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Growth and yield response of maize (*Zea mays* L.) to foliar NPK-fertilizers under moisture stress condition

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Abstract

Improper water and nutrients management are the two main factors that adversely affect the growth and crop productivity under moisture stress (drought) condition in Khyber Pakhtunkhwa province of Pakistan. Foliar nutrient management could not only apply nutrients to the hungry crops but it could also be beneficial in terms of providing water to the thirsty crops under moisture stress condition. This field experiment was designed to investigate effects of foliar NPK (2% each) applied alone and in various combinations (N, P, K, N + P, N + K, P + K and N + P + K) and their application time (one split at 30 and 60 days after emergence (DAE), and two equal splits at 30 + 60 DAE) on the growth and yield of maize (Zea mays L., cv. Azam) under moisture stress condition at the Research Farm of The University of Agriculture Peshawar, Pakistan during summer 2011. The experiment was laid out in randomized complete block design using three replications. The results revealed that the rest (all foliar treated plots) plots significantly took more time to physiological maturity (88.2 days), produced taller plants (221 cm), higher mean single leaf area (413 cm^2), biological yield (10285 kg ha^{-1}), heavier grains (229 g/1000 grains), grains ear^{-1} (376), grain yield (2896 kg ha^{-1}) and harvest index (28.2%) than the control plots (foliar nutrients not applied). Sole application of N, P, and K in one split (2% each) at the early growth stage (30 DAE) decreased grain yield in maize, while combined application of N+P and N+P+K in one split at 30 DAE or 60 DAE or in two equal splits (1% each at 30 and 60 DAE) increased grain yield in maize. It was concluded from the results that 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 DAE increased maize productivity under moisture stress condition in the study area.

Keywords*: Zea mays, growth, yield, foliar application, NPK, moisture stress*

Introduction

Maize (*Zea mays* L.) growth and yield are most sensitive to nutrients applications under moisture stress condition. Improper fertilizer and water management are the two major factors adversely affecting maize growth and productivity under dryland condition. The aim of this research project was to find out suitable foliar NPK combination and its time of application for improving maize growth and maximizing yield under moisture stress (dryland) condition. Judicious use of proper fertilizer combination, to replenish the nutrient supply systems, is a key factor in the system aiming at intensification of crop production for sustainable agriculture (Amanullah *et al*., 2009a). Maize is the second most important crop after wheat in the Khyber Pakhtunkhwa but its yield unit^{-1} area is very low (Amanullah *et al*., 2012). The causes of yield gap include injudicious use of fertilizer by the farmers. In order to bridge this gap in maize productivity, the package of latest production technology involving the use of foliar fertilizer application under water stress condition at appropriate time need to be used to increase maize production as well as net profit of the farmers under dryland condition.

Efficient water management under moisture stress could enhance the crop productivity in the coming decades (Yudelman, 1994). The use of modern technology, particularly irrigation water management and nutrient application is essential to maximize crop production and returns for the farmers (Pandey *et al*., 2000). Water shortage during the vegetative stages of development limits the grain yield in many maize production areas. In northern China, maize is the second-most (following wheat) important cereal crop, which is frequently subjected to delay in irrigation or water stress (WS) causing a significant yield reduction (Li, 2007). Grain yield reduced by 22.6-26.4% due to decrease in kernel number and weight (Pandey *et al*., 2000), and decreased by 37% due to a decline of 18% in kernel weight and 10% in kernel number under water stress conditions (Karam *et al*., 2003). Poor water availability and high temperatures result significant stress during critical phases of maize (*Zea mays* L.) development (Al-Kaisi *et al.*, 2013). These stress factors

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lead to management challenges with insects, diseases, and reduced nutrient availability and uptake by plants.

Balanced use of nitrogen (N), phosphorus (P) and potassium (K) fertilizers could play a pivotal role in increasing the yields of cereals under moisture stress condition. Among the limiting factors; proper level and ratio of NPK are of prime importance (Asghar *et al*., 2010). Foliar application of NPK could increase crop productivity many fold under moisture stress condition. Foliar spray not only provides the nutrients but can also provide a significant amount of water in the time of water stress. In addition to supplying a nutrient for plant growth, N application could enhance drought tolerance of plant to increase yield under water deficit (Chipman *et al*., 2001; Li, 2007). Research shows that N application during grain filling could enhance the remobilization from stored carbohydrates in vegetative organs to grain under moderate water stress (WS), which might benefit starch synthesis and grain yield formation under post-anthesis drought (Yang *et al*., 2000). Foliar-applied N can be up to seven times more efficient than soil applied N (Dixon, 2003). Other benefits of foliar applied N include lower application rates (higher efficiency), plus the relative ease of obtaining timely, uniform applications. A combination of soil-applied and foliar applied N is the best management practice to reduce the efficient alternative for feeding N to plants. The tendency for nitrate to move below the root zone and eventually to groundwater is being significantly reduced with foliar applied N. A supplemental dose of 7 kg N ha^{-1} as urea spray significantly increased maize grain yield (Singh *et al.*, 2005). Foliar applications of urea to the chlorotic leaves of N-deficient maize restored both normal chlorophyll content and stomatal behavior of leaves (Shimshi, 1967). Application of half N as basal and half N as foliar spray at increased the grain yield of maize by 43 percent compared to that obtained by applying full N (100 kg N ha^{-1}) as basal dose but foliar spray without basal N reduced the yield of maize by 15 percent compared to normal practices (Islam *et al.*, 1996). Foliar fertilization with NPK can be used supplementation with soil applied fertilizers but cannot replace soil fertilization in the case of maize (Ling and Silberbush, 2002), because demand for P is 1/10 that of N hence, foliar application might be beneficial. Haloi (1980) 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. Since P can be very immobile in the soil, foliar applications can be up to 20 times more effective than soil applications (Dixon, 2003). Aown *et al*. (2012) reported that foliar application of K at grain filling stage of wheat alleviated the adverse effect of water deficit and increased the yield and yield components tremendously. Nutrient deficiencies often occur for a variety of reasons, but can be rectified by timely applications of the deficient nutrient. This usually entails some sort of soil application but, after canopy closure during flowering and fruit development, foliar applications may be more appropriate (Oosterhuis, 2009). Studies on the combine foliar NPK and its application time have not been carried out under dryland (moisture stress) condition. The present study was therefore designed to investigate best the foliar NPK combination and its application time for improving maize productivity under dryland condition.

Materials and Methods

A field experiment was conducted under water stress condition to investigate effects of foliar NPK combination and their application time on the growth and yield of maize (*Zea mays* L., cv. Azam) at the Research Farm of the University of Agriculture Peshawar, Pakistan during summer, 2011. The details of factors and their levels used were given below:

Control

One in each replication (no foliar application)

Foliar NPK Application Time

T_1 = One split at 30 DAE (2%)
T_2 = One Split at 60 DAE (2%)
T_3 = Two equal splits at 30 and 60 DAE (1% at each stage)

Foliar NPK combinations (2 kg of each nutrient/100 liter H_2O)

F_1 = N (nitrogen)
F_2 = P (phosphorus)
F_3 = K (potassium)
F_4 = N + P
F_5 = N + K
F_6 = P + K
F_7 = N + P + K

The experiment was laid out in randomized complete block design using three replications. Each replication consisted of 22 treatments. A sub-plot size of 3.5 m × 3 m, having 5 rows, 5 m long and 70 cm apart was used. A uniform basal dose of 45 kg ha^{-1} P_2O_5 as single super phosphate was applied and mixed with the soil during seedbed preparation. Nitrogen at the rate of 120 kg N ha^{-1} as urea was applied to soil in two equal splits (sowing and first irrigation).

Data were recorded on days to physiological maturity, plant height, mean single leaf area, yield and yield components. Data on days to physiological maturity was recorded when more than 50 % ears per plot reached physiological maturity (black layer formation in seed). The data on plant height was taken from base to top of the plant for 10 selected plants per plot in each treatments, and then average plant height was worked out. Leaf length and width of three middle leaves of 10 plants in each treatment were measured. Then average length and width was worked out, and the mean single leaf was calculated using the formula (Dwyer and Stewart, 1986):

Mean single leaf area = Leaf length x width x 0.75

Thousand grains were taken at random from the grain lot of each subplot and weighed by electronic balance. This was repeated thrice and then average weight per 1000 grains was calculated and recorded. Number of grains per 10 ears was counted and then averages grains ear^{-1} was calculated. Data on biological yield was recorded after harvesting the four middle rows from each subplot. The harvested material was dried up to constant weight, weighed by spring balance and converted into biological yield in kg ha^{-1}. The material was then threshed, the seeds were cleaned and weighed and then converted into grain yield in kg ha^{-1}. The harvest index was calculated in percentage according to the formula (Gardner *et al*., 1985):

Harvest index = Grain yield ÷ Biological yield x 100

Statistical analysis

Data were statistically analyzed according to Steel *et al.* (1997) and means were compared using LSD test ($p \leq 0.05$).

Results and Discussions

Days to physiological maturity

Nutrients combination and interaction had significant effects on days to physiological maturity, while application time had no significant effects on days to physiological maturity (Table 1). Among the nutrient combinations, application of N alone delayed the physiological maturity to 90.2 days. Application of foliar N increased the vegetative growth period of maize thereby delayed days to physiological maturity (Amanullah *et al*., 2010a). Similarly, days to physiological maturity were delayed in maize with nitrogen application (Karim *et al.*, 1983). Increase in N rate and number of split application might have increased the rate of photosynthesis (Oikeh *et al*., 1997) that resulted in the leaf longevity and delayed phenological characteristics in maize (Gungula *et al*., 2003, Amanullah *et al*., 2009a). Early physiological maturity of 87.4 days was observed when K was applied alone or N+P were applied together. In case of application time, it ranged between 87.7 and 88.2 days. The interaction between foliar nutrients combination and application time (F x T) indicated that N application in one split (2% at 30 DAE) and N+K application in two equal splits (1% each at 30 and 60 DAE) delayed maturity in maize, while application of K one split, N+P and N+P+K application in two equal splits resulted in early physiological maturity in maize (Figure 1). Amanullah *et al*. (2013) reported that foliar application of urea and CAN (calcium ammonium nitrate) delayed maturity by one day as compared with foliar application of AS (ammonium sulphate). They also reported that foliar-N application at 45 and 60 DAE delayed maturity (94 days) as compared to early application (15 or 30 DAE) which enhanced maturity in maize by two days. According to Amanullah *et al.* (2010b) the early phenological development in maize with P application probably may be due to the increased root development and thus helped the plants to obtain more P to complete its life cycle quickly.

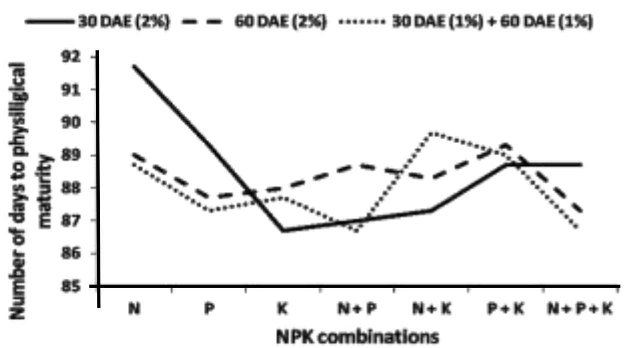

Figure1: Interactive effect of foliar NPK combination and application time on the days to physiological maturity of maize (*Zea mays* L.) under moisture stress condition

Plant height

Statistical analysis of the data indicated that nutrients combination, application time and interaction had significant effects on plant height (Table 1). Combined foliar application of N + P resulted in tallest plants (226.6 cm), followed by P + K (225.2 cm). Similarly to our results, nitrogen in combination with P and K greatly influenced the vegetative growth and plant height of maize (Asghar *et al.*, 2010). The shortest plants (212.7 cm) were observed when N was applied alone (Table 1). Among the application time, application of 1% nutrients at two stages each at 30 and 60 DAE resulted in taller plants (227.6 cm), while the application of 2% nutrients in one split at 30 DAE produced the dwarf plants (213.7 cm). The interaction between foliar nutrients combination and application time (F x T) indicated that N, P and K application in one split (2% at 30 DAE) decreased the plant height in maize, while application of K in two equal splits, and N+K application

Table 1: Effects of foliar NPK combination and its application time on days to physiological maturity, plant height, mean single leaf area and biological yield (kg ha^{-1}) of maize (*Zea mays* L.) under moisture stress condition

Foliar Nutrient (2% each)	Days to physiological maturity	Plant height (cm)	Mean single leaf area (cm^2)	Biological yield (kg ha^{-1})
N	90.2	212.7	416.6	2969
P	88.1	217.9	395.5	2575
K	87.4	220.9	412.1	2547
N+P	87.4	226.6	405.7	3187
N+K	88.4	225.2	414.1	2927
P+K	89.0	221.6	413.4	2779
N+P+K	87.6	227.0	433.3	3287
$LSD_{0.05}$	0.36	1.95	5.19	246
Application Time				
2% at 30 DAE	88.1	213.7	412.4	9895
2% at 60 DAE	88.2	223.8	411.5	10323
1% each at 30 & 60 DAE	87.7	227.6	415.0	10638
$LSD_{0.05}$	ns	0.83	ns	105
Control vs.	86.2b	192b	381b	8259b
Rest (all treated plots)	88.2a	221a	413a	10285a
Interaction	*	*	ns	ns

Means in the same category followed by similar letters are not significantly different at 5% level of probability
***** = Significant at $p \leq 0.05$; N = Nitrogen; P = Phosphorus; K = Potassium; DAE = Days after emergence; LSD = Least significant difference; ns = Non-significant

one split at 60 DAE, and N+P+K application in one split at 30 DAE increased plant height in maize (Figure 2). Amanullah *et al.* (2010a) reported significant variation in plant height of maize while spraying urea at different growth stages. According to Aown *et al*. (2012), foliar potassium application increased plant height in wheat when sprayed under drought at vegetative stage (7.18%) than at flowering (1.2%) or grain filling stages (1.87%). Amanullah *et al*. (2013) found tallest plants (204 cm) in maize crop with foliar application of urea, and dwarf plants (190 cm) were observed with water spray (no N). They also found that delayed foliar spray (60 DAE) produced taller plants (203 cm), and the shortest plants (190 cm) were recorded when spray was applied at 15 DAE.

Mean single leaf area

The data regarding mean single leaf area is given in Table 1. The statistical analysis of the data shows that nutrient combination had significant effects, while application time and interaction had no significant effect on the mean single leaf area in maize. Among the nutrients combination, foliar spray of N + P + K (2% each) resulted in maximum mean single leaf area (433.3 cm^2), followed by N application alone (416.6 cm^2). The lowest mean single leaf area (395.5 cm^2) was observed when P was sprayed alone. Among the application time, application of 1% nutrient each at 30 and 60 DAE produced the highest mean single leaf area (415.0 cm^2) when compared with other timings. Amanullah *et al.* (2010a) found that late foliar application of urea delayed growth period and increased leaf area in maize. According to Shimshi (1967), foliar applications of urea to the chlorotic leaves of N-deficient maize restored both normal chlorophyll content and normal stomatal behavior to the treated leaves which might be the possible cause of increase in the mean single leaf area in maize. Amanullah *et al*. (2013) reported that foliar N application time had significant effects, while foliar N source had no significant effects on mean single leaf area of maize.

Biological yield

Nutrient combination and application time had significant effects, while interaction had no-significant effects on biological yield (Table 1). Among the nutrient combination, application of N+P+K produced the maximum biological yield (11333 kg ha^{-1}), followed by N + P (10761 kg ha^{-1}); while the lowest biological yield (9740 kg ha^{-1}) was obtained when K was sprayed alone. Among the application times, application of nutrients in two equal splits (1% each at 30 and 60 DAE) increased the biological yield to maximum (10638 kg ha^{-1}), while application of nutrients (2%) at 30 DAE decreased the biological yield to minimum (9895 kg ha^{-1}). Amanullah *et al*. (2010a) reported that delaying the phenological development while increasing the number of leaves and plant height through foliar urea spray increased biological yield in maize. According to Alston (1979), late season foliar N and P application in wheat influenced straw yield. Arif *et al*. (2006) found that three sprays of combined use of NPK resulted in highest biological yield, followed by two sprays while control (water spray) treatment produced grains with least weight in wheat crop at Peshawar.

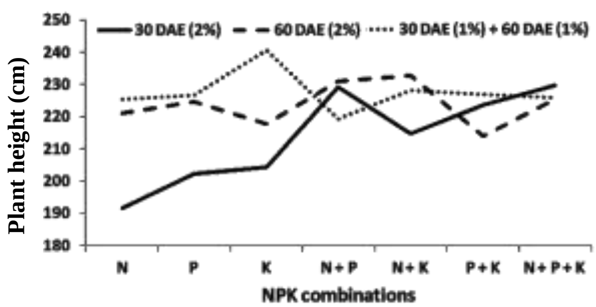

Figure 2: Interactive effect of foliar NPK combination and application time on the plant height (cm) of maize (*Zea mays* L.) under moisture stress condition

maize (Table 2). Among the nutrient combinations, application of N + P produced the maximum 1000-grains weight (236.7 g), followed by N sprayed alone (231.8 g). The lowest 1000-grain weight (223.3 g) was recorded when K was sprayed alone. Among the application time, application of nutrients in one split (2% each) at 60 DAE increased 1000 grains weight (232.5 g), while application of nutrients in one split (2% each) at 30 DAE decreased 1000 grain weight (225.9 g) in maize. The interaction between foliar nutrient combination and application time (F x T) indicated that N+K and P+K application in one split (2% at 30 DAE), and K application in two equal splits (1% each at 30 and 60 DAE) decreased 1000-grain weight in maize, while application of N+P and P+K in one split at 60 DAE, and N+K application in two equal splits (1% each at 30 and 60 DAE) increased 1000-grains weight in maize (Figure 3).

As reported by Sanjeev *et al*. (1997) that individual grain weight or 1000 grain weight are regarded as the basis for final economic yield, higher nitrogen rate can promote leaf area development during vegetative development and maintaining functional leaf area during growth period may be the possible reason for photo assimilate formation and increase in grains weight. In case of wheat, Parvez *et al*.

Table 2: Effects of foliar NPK combination and its application time on 1000-grains weight (g), grains ear^{-1}, grain yield (kg ha^{-1}) and harvest index (%) of maize (*Zea mays* L.) under moisture stress condition

Foliar Nutrient (2% each)	1000 grains weight (g)	Grains ear^{-1}	Grain yield (kg ha^{-1})	Harvest index (%)
N	231.8	372.8	2969	29.6
P	229.7	382.6	2575	25.6
K	223.3	378.8	2547	26.1
N + P	236.7	379.7	3187	30.0
N + K	227.8	378.3	2927	29.3
P + K	226.4	343.8	2779	27.8
N + P + K	229.3	397.0	3287	29.2
$LSD_{0.05}$	2.68	9.5	56	0.85
Application Time				
2% at 30 DAE	225.9	383.1	2795	28.3
2% at 60 DAE	232.5	370.2	2825	27.4
1% each at 30 & 60 DAE	229.5	375.0	3067	29.0
$LSD_{0.05}$	1.15	ns	24	ns
Control vs.	203b	326b	2105b	25.7b
Rest (all treated plots)	229a	376a	2896a	28.2a
Interaction	*	ns	*	ns

Means in the same category followed by similar letters are not significantly different at 5% level of probability
* = Significant at $p \leq 0.05$; N = Nitrogen; P = Phosphorus; K = Potassium; DAE = Days after emergence; LSD = Least significant difference; ns = Non-significant

Thousand grain weight

Nutrient combination, application time and interaction had significant effects on the thousand grain weight in

(2009) concluded that the foliar spray of 4% urea solution gave heavier grains. Arif *et al*. (2006) found that three sprays of combine of NPK resulted in heavier grains (26.8 g) followed by two sprays (25.7 g) while control (water spray) treatment produced grains with least weight (20.8 g) in wheat crop at Peshawar.

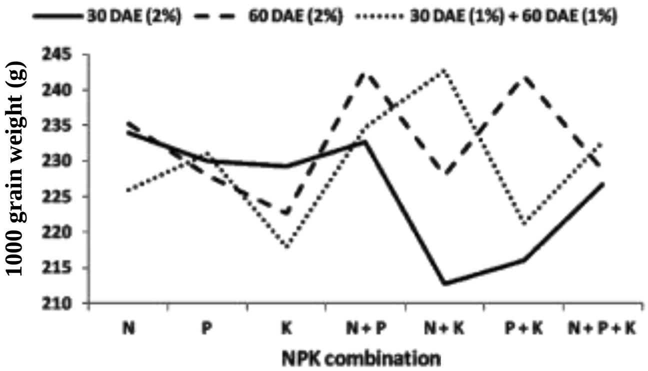

Figure 3: Interactive effect of foliar NPK combination and application time on the 1000-grains weight (g) of maize (*Zea mays* L.) under moisture stress condition

Number of grains ear^{-1}

Nutrient application time and interaction had no significant effects, while nutrient combination had significant effects on number of grains ear^{-1} (Table 2). Among the nutrient combinations, application of N+P+K produced the maximum number of 397.0 grains ear^{-1}, followed by 382.6 grains ear^{-1} when P was sprayed alone. The lowest number of grains per ear (343.8) were recorded when P+K were applied together. Amanullah *et al*. (2010a) found that grains ear^{-1} in maize increased when foliar urea was sprayed at the rate of 6% at the V12 stage. In case of wheat crop, Arif *et al.* (2006) found that number of grains spike^{-1}increased to maximum (230) with three sprays of NPK, followed by two sprays (213), while minimum number of grains spike^{-1} was produced by single spray (180) par control (198).

Grain yield

Nutrient combination, application time and interaction had significant effects on grain yield (Table 2). Combine application of N + P + K produced the maximum grain yield (3287 kg ha^{-1}), followed N + P (3187 kg ha^{-1}); while the lowest grain yield (2547 kg ha^{-1}) was obtained when K was sprayed alone. Application of nutrients in two equal splits (1% each at 30 and 60 DAE) increased the grain yield to maximum (3067 kg ha^{-1}), while application of nutrients (2%) at 30 DAE decreased the grain yield to minimum (2795 kg ha^{-1}). The interaction between foliar nutrients and their application time (Figure 4) indicated that sole N application at 2% at 30 DAE increased grain yield; whereas, combined foliar application of N+P or N+P+K at 2% at 60 DAE or at 1% at both 30 and 60 DAE increased maize grain yield significantly. Amanullah *et al.*, (2010a) reported that delaying in the phenological development, while increasing the number of leaves and grains plant^{-1} through foliar urea spray resulted in maximum grain yield. The increase in the grain yield with combined application of NPK in two equal splits increased grains ear^{-1} and 1000 grains as well as grain yield. A supplemental dose of 7 kg N ha^{-1} as urea spray significantly increase maize grain yield (Singh *et al.*, 2005). Earlier, Parvez *et al.* (2009) found that foliar N application increased grain yield in wheat. According to Girma *et al*. (2006), maize grain yield reached its peak when foliar P was applied at the V8 growth stage, with increase of 3000 kg ha^{-1} over control. Luxurious vegetative growth due to excess supply of N might induce hidden P hunger and the foliar P correction of this demand would likely improve yield. According to Alston (1979), late season foliar N and P application in wheat influence grain yield. In case of wheat crop, El-Ashry *et al*. (2005), found potassium spray reduced the negative effect of drought on growth and increased grain yield tremendously.

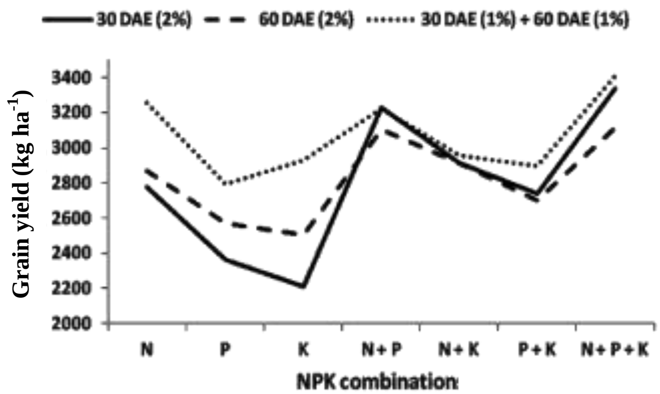

Figure 4: Interactive effect of foliar NPK combination and application time on the grain yield (kg ha^{-1}) of maize (*Zea mays* L.) under moisture stress condition

Harvest index (%)

Nutrient combination had significant effects, while application time and interaction had no-significant effects on the harvest index in maize (Table 2). Among the nutrient combinations, application of N + P produced the maximum harvest index (30.0%), followed by N spray alone (29.6%); while the lowest harvest index (25.6%) was obtained when P was sprayed alone. Among the application time, harvest index ranged from 27.4 to 29.0% among different treatments. Amanullah *et al.* (2010a) reported that increase in yield and yield components with foliar urea spray increased harvest index in maize. Amanullah *et al.* (2013) reported that foliar N sources had significant effects, while application time and interaction had no significant effects on the harvest index of maize. They also reported that foliar

N-sources (urea, calcium ammonium nitrate, and ammonium sulphate) had significantly higher harvest index than control (water spray only). Among the N source, CAN with harvest index of 39.0% stood first, followed by AS (38.4%), and control (35.8%) stood in the bottom in terms of harvest index. Delayed application of foliar spray (60 DAE) resulted in higher harvest index (38.5%), and the lowest harvest index (36.9%) was recorded when the spray was applied at 15 DAE. The increase in yield components (grain weight and grains ear^{-1}) and grain yield with foliar N application resulted in higher harvest index in maize and indicated positive relationship of harvest index with yield components and grain yield.

Control vs. foliar application

All foliar treated plots significantly took more time to physiological maturity (88.2 days), produced taller plants (221 cm), higher mean single leaf area (413 cm^2) and biological yield (10285 kg ha^{-1}) as shown in Table 1; and produced heavier grains (229 g/1000 grains), more number of grains ear^{-1} (376), grain yield (2896 kg ha^{-1}) and harvest index (28.2%) than the control plots (foliar nutrients not applied) in maize grown under moisture stress condition. Foliar application of phosphorus in maize is a potential option to improve P-use efficiency (PUE) and minimize environmental impacts (Girma *et al*., 2006). In case of winter wheat, low rates of foliar applied P might correct mid-season P deficiency in winter wheat, and that might result in higher P use efficiencies when compared to soil applications. Foliar P appeared to be more beneficial when yield levels were lower, likely due to moisture stress. Our results are in line with those of Aown *et al*. (2012) was reported that foliar application of K at grain filling stage was more effective in alleviating the adverse effect of water deficit on number of spikelets per spike, 1000-grain weight and grain yield and improved these by 8.76, 35.84 and 49.03%, respectively, in wheat crop. Similarly, Ling and Silberbush (2002) found that foliar NPK may partially compensate for insufficient uptake by the maize roots, but it requires sufficient leaf area to become effective. In case of wheat crop, Arif *et al*. (2006) found that yield and yield components increased in wheat with foliar NPK than control (no spray).

Conclusion

Maize growth and yield are adversely affected under nutrients and moisture stress conductions. Foliar application of major nutrients (NPK) as sole or in combination improves growth, increase yield and yield components of maize under moisture stress condition. Because foliar nutrients application not only provides the nutrients to the hungry plants under dryland condition but it could also provide water to the thirsty maize plants under drought condition. The benefits of foliar nutrition should be therefore demonstrated to the growers under dryland condition.

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