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Foliar Phosphorus and Zinc Application Improve Growth and Productivity of Maize (*Zea mays* L.) Under Moisture Stress conditions in Semi-Arid Climates

Amanullah[1]*, Amir Saleem[1], Asif Iqbal[1] and Shah Fahad[2]

[1]*Department of Agronomy, Faculty of Crop Production Sciences, The University of Agriculture, Peshawar, Pakistan*
[2]*Crop Physiology and Production Center (CPPC), College of Plant Science and Technology Huazhong Agricultural University, Wuhan, Hubei, PR China*

Abstract

Foliar fertilizers application is beneficial for improving growth, yield and yield components of field crops under moisture stress condition in semiarid climates. Field experiment was conducted to study the response of dryland maize (*Zea mays* L., cv. Azam) to foliar phosphorus (1, 2 and 3% P) and zinc levels (0.1, 0.2, and 0.3% Zn) and their application time (T_1=at boot stage and T_2=at silking stage) at the Agronomy Research Farm of The University of Agriculture Peshawar during summer 2014. The experiment was conducted under moisture stress condition (with three irrigations only: 1st at emergence, 2nd at knee height and third at seed development stage). The results revealed that foliar treated plots (rest) had significantly ($P<0.05$) better growth, higher yield components and grain yield than control (no foliar spray). Plots applied with 3% foliar P had improved growth and resulted in significantly ($P<0.05$) higher yield and yield components. Yield and yield components of maize increased significantly ($P<0.05$) with 0.3% foliar Zn application. Maize growth, yield and yield components also increased significantly ($P<0.05$) when foliar nutrients were applied at early stage (booting) than late (silking) application. It was concluded from this study that application of 3% foliar P+0.3% foliar Zn at boot stage improve growth and increase maize productivity and profitability under moisture stress condition in semiarid climates.

Keywords: Maize; Growth; Yield; Foliar; Phosphorus; Zinc; Phosphorus × zinc; Limited irrigation

Introduction

Maize (*Zea mays* L.) is the 3rd highest yielding cereal crop in the world after wheat and rice. In Pakistan 64% maize is grown in irrigated and 36% in rainfed areas. In northwest Pakistan (Khyber Pakhtunkhwa) having semiarid climate maize yield is very low1868 kg ha^{-1} [1]. Improper water and nutrients management are the two main factors that adversely affect the growth and crop productivity under moisture stress (drought) condition in the Khyber Pakhtunkhwa (province of Pakistan [2]. Balance fertilization is essential for improving crop growth [3], increasing yield and harvest index [4], grain quality [5,6], fertilizer use efficiency [7] and profitability [8-11].

The diffusion coefficient of soil applied phosphorus (P) is very low and plants cannot get P when needed [12] particularly in the calcareous soils under semiarid condition [4]. Therefore, foliar P application is very important under semiarid climate. The mechanistic processes by which foliar applied nutrients are taken up are through leaf stomata [13] and hydrophilic pores within the leaf cuticle [14]. Foliar applications of KH_2PO_4 is reported to delay leaf senescence and increase winter wheat grain yields during hot and dry summers [15,16]. Increased yields in barley were obtained using dilute solutions of foliar P [17]. Foliar fertilization with nitrogen, phosphorus, and potassium (N-P-K) can be supplemented with soil applied fertilizers but cannot replace soil fertilization in the case of maize [18,19] reported that when initial P deficiency symptoms appeared 25 days after sowing in wheat, higher doses of ammonium phosphate as a foliar spray gave the greatest reduction in P deficiency and highest yields. Foliar P can increases fertilizer use efficiency [20].

Zinc (Zn) is very important for various physiological functions in plants [21-24]. Zinc deficiency not only reduces the crop production but also cause Zn deficiency in our diet [25]. Application of Zn to zinc deficient soils increased maize grain yield as well as the Zn and N concentrations in maize grains. Application of Zn increases dry matter by increasing leaf chlorophyll contents [26] and increase in N and P efficiencies [27]. In soils the P interferes Zn uptake by the plants [2,28]. About the interaction of zinc and phosphorus numerous studies have been done and all confirms this point that zinc and phosphorus imbalance in the plant, as a result excessive accumulation of phosphorus, causing zinc imposed deficiency [29]. Therefore, foliar Zn application is a simple way for making quick correction of plant nutritional status in wheat [30] and maize [31]. Foliar application of Zn enhances the uptake and accumulation of nitrogen and finally increased the maize grain. Foliar application of Zn significantly improved starch contents of forage maize [32]. In case of greater bioavailability of the grain zinc derived from foliar applications than from soil, agronomic bio-fortification would be a very attractive and useful strategy in solving zinc deficiencyrelated health problems globally and effectively [24,33,34].Therefore, foliar application of nutrients to crop plants is very effective for improving crop growth and yield [35]. However, there is lack of research on crops response to combined use of foliar P and Zn. The present study was therefore designed to investigate impact of various foliar P (1, 2 and 3%) and foliar Zn levels (0.1, 0.2 and 0.3%) applied at different growth stages (T1=boot stage and T2=silking stage) on the growth and yield of maize (*Zea mays* L., cv. Azam) under limited irrigation in semi-arid condition.

***Corresponding author:** Amanullah, Department of Agronomy, Faculty of Crop Production Sciences, The University of Agriculture, Peshawar, Pakistan, Tel: +92 91 9221144; E-mail: amanullah@aup.edu.pk

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Materials and Methods

To study the effect of foliar phosphorus (P) and zinc (Zn) levels on growth and yield of maize (*Zea mays* L., cv. Azam), field experiment was conducted at the Agronomy Research Farm of The University of Agriculture Peshawar, during summer, 2014. The experiment consisted of three foliar P levels (P_1=1, P_2=2 and P_3=3%), three foliar Zn levels (Zn_1=0.1, Zn_2=0.2 and Zn_3=0.3%), two application times (T_1=boot stage and T_2=silking stage) and one control ($P_0 Zn_0$). The experiment was laid out in a randomized complete block design having three replications. Each replication consisted of 10 treatments per replication with a plot size of 3 m × 3 m (4 rows, 3 m long and 70 cm apart) at the rate of 66, 000 plants ha^{-1}. Local variety of maize "Azam" was used as test crop and sown on 29th June, 2014. Data were recorded on plant height, leaf area index, number of grains ear^{-1}, thousand grains weight, biomass yield, grain yield and shelling percentage. Data on plant height (cm) at physiological maturity was recorded with the help of meter rod by selecting five plants randomly from each plot and then average plant height was calculated. Leaf area index at silking was calculated as leaf area $plant^{-1}$ (mean single leaf area x leaves $plant^{-1}$) divided by ground area per plant. Number of grains ear^{-1} was calculated on ten randomly selected ears from each plot and then averaged. Thousand grains weight were calculated by taking of randomly 1000 grains from seed lot of each plot and was weighted with the help of electronic balance. Data on biomass yield was recorded by harvesting the four central rows in each plot, the material was sun dried for several days and weighed, and then converted into biomass yield in kg ha^{-1}. For grain yield, the four central rows of each treatment harvested for biomass yield, the ears were separated, dried, threshed, grains were cleaned and weighed and then converted into grain yield (kg ha^{-1}). Shelling percentage was calculated by using the formula [36,37]:

$$Shelling\ percentage\ (\%) = \frac{Grains\ weight\ of\ 10\ ears\ x\ 100}{Total\ weight\ of\ 10\ ears}$$

Statistical Analysis

The data were statistically analyzed according to Steel et al. [38] for randomized complete block design and means among different treatment were composed using least significant differences (LSD) test ($P \leq 0.05$). Brief ANOVA and level of significance is given in Table 1.

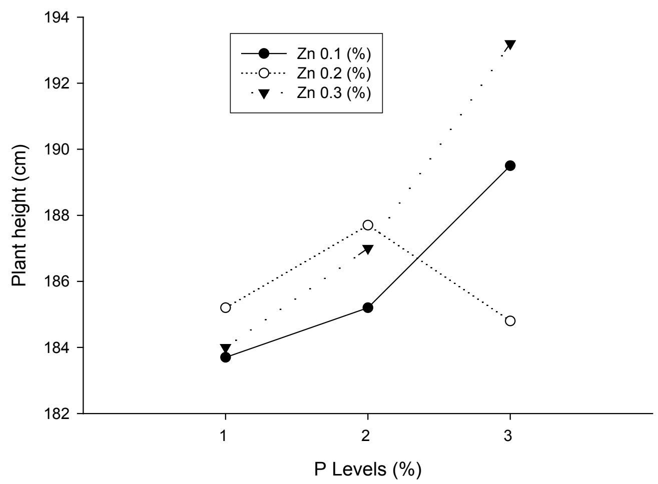

Figure 1: Interaction between foliar P and foliar Zn (P × Zn) influence plant height (cm) in maize (*Zea mays*).

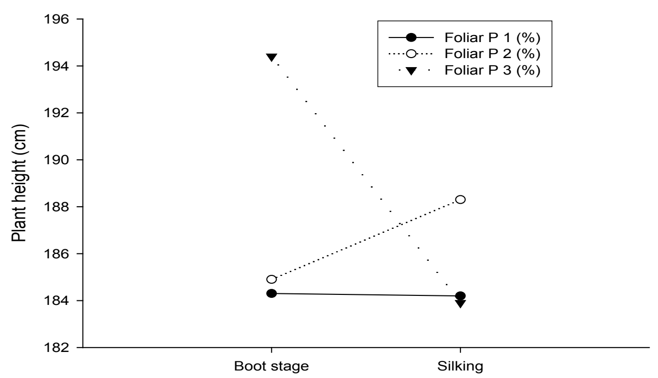

Figure 2: Interaction between foliar P and application time (P × T) influence plant height (cm) in maize (*Zea mays*).

Results

Growth

Plant height (cm) was significantly (P<0.05) affected by control vs. rest (average of all foliar P and Zn treated plots), application time (T), foliar Zn, foliar P, Zn × P and T × P (Table 1). The rest had produced significantly taller plants (187 cm) over control (180 cm) (Table 2). Maize produced taller plants with early (boot stage) foliar application than late (silking stage) application. Among the foliar P levels, plant height was increased with 3% P (189.2 cm) and lower plant height (184.3 cm) was obtained with 1% P. Among the foliar Zn levels, the tallest plants were recorded with 0.3% Zn (188.1cm) and minimum (185 cm) with 0.2% foliar Zn. Interaction between P x Zn indicated that at lowest foliar P level (1 % P); all the foliar Zn levels resulted in shorter plants (Figure 1). At the highest foliar P (3%), application of 0.1% and 0.3% foliar Zn increased plant height over 0.2% foliar Zn (Figure 1). However, 0.2% foliar Zn increased plant height over 0.1% and 0.3 foliar Zn when applied in combination with 2% P (Figure 1). Interaction between P × T indicated that the highest foliar P level (3%) resulted in the tallest plant heights when applied at boot stage (Figure 2). Application of 2% foliar P was better in terms of taller plants when applied at silking stage (Figure 2). However, no difference in plant heights was observed when 0.1% foliar Zn was applied either at booting or sulking (Figure 2).

Leaf area index (LAI) was significantly (P<0.05) affected by control vs. rest, foliar P and Zn levels (Table 1). The rest had produced significantly higher LAI over control (Table 2). Maximum LAI was obtained with 3% foliar P (2.7) and minimum (2.5) was obtained with 1% foliar P. Among the foliar Zn levels, maximum LAI was obtained with 0.3% Zn (2.8) and lowest with 0.1% foliar Zn (2.5).

Yield components

Number of grains ear^{-1} was significantly (P<0.05) affected by control vs. rest, foliar P and Zn levels, and P x Zn interaction (Table 1). The rest had produced significantly more number of grains ear^{-1} (456) as compared to control (321) (Table 2). Among the foliar P levels, the highest number of grains ear^{-1} was obtained with 2% P (478.5) and lower with 3 % P (429.6). Among the foliar Zn levels, maximum number of grains ear^{-1} were recorded with 0.2% Zn (498.7) and lowest number of grains ear^{-1} were obtained with 0.3% Zn (411.8). Interaction between P × Zn indicated that at lowest foliar P level (1% P); application of 0.2% foliar Zn increased number of grains ear^{-1} than other P and Zn

Source of Variance	Plant height (cm)	Leaf area index	Grains ear^{-1}	1000 grains eight (g)	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Shelling (%)
Control vs. Rest	***	***	***	***	***	***	***
Application time (T)	*	*	*	*	***	***	***
Zinc (Zn)	**	***	**	*	***	***	***
Phosphorus (P)	***	***	**	*	*	***	***
P × Zn	***	ns	*	*	ns	**	ns
Zn × T	ns	ns	ns	ns	**	***	*
P × T	***	ns	ns	ns	ns	ns	ns
P × Zn × T	ns	ns	ns	ns	ns	ns	ns

*, **, *** indicates that data is significant at 5, 1 and 0.1% level of probability, respectively. The word ns stand for the non-significant data at 5% level of probability

Table 1: Analysis of variance for plant height (cm), leaf area index, number of grains ear^{-1}, thousand grains weight, biomass yield (kg ha^{-1}), grain yield (kg ha^{-1}) and shelling percentage (%) of maize as affected by foliar phosphorus (P) and zinc (Zn) levels and their application time (T).

Treatments	Plant height (cm)	Leaf area index	Number of Grains ear^{-1}	Thousand Grains Weight (g)	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Shelling Percentage (%)
P 1%	184.3 c	2.5 c	460.5 b	213.50 b	9471 b	3560 c	75.8 c
P 2%	186.6 b	2.6 b	478.5 a	216.60 a	9544 ab	3624 b	77.1 b
P 3%	189.2 a	2.7 a	429.6 c	205.50 c	9567 a	3708 a	78.2 a
SD	**± 2.5**	**± 0.1**	**± 24.7**	**± 5.7**	**± 50.1**	**± 74.2**	**± 1.2**
Zn 0.1%	186.1 b	2.5 b	458.2 b	206.90 b	9321 c	3446 c	73.9 c
Zn 0.2%	185.9 b	2.5 b	498.7 a	217.70 a	9506 b	3603 b	76.4 b
Zn 0.3%	188.1a	2.8 a	411.8 c	211.00 b	9754 a	3842 a	80.8 a
SD	**± 1.2**	**± 0.2**	**± 43.5**	**± 5.5**	**± 217.3**	**± 199.4**	**± 3.5**
Boot stage	187.9 a	2.7 a	441.7 b	211.00 a	9779 a	3698 a	78.6 a
Silking stage	185.5 b	2.5 b	470.7 a	212.70 a	9276 b	3563 b	75.5 b
SD	**± 1.7**	**± 0.1**	**± 20.5**	**± 1.2**	**± 355.7**	**± 95.5**	**± 2.2**
Control plots	180.0 b	2.0 b	321.2 b	213.50 b	8841 b	3289 b	72.0 b
Treated plots	187.0 a	3.0 a	456.4 a	216.60 a	9527 a	3631 a	77.0 a
SD	**± 4.9**	**± 0.7**	**± 95.6**	**± 2.2**	**± 485.1**	**± 241.8**	**± 3.5**

Where SD stands for standard deviations

Means of the same category followed by different letters are significantly different from each other using LSD test (P ≤ 0.05)

Table 2: Plant height (cm), leaf area index, number of grains ear^{-1}, thousand grains weight, biomass yield (kg ha^{-1}), grain yield (kg ha^{-1}) and shelling percentage (%) of maize as affected by foliar phosphorus (P) and zinc (Zn) levels and their application time (T).

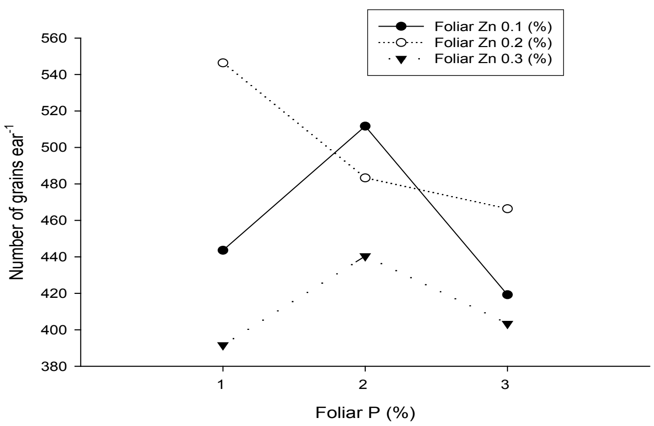

Figure 3: Interaction between foliar P and foliar Zn (P × Zn) influence number of grains ear^{-1} in maize (*Zea mays*).

combinations (Figure 3). The combined application of 2% foliar P+0.1% foliar Zn stood second in the ranking in terms of higher number of grains ear^{-1} (Figure 3).

Thousand grains weight (g) was significantly (P<0.05) affected by control vs. rest, foliar P and Zn levels, and P × Zn interaction (Table 1). The rest had significantly higher thousand grains weight (216.6 g) as compared to control (213.5 g) (Table 2).Among the foliar Zn levels, application of 0.2% Zn gave highest thousand grains weight (217.7 g), while 0.1% Zn gave lowest thousand grains weight (206.9 g). Among the foliar P levels, the highest thousand grains weight was obtained with 2% P (216.6 g), while the lowest thousand grains weight was recorded with 3% P (205.5 g). Interaction between P × Zn indicated that combination of 2% foliar P+0.2% foliar Zn increased 1000 grains weight in maize than any other foliar P and Zn combinations (Figure 4). The combined application of 1% foliar P+0.2% foliar Zn stood second in the ranking in terms of heavier grains (Figure 4).

Yield and shelling percentage

Biomass yield (kg ha^{-1}) was significantly (P<0.05) affected by control vs. rest, foliar P and Zn levels, and interaction between foliar P and application time (P × T) (Table 1). The rest plots had significantly higher biomass yield (9527 kg ha^{-1}) as compared to control (8841 kg ha^{-1}) (Table 2). Among the foliar P levels, the highest biomass yield was obtained with 3% P (9566 kg ha^{-1}) and the lowest biomass yield was obtained with 1% P (9470 kg ha^{-1}). Among the foliar Zn levels, the highest biomass yield was obtained with 0.3% Zn (9754 kg ha^{-1}) and the lowest biomass yield (9321 kg ha^{-1}) with 0.1% foliar Zn. The interaction between P × T indicated that the biomass yield in maize increased significantly when any of the three P levels (1, 2 and 3% P) was applied at the early growth stage (booting) than applied late at silking stage of maize (Figure 5).

Grain yield (kg ha^{-1}) of maize was significantly (P<0.05) affected by control vs. rest, foliar P and Zn levels, and interactions between P

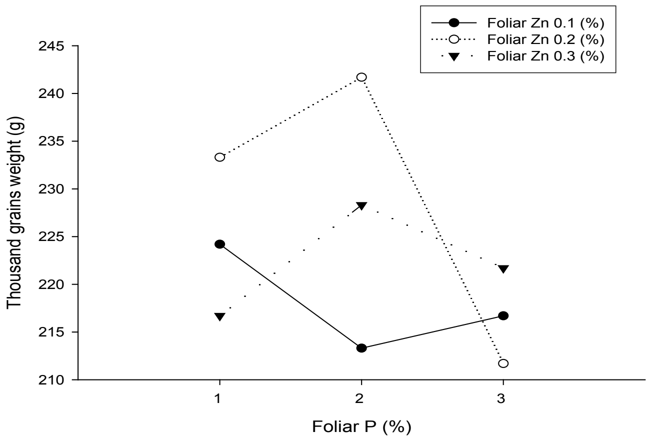

Figure 4: Interaction between foliar P and foliar Zn (P × Zn) influence 1000 grains weight (g) in maize (*Zea mays*).

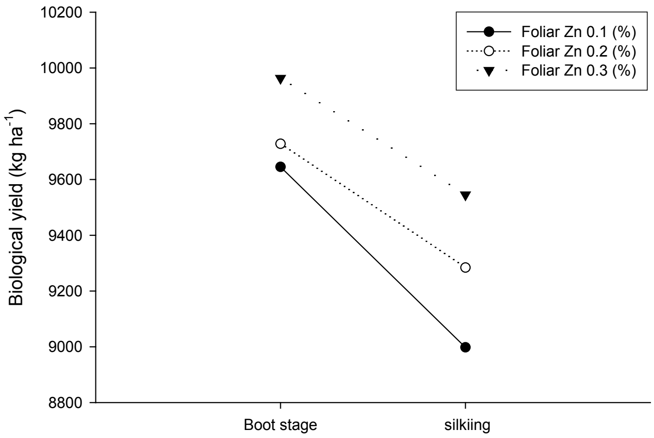

Figure 5: Interaction between foliar P and application time (P × T) influence biological yield (kg ha^{-1}) in maize (*Zea mays*).

× Zn and P × T (Table 1). The rest had significantly higher grain yield (3631 kg ha^{-1}) as compared to control (3289 kg ha^{-1}) (Table 2). Among the foliar Zn levels, the highest grain yield (3842 kg ha^{-1}) was obtained with 0.3% Zn, while the lowest grain yield (3446 kg ha^{-1}) was obtained with 0.1% foliar Zn. Among the foliar P levels, the highest grain yield (3707 kg ha^{-1}) was obtained with 3% P, while the lowest grain yield (3560 kg ha^{-1}) was obtained with 1% P. The interaction between P × Zn indicated that the grain yield in maize increased significantly with the increase in both foliar P and Zn levels and vice versa (Figure 6). The interaction between P × T indicated that the grain yield in maize increased significantly when any of the three P level (1, 2 and 3% P) was applied at the early growth stage (booting) than applied late at silking stage of maize (Figure 7).

Shelling percentage (%) was significantly ($P<0.05$) affected by control vs. rest, foliar P and Zn levels, and Zn × T interaction (Table 1). The rest had significantly higher shelling (77.0%) as compared to control (72.0%) (Table 2). Among the foliar P levels, maximum shelling percentage was obtained with 3% P (78.2%), while the lowest shelling percentage was obtained with 1% P (72.2%). Among the foliar Zn levels, maximum shelling percentage was obtained with 0.3% Zn (80.8%) and the lowest shelling percentage was obtained with 0.1% Zn (73.9%). The interaction between P × T indicated that the shelling percentage in maize increased significantly when any of the three P levels (1, 2 and 3% P) was applied at the early growth stage (booting) than applied late at silking stage of maize (Figure 8) and showed positive relationship with increase in grain yield.

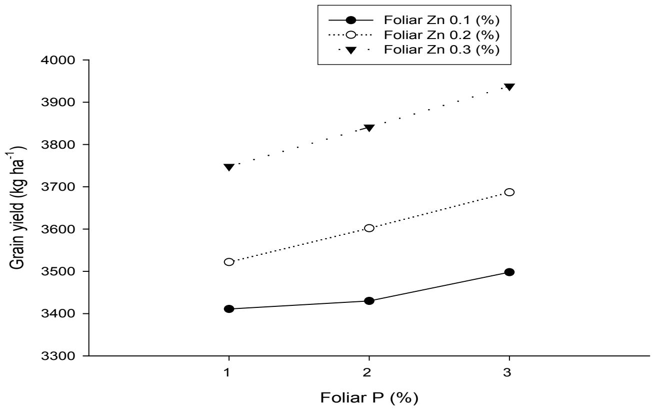

Figure 6: Interaction between foliar P and foliar Zn (P × Zn) influence grain yield (kg ha^{-1}) in maize (*Zea mays*).

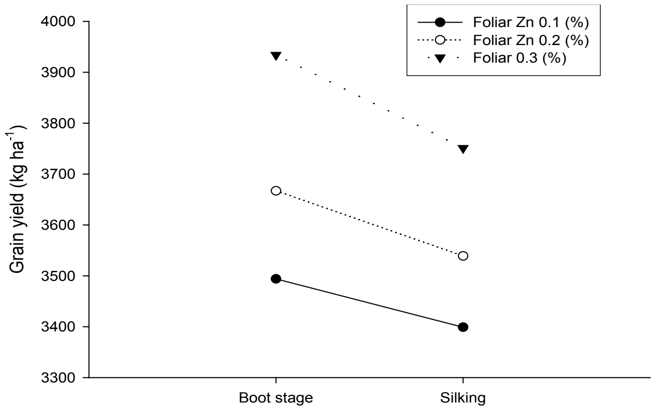

Figure 7: Interaction between foliar P and application time (P × T) influence grain yield (kg ha^{-1}) in maize (*Zea mays*).

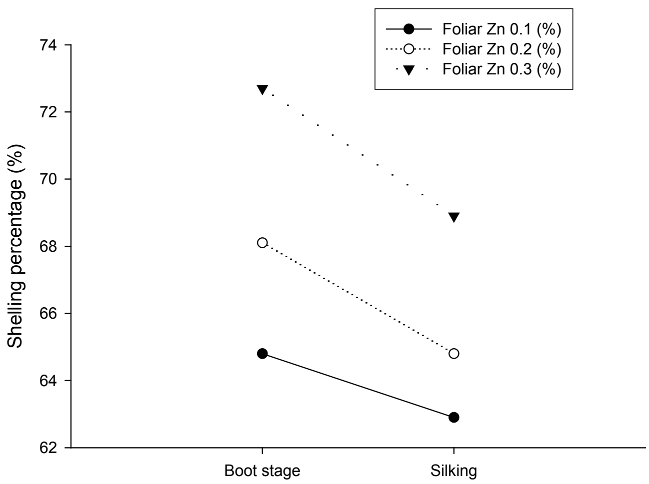

Figure 8: Interaction between foliar P and application time (P × T) influence shelling (%) in maize (*Zea mays*).

Discussion

Both foliar P and Zn application improved the growth parameters (plant height and LAI) over control (no foliar P and Zn application) under calcareous soils in semiarid condition. Amanullah et al. [2] reported significant variation ($P<0.05$) in plant height and LAI of maize while spraying NPK at different growth stages. The increase in plant height with P and Zn application was earlier reported by many researchers [39-46]. Similarly, the increase in LAI in wheat with P and Zn application was earlier reported by Shukla and Warsi [47]. Other researchers [48]; Mohsin et al. [46] reported increase in the LAI of maize with foliar Zn application. The increase in LAI with Zn application probably may be due to increase in tryptophan amino acid and indole acetic acid hormone which are two main factors in leaf area expansion [49]. According to Firouzi [50], foliar spray of Zn increase LAI due to an increase in length and width of leaves with increase in auxin. Amanullah et al. [6] reported that foliar N application time had significant ($P<0.05$) effects, while foliar N source had no significant ($P>0.05$) effects on mean single leaf area of maize. Amanullah et al. [6] reported that foliar spray of N+P+K (2% each) resulted in maximum mean single leaf area, followed by foliar N application alone and the lowest mean single leaf area was observed with sole foliar P.

The yield components (number of grains ear^{-1} and 1000 grains weight) also showed positive and significant ($P<0.05$) response to foliar P and Zn application over control. Earlier, Amanullah et al. [6] found that number of grains ear^{-1} in maize increased with foliar spray of NPK in combination over control. The increase in grains ear^{-1} with foliar P application are in agreement with those of Alston [51], they reported that grains spike^{-1} of wheat significantly increased with foliar P. Similarly, Soleimani [52] reported marked increase in number of grains spike^{-1} of wheat for foliar application Zn. The tendency of increasing number of grains ear^{-1} with Zn application was also in line with the findings of many workers [53,54]. The increase in 1000 grains weight in maize with foliar nutrition was in accordance with our early study [6]. According to Samad et al. [55], the combine application of soil and foliar applied P increased 1000-grains weight over control but did not improve it over the sole application of soil or foliar applied P. Tahir et al. [43] and Mohsin et al. [46], reported increase in the 1000-grains weight with foliar Z application over control. These results are in line with the results of Guenis et al. [56], Soylu et al. [57], Harris et al. [54] and Farajzadeh et al. [58]; they reported significant increase in thousand grains weight with foliar application of micronutrients.

Both biomass and grain yields as well as shelling increased significantly ($P<0.05$) with foliar P and Zn application over control and the increase was more when foliar nutrients were applied at boot stage than applied at silking. The increase in biomass yield with foliar nutrition was attributed to the improvement in growth parameters, yield and yield components of maize. According to Amanullah et al. [6], combined foliar application of the three major nutrients (N+P+K) at the rate of 1% each in two equal splits at 30 and 60 days after emergence increased maize productivity under moisture stress condition under semiarid condition. Many researchers [20,59] reported increase in grain and biomass yields with foliar P. Other researchers [46,60] showed positive response of biomass and grain yields to foliar Zn application. The increase in biomass yield with foliar application of Zn probably might be due to their critical role of Zn in crop growth, involving in photosynthesis processes, respiration and other biochemical and physiological activates and thus their importance in achieving higher yields [61]. Higher yield due to Zn fertilization was also attributed to the enhanced synthesis of carbohydrates and their transport to the site of grain production [62-65].

Conclusion

The foliar P and Zn treated plots (rest) had better performance in terms of improved growth, higher yield and yield components than control (no foliar spray). Application of foliar P at the rate of 3% and Zn at the rate of 0.3% improved growth, increased yield and yield components of maize under moisture stress condition. Early application of foliar P and Zn at boot stage had positive impact on growth, yield and yield components of maize as compared to late spray at silking.

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