zn+P application (Fig. 1). Excessive P application without Zn fertilization reduces Zn uptake in maize (Nichols *et al.*, 2011). Zinc utilization efficiency decreased in maize cultivars with combined Zn+P application to plants grown with only P application (Fig. 2). Differential P and Zn utilization efficiency in maize cultivars was influenced by P–Zn interactions (Gill *et al.*, 2004). Maximum nutrient use efficiency (NUE) at low nutrient rate would possibly be due to intense root structure in the soil causing efficient utilization of applied nutrient. At higher nutrient fertilization, plants used smaller fraction of fertilizer nutrient which causes decrease in low NUE (Rehim *et al.*, 2012). Different cultivars also have different P and Zn use efficiencies (Irshad *et al.*, 2004). However, degree of variation in Zn concentration under P applications may be genotype specific. Genotypic variations in response to P and Zn deficiencies could be exploited to increase crop production in soils low in available Zn and P and can be a better strategy in low input sustainable agriculture systems especially in developing countries. Individual applied P also reduces grain Zn that ultimately decreases the nutritional quality of cereal grain which is a

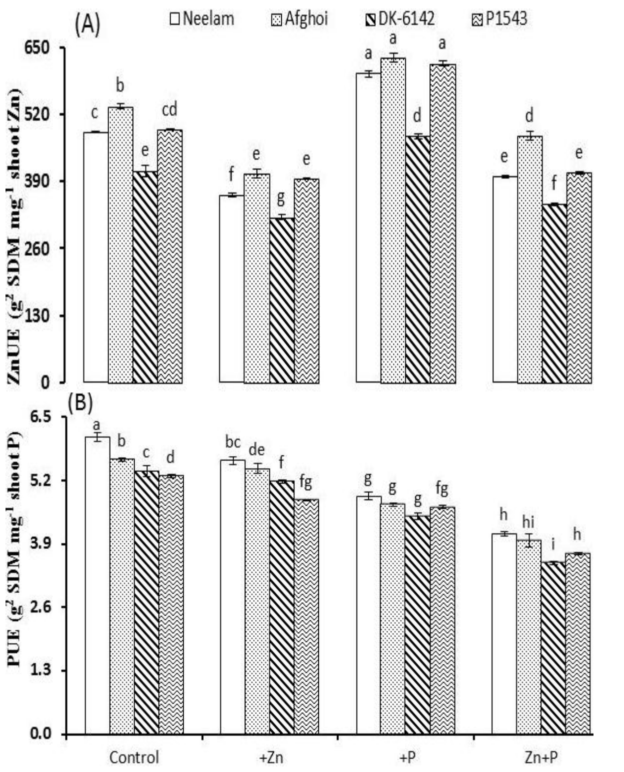

Fig. 2: Utilization efficiency of Zn and P in maize cultivars affected by applied P and Zn levels

Means not sharing the same letter within a box differ significantly at 5% level of probability by LSD test and error bars indicate ± standard deviation of three replications. ZnUE and PUE indicate Zn utilization efficiency and P utilization efficiency respectively

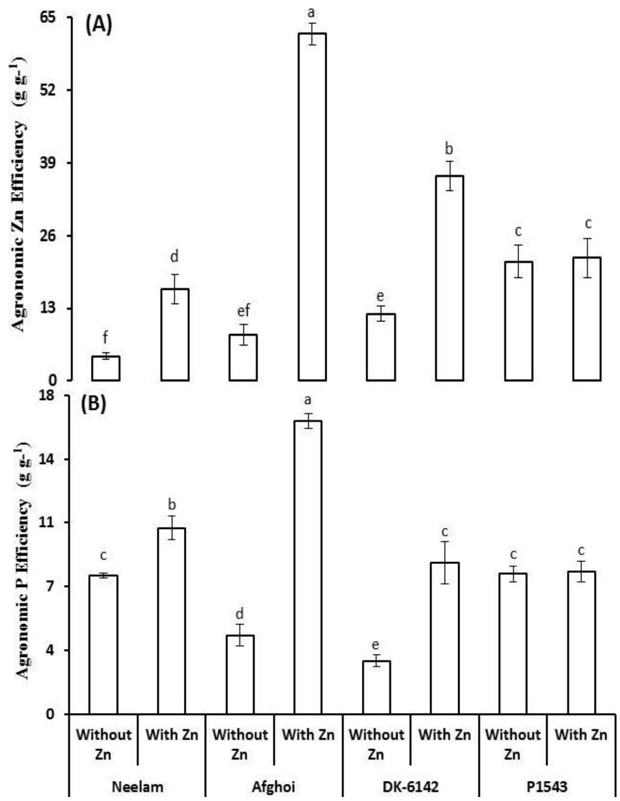

Fig. 3: Agronomic Zn and P efficiency of maize cultivars at control (without) and recommended (with) rates of P and Zn

Means not sharing the same letter within a box differ significantly at 5% level of probability by LSD test. Error bars indicate ± standard deviation of three replications

major concern (Cakmak, 2002). Hence, combined fertilization of Zn+P may also be good to improve better nutritional quality of maize crop (Gill *et al.*, 2004).

In fact, plant physiological and genetic components affect uptake and utilization of nutrients under many ecological and environmental surroundings (Baligar *et al.*, 2001). The nutrient utilization efficiency for the shoot dry matter decreased with increasing nutrient supply to roots (Furlani *et al.*, 2005). In present study, Zn utilization efficiency of all the tested maize cultivars was highest for individual applied nutrients (Fig. 2). Among cultivars, DK–6142 had highest Zn as well as P utilization efficiency as compared to all other cultivars. According to Furlani *et al.* (2005), genetic make up for different varieties have their different nutrient utilization efficiency. Fageria *et al.* (2008) demonstrated that higher Zn utilization efficiencies of cereals were found as compared to legumes and these are associated with higher grain yields of maize. Differences in nutrient utilization efficiency may also be attributed to difference in internal utilization efficiency of cultivars contrasting in their growth rates.

Recovery efficiency of Zn and P was significantly higher in the presence of other nutrient (Fig. 5). However, recoveries of applied Zn and P by four cultivars of maize were low from the soil and never more than 50%. Low efficiencies might be due to nutrients fixation on soil colloids (Baligar *et al.*, 2001). These losses could possibly add towards the soil degradation and high fertilizer demand. Higher nutrient efficiency by crops not only reduces the fertilizer input costs but it decreases the nutrient losses and protect the environment. Modern genotypes of different crops are more efficient in absorption and utilization of nutrients from the soil as compared to obsolete cultivars (Clark and Duncan, 1991).

Highest agronomic, physiological and apparent recovery efficiency for Zn or P is directly correlated with grain yield and fertilizer use efficiency (Fageria and Baligar, 2005). Agronomic and physiological efficiency of applied Zn and P also significantly increased with either of nutrients applied (Figs. 3 and 4). If appropriate Zn and P quantities are selected for crop production, the relationship between these two nutrients could turn to be positive or stabilizer and more affective (Srivastava *et al.*, 2014). Efficient cultivars may absorb more quantities of nutrients from deficient soils by maintaining required physiological processes and higher enzyme activities. By this, efficient cultivars may produce greater yields with low fertilizer rates.

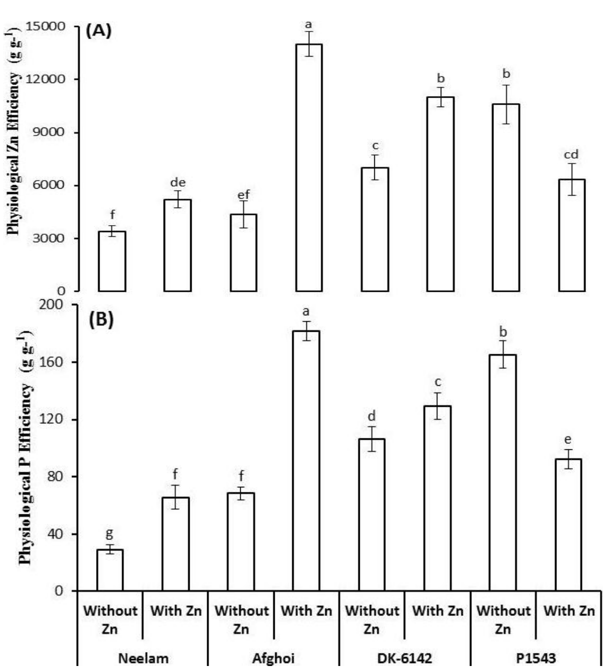

Fig. 4: Physiological Zn and P efficiency of maize cultivars at control (without) and recommended (with) rates of P and Zn

Means not sharing the same letter within a box differ significantly at 5% level of probability by LSD test. Error bars indicate ± standard deviation of three replications

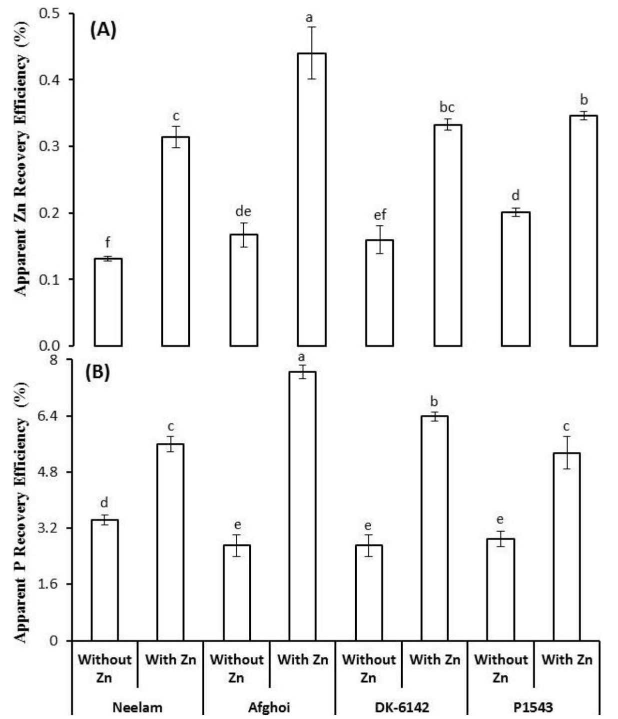

Fig. 5: Apparent Zn and P recovery efficiency of maize cultivars at control (without) and recommended (with) rates of P and Zn

Means not sharing the same letter within a box differ significantly at 5% level of probability by LSD test. Error bars indicate ± standard deviation of three replications

Conclusion

This study revealed significant effects of Zn and P application on growth, nutrient concentration and efficiency in four maize cultivars. The study also demonstrated that optimum Zn supply may not have antagonist effect on P uptake by maize plants. Further, NUE was highly genotype dependent. It was observed that both P and Zn applied to calcareous soils, having deficiency of Zn and P, increased efficiency of each other. This is possibly due to the improved metabolism, which may enhance uptake and assimilation of plant nutrients. In conclusion, balanced nutrition of P and Zn in nutrient–deficient calcareous soils is imperative for optimum plant growth and NUE.

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