Cercetări Agronomice în Moldova
Vol. XLVIII , No. 1 (161) / 2015

POTASSIUM FERTILIZATION INFLUENCES GROWTH, PHYSIOLOGY AND NUTRIENTS UPTAKE OF MAIZE (*ZEA MAYS* L.)

A. HUSSAIN[1], M. ARSHAD[1], Z. AHMAD[1], H.T. AHMAD[1], M. AFZAL[1,2], M. AHMAD[1,2*]

*E-mail: munirsoomra@yahoo.com

Received April 11, 2014

ABSTRACT. A pot experiment in wire house was conducted to investigate the effect of potassium fertilization on physiology, growth and nutrient uptake of maize. Surface soil samples were collected and analyzed for soil physico-chemical properties and NPK contents. Pots were saturated with water and filled with soil (5 kg soil/pot). Potassium fertilizer was applied in five different treatments as T1, T2, T3, T4 and T5 with 0, 70, 100, 130, and 160 kg ha^{-1}, respectively. Nitrogen and phosphorus were applied @ 250 and 100 kg ha^{-1} (recommended), respectively, in all the pots, including control. Experiment was planned in completely randomized design (CRD), with three repeats. Plant growth, nutrient uptake and concentration in roots and shoots, net photosynthesis, rate of transpiration, stomatal conductance and substomatal CO_2 concentration were significantly improved with increasing K application rate. It also increased water use efficiency (WUE) and decreased root: shoot dry weight ratio of maize. Treatment T3 resulted in maximum growth, physiological characteristics and nutrient uptake. It was concluded that K fertilization improves physiological characteristics resulting in enhanced WUE and nutrient uptake eventually producing more yield. It is recommended to apply K fertilization in drought stress conditions.

Key words: Nutrient uptake; Photosynthesis; Root: shoot ratio; Stomatal conductance; Water use efficiency.

INTRODUCTION

Increasing population demands more food with every day in the future. About 1000 million people in world are unable to get daily dietary intakes, and more than 400 million are facing malnutrition problems. Hunger and hunger induced diseases

[1] Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan
[2] Department of Soil Science, College of Food and Agricultural Sciences, King Saud University, Riyadh, Kingdom of Saudi Arabia

kill about 11 million children of less than 5 years of age annually (Lean *et al.,* 1990). To cope with the problem of food scarcity, maize (*Zea mays* L.) could be the better option as it is a high yielding cereal crop which provides food and forage. United States of America, China, Brazil, European Union and Mexico are the largest maize producing countries. United States of America and China produce approximately 60% of the world maize crop, while 68% of land devoted to maize crop is located in the developing world, which contribute only 46% of total maize production, indicating the need for improving yield of maize crop in developing countries (Pingali and Pandey, 2000). Maize is 3rd largest food crop after wheat and rice. In Pakistan it is grown as a fodder, food and feed crop. Its annual production is 3,487 thousand tons which is planted on an estimated area of 950 thousand hectares in Pakistan (Anonymous, 2009-'10). Maize is primary source of energy in the dairy industry as it is a good source of proteins, carbohydrates, Fe, vitamin B, and minerals. Maize green fodder is quite rich in proteins (Dowswell *et al.,* 1996). It provides raw materials for flakes, starch, corn oil and custard.

In spite of the modern agricultural technologies, there is still a gap between average and potential yield. To increase the average yield, nutrient and water management is of prime importance and beneficial to fulfil the yield gap. For normal growth potassium is the essential elements and plays and important regulatory roles in the plant growth and development. It has the better effect on yield improving the growth of roots, drought resistance activating various enzymes, reducing respiration preventing energy losses aids in food formation and photosynthesis enhancing translocation of sugars and starch protein contents producing grain rich in starch, building cellulose and reducing lodging. Potassium (K^+) has significant effect on protein synthesis, stomatal movement, enzyme activation, water relation and photosynthesis in plants (Marchner, 1995). It also used for increases water use efficiency plants (James, 2004). It improves the soil physical properties known as soil aggregating agent (Hamza and Anderson, 2003). Potassium cations are present in plants in large amount and plays an essential role in several biochemical and physiological processes (Igras and Danyte, 2007). Potassium also affects protein synthesis (Hasiao *et al.,* 1970). Water is an integral part of plant cells. Most of the plant parts (fleshy fruits) contain up to 95 % water. Potassium has a vital role to withstand the plant during water shortage (Parson *et al.,* 2007).

Soil K deficiency has been reported in many parts of the world, especially in the developing countries (Rengel and Damon, 2008). About one-third soils of Pakistan are deficient in available potassium

(Akhtar *et al.,* 2003). K deficient soils face many abnormalities, such as reduced photosynthesis rate in maize and sugar beet, reduced root length density (RLD) and total root length (TRL) at later stages of growth and effect stomatal activity causes loss of water at damaging level (Terry and Ulrich, 1973; Roshani and Narayanasamyb, 2010). During the rapid dry matter accumulation phase of maize growth before pollination, deficiency in K availability in soil volumes that can result in inadequate K nutritional status and may result in reduced productivity and to increase the yield potassium have immense scope in crop productivity (Heckman and Kamprath, 1992; Bhattacharyya, 2000). Although K is most essential element for plants, but still it is considered as "the forgotten nutrient", as in many parts of the world.

Keeping in view the facts K acts as an essential ion in the physiology of plant water relations and also enhances the crop growth, development leads to yield of corn and forage. For this purpose, an experiment has been carried out to investigate the effect of different levels of potassium fertilization on net photosynthesis, transpiration rate, substomatal CO_2 concentration and stomatal conductance in maize. The objectives of the study were to investigate; i) the impact of K^+ fertilization on physiology of maize plants, ii) the influence of K^+ fertilization rates on nutrient concentration and uptake by maize plants, and iii) the optimum dose of K^+ fertilization for maximum and healthier growth of maize (EV-77).

MATERIALS AND METHODS

Experimental layout

A pot experiment was conducted in the rain protected wire house of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan, during 2011-'12. Surface soil samples (0-15 cm depth) were collected and stored in polythene bags. The soil was brought to the laboratory, air dried, grind and passed through 2 mm sieve. A subsample of prepared soil was analyzed for various physical and chemical characteristics (*Table 1*) in Soil fertility and plant nutrition laboratory and Soil salinity laboratory of the Institute of Soil & Environmental Sciences (U.S. Salinity Lab. Staff, Hand Book No. 60, 1954). Plastic pots were lined with polyethylene sheets. Pots were saturated with water and 5 kg soil was filled in each pot. Potassium fertilizer was applied in five different treatments as T1, T2, T3, T4 and T5 with 0, 70, 100 (recommended), 130, and 160 kg K ha^{-1}, respectively. Nitrogen and phosphorus were applied @ 250 and 100 kg ha^{-1}, respectively, i.e. recommended dose in all the pots including control. The experiment was planned in completely randomized design (CRD) with three repeats. Sulphate of potash (SOP) was used as a source of potassium. All K and P and half N were applied at the time of sowing while half N was applied after 50 days of germination. Five soaked seeds of maize (conventional maize variety EV-77) were sown per pot. Tap water was used for irrigation and plant protection measures adopted when needed. Thinning was performed leaving three plants per pot. Maize was harvested from 70 days after the sowing. Various plant parameters (growth, physiological and chemical) were collected following the standard procedures.

Table 1 - Physico-chemical characteristics and NPK contents of surface soil samples (0-15 cm depth) used to fill the pots for the experiment

Characteristics	Mean ±SD	Minimum	Maximum
Sand (%)	53. 1 ±5.3	42	57
Silt (%)	27. 5 ±2.5	21	36
Clay (%)	19. 4 ±2.7	13	24
Textural class	Sandy clay loam		
PHs	7.70 ±0.2	7.4	7.98
EC (dS m^{-1})	1.41 ±0.07	1.32	1.51
CEC (C mol^+ kg^{-1})	5.12 ±0.4	4.8	5.7
Saturation percentage (%)	33.0 ±3.1	26	37
Lime contents (%)	2.17 ±1.02	1.98	2.5
[1]Available phosphorus (mg kg^{-1})	3±0.1	2.85	3.54
[2]Extractable potassium (mg kg^{-1})	154 ±4.1	146	162
Organic matter (%)	0.71 ±0.03	0.62	0.91
[3]Total nitrogen (%)	0.05 ±0.01	0.03	0.06

[1]Watanabe and Olsen, 1965; [2]Mason, 1963; [3]Jackson, 1962

Studied characters

1. Soil physico-chemical characteristics

Soil physical and chemical parameters are shown in *Table 1*. Soil nutrients were determined by Standard methods (*Table 1*). The pH of soil was determined using saturated soil paste (Richard, 1954). Soil saturated paste extract was used to determine electrical conductivity (EC) of the soil (Richard, 1954). Particle size distribution was determined using hydrometer method (Bouyoucos, 1962) and USDA textural triangle was used to determine soil textural class. Cation exchange capacity was determined using the method used by Chapman (1965). Lime contents were determined with acid neutralization method (Allison and Moodie, 1965). Walkly-Black method was followed to determine the contents of organic matter in the soil samples (Nelson and Sommers, 1982).

2. Growth parameters of maize

The root and shoot samples were collected and washed after harvesting the crop. Fresh weight, dry weight and length of root and shoot were measured.

Root: shoot dry weight ratios were measured as:

$$\text{Root to shoot ratio} = \frac{\text{Dry root weight}}{\text{Dry shoot weight}}$$

3. Physiological parameters of maize

Infrared gas analyzer (IRGA) was used to measure net photosynthesis (Pn), the rate of transpiration (E), stomatal conductance (g_s) and substomatal CO_2 concentration (C_i) in maize plants. Water use efficiency was calculated through the ratio of net photosynthesis and transpiration rate.

$$\text{Water use efficiency} = \frac{\text{Net photosynthesis (Pn)}}{\text{Transpiration rate (E)}}$$

4. *Chemical parameters of maize*

Nitrogen concentration in roots or shoots was determined by Kjeldhal method (Jackson, 1962). Available phosphorous concentration in roots and shots was determined by Olsen method (Watanabe and Olsen, 1965) using Atomic absorption spectrophotometer (AAS) (Perkin Elmer Aanalyst 100). Potassium concentration in roots or shoots was determined by Jenway PFP-7 Flame photometer (Mason, 1963).

Nutrient uptake by roots and shoots were calculated as:

$$\text{Nutrient uptake root to shoot} = \frac{\text{\% Nutrient (roots or shoots)}}{100} \times \text{Dry(root or shoot) weight}$$

Statistical analysis

Statistics software package 8.1 and Microsoft Excel were used for statistical analysis (Steel *et al.,* 1997). Means were compared by least significant difference test (LSD) and Pearson coefficient of correlation was used to investigate relationships among various parameters.

RESULTS

Growth parameters

The data summarized in *Table 2* clearly indicates that potassium fertilization enhanced the growth parameters significantly. Potassium application at the rate of 100 kg ha^{-1} (T3) improved all growth related parameters significantly, as it improved the shoot length by 31%, root length by 40%, fresh root weight by 22%, fresh shoot weight by 19%, and dry root weight by 30%, compared with control (without K fertilizer), while shoot dry weight was maximum in T4 and T5 (130 and 160 kg K ha^{-1}). It was also noted that further increase in potassium application over 100 kg ha^{-1} did not increased these parameters significantly. Potassium application at the rate of 130 and 160 kg ha^{-1} (T4 and T5) increased root length by 23 and 21%, shoot length by 20 and 14%, fresh root weight by 18 and 13%, and dry root weight by 23 and 16%, respectively, as compared to control. Further increase in K dose increased fresh shoot weight only 10 % over the control.

Root: shoot dry weight ratios

Influence of shoot K concentration on root: shoot dry weight ratio is demonstrated in *Fig. 1*. Increase in K % concentration in shoot of maize, the root: shoot ratio decreased significantly. Control had minimum K in shoot so root: shoot ratio was recorded maximum. As K concentration increased towards maximum, root: shoot ratio decreased gradually. The line of graph is more abrupt when K application was increased from 100 to 130 kg ha^{-1}. The minimum root: shoot dry weight ratio was observed in T5 (130 kg ha^{-1}).

Table 2 - Effect of different potassium fertilization rates on various growth parameters of maize grown in rain protected wire house

*Trt.	Fresh[1]RW (g pot^{-1})	Dry[1]RW (g pot^{-1})	Fresh[2]SW (g pot^{-1})	Dry[2]SW (g pot^{-1})	Root length (cm)	Shoot length (cm)
T1	30.8d±1.5	5.7c±0.3	104.3d±1.8	17.3d±1.1	28.5c±2.7	57.6c±4.3
T2	33.4cd±1.6	6.2bc±0.4	110.3c±2.6	22.6c±1.5	33.4bc±2.8	64.8b±3.1
T3	37.7a±1.8	7.3a±0.6	124.3a±3.8	28.4ab±2.3	39.8a±3.0	75.3a ±4.7
T4	36.3ab±0.5	6.9ab±0.3	120.7a±2.2	29.7a±1.2	35.1ab±1.9	68.9ab±3.1
T5	34.8bc±1.1	6.7ab±0.2	114.9b±1.2	29.3a±0.9	34.6b±3.9	65.4b±2.7
LSD	**0.83**	**2.56**	**4.54**	**2.67**	**5.00**	**6.67**

*Treatments; T1 = control, T2 = 70 kg K ha^{-1}, T3 = 100 kg K ha^{-1}, T4 = 130 kg K ha^{-1}, T5 =160 kg K ha^{-1}, [1]Root weight, [2]Shoot weight

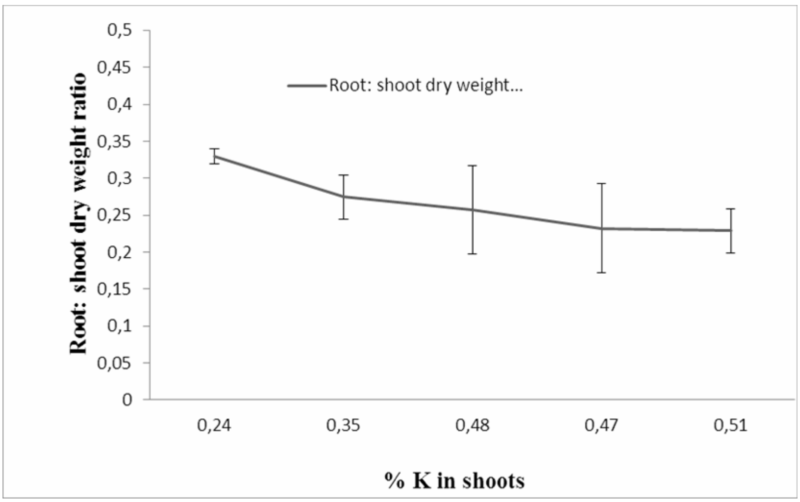

Figure 1 - Influence of shoot K concentration on root: shoot dry weight ratio of maize grown in rain protected wire house under different K fertilization rates

Nutrient concentration and uptake by maize plants

The highest K^+ concentration in roots and shoots of maize was observed under the application of 160 kg K ha^{-1} (*Table 3*). It gave 200% more K^+ concentration in roots and 93% more K^+ concentration in shoots, compared with control. The minimum K^+ concentration in roots and shoots was under the control where no K fertilizer was applied. As K application increased, the concentration of K^+ in roots and shoots increased and reached up to its maximum when K was applied at 160 kg ha^{-1}. Potassium application improved nutrient concentration in root and shoot of maize (*Table 3*). Maximum P concentration in shoots and roots was observed in T4 where 130 kg K ha^{-1} was applied. There was

200% more P in root and 105 % more P in shoot in T4, compared with control. Further increase in K fertilization over 130 kg ha^{-1} did not increase P concentration significantly. Potassium application 160 kg ha^{-1} increased shoot and root P concentration by 62 and 125%, respectively, compared with control. Potassium application at 160 kg ha^{-1} (T5) exhibited maximum K uptake by shoots (114% more, compared with control), followed by the K application at 130 and 100 kg ha^{-1} (*Table 4*). Similarly maximum K uptake in roots was observed when K was applied at 160 kg ha^{-1}, which was 260% more, compared with control. While minimum K uptake by roots and shoots of maize was observed in control. Maximum N uptake in shoots was observed in T3 and T4, which was 78% more as compared with control. Further increase in K dose did not increase shoot N uptake significantly. While maximum uptake of N by roots was observed in T4, which was 86 % more, compared with control. The potassium application at 130 kg ha^{-1} (T4) exhibited maximum phosphorus uptake by root and shoots, as there was 286 % more P uptake in roots and 142 % in shoots, compared with control. While T5 did not increase P uptake by roots and shoot significantly.

Table 3 - Nutrient concentration (%) in roots and shoots of maize grown in rain protected wire house as affected by different K application rates

*Trt.	Shoot P	Root P	Shoot N	Root N	Shoot K	Root K
T1	0.20c±0.02	0.07d±0.01	1.92e±0.04	1.37e±0.06	1.23d±0.11	0.37e±0.05
T2	0.25c±0.03	0.13c±0.04	2.34d±0.04	1.51d±0.05	1.74c±0.05	0.58d±0.04
T3	0.35b±0.04	0.18b±0.01	3.06a±0.04	1.87a±0.04	2.00b±0.09	0.72c±0.05
T4	0.43a±0.05	0.24a±0.03	2.85b±0.05	1.74b±0.05	2.11b±0.06	0.97b±0.04
T5	0.34b±0.03	0.18b±0.02	2.48c±0.04	1.64c±0.05	2.38a±0.09	1.10a±0.06
LSD	**0.06**	**0.04**	**0.07**	**0.08**	**0.15**	**0.09**

*Treatments; T1 = control, T2 = 70 kg K ha^{-1}, T3 = 100 kg K ha^{-1}, T4 = 130 kg K ha^{-1}, T5 =160 kg K ha^{-1}

Table 4 - Nutrient uptake (g pot^{-1}) by roots and shoots of maize grown in rain protected wire house as affected by different K application rates

*Trt.	Shoot P	Root P	Shoot N	Root N	Shoot K	Root K
T1	0.04c±0.01	0.03d±0.00	0.37c±0.01	0.07e±0.01	0.24d±0.01	0.02d±0.00
T2	0.05c±0.00	0.03c±0.00	0.45bc±0.05	0.09d±0.01	0.35b±0.03	0.03c±0.01
T3	0.08ab±0.01	0.01b±0.01	0.73a±0.07	0.12b±0.01	0.48a±0.06	0.05b±0.01
T4	0.09a±0.02	0.02a±0.01	0.67a±0.07	0.13a±0.00	0.47a±0.02	0.06a±0.01
T5	0.07b±0.02	0.01b±0.00	0.53b±0.03	0.10c±0.01	0.51a±0.03	0.07a±0.01
LSD	**0.01**	**0.03**	**0.09**	**0.01**	**0.05**	**0.01**

*Treatments; T1 = control, T2 = 70 kg K ha^{-1}, T3 = 100 kg K ha^{-1}, T4 = 130 kg K ha^{-1}, T5 =160 kg K ha^{-1}

Physiological parameters

1. Net photosynthesis

With increase in K fertilizer, increase in net photosynthesis was significant (*Table 5*). Potassium application at the rate of 70 kg ha^{-1} (T2) and 100 kg ha^{-1} (T3) improved the net photosynthesis by 19 and 29%, respectively, over the control. The potassium application at 130 kg ha^{-1} (T4) exhibited maximum net photosynthesis as it boosted the net photosynthesis by 50 % more as, compared to control (*Table 5*).

Table 5 - Effect of different potassium application rates on physiological parameters of maize plants grown in rain protected wire house

*Trt.	[1]Pn (µmol/m^{2}s)	[2]E (mmol/m^{2}s)	[3]Ci (mmol/m^{2}s)	[4]g_s (mmol/m^{2}s)
T1	10.4dc±1.03	4.6c±0.37	180.3d±17.49	0.21d±0.04
T2	12.4c±0.20	3.54b±0.22	201.3cd±13.53	0.28c±0.02
T3	13.5bc±0.90	5.7ab±0.11	227.3bc±13.50	0.32b±0.01
T4	15.8a±0.50	6.2a±0.01	255.0a±19.14	0.37a±0.01
T5	14.2b±0.87	5.9ab±0.37	236.7ab±3.51	0.34ab±0.01
LSD	**1.43**	**0.62**	**26.49**	**0.03**

*Treatments; T1 = control, T2 = 70 kg K ha^{-1}, T3 = 100 kg K ha^{-1}, T4 = 130 kg K ha^{-1}, T5 =160 kg K ha^{-1}, [1]Net photosynthesis, [2]Rate of transpiration, [3]Substomatal CO2 concentration, [4]Stomatal conductance

2. Rate of transpiration

The potassium application at 130 kg ha^{-1} exhibited maximum transpiration rate as it boosted the transpiration rate by 35 % more, as compared to control (*Table 5*). While K application at the rate of 70 kg ha^{-1} and 100 kg ha^{-1} improved the transpiration rate by 17 and 24 %, respectively, over the control. Further increase in potassium application over 130 kg ha^{-1} did not significantly increase the transpiration rate.

3. Stomatal conductance

Stomatal conductance (g_s) of maize plants was increased with increase in potassium application at a certain level. Potassium applied at rate of 70 kg ha^{-1} and 100 kg ha^{-1} improved the stomatal conductance by 33 and 52 %, respectively, over the control (*Table 5*). The maximum stomatal conductance was observed (0.38 m mol/m^{2}s) in case of treatment where potassium application was 130 kg ha^{-1}, which was 81 % more than control. Minimum stomatal conductance was obtained (0.21 m mol/m^{2}s) in control condition.

4. Substomatal CO_2 concentration

Maximum substomatal CO_2 concentration (Ci) was observed in plants where K was applied at the rate of 130 kg ha^{-1} as it improved the Ci by 41%, compared with control (*Table 5*). Potassium application at the rate of 70 and 100 kg ha^{-1} improved the substomatal CO_2 concentration by 17 and 26%, respectively, over the control. But at the rate of 160 kg K ha^{-1}, the increase in Ci was not significant.

5. Water use efficiency

Fig. 2 illustrates that increase in K application enhanced water use efficiency of maize at a certain level. Potassium applied at the rate of 70 and 100 kg ha^{-1} improved water use efficiency by 2 and 5%, respectively, over the control. Maximum WUE was observed in T4 (130 kg ha^{-1}), which was 13% more, compared with control (*Fig. 2*). But, further increase in potassium application over 130 kg ha^{-1} did not improve WUE significantly.

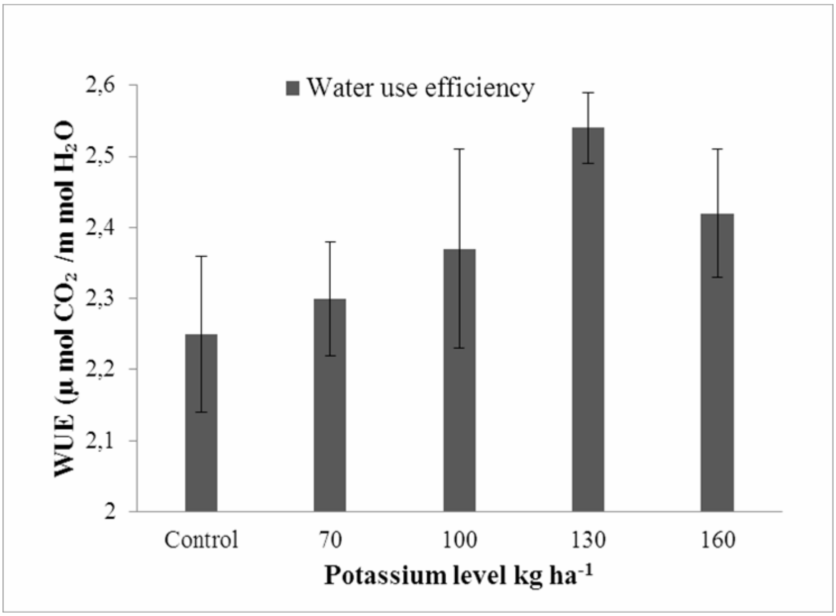

Figure 2 - Effect of different K application rates on water use efficiency of maize grown in rain protected wire house

Correlation studies

Relationship of shoot and root K concentration to various physiological parameters and WUE of maize has been shown using Pearson coefficient of correlation (*Tabs. 6 and 7*). Shoot K concentration had significant positive correlation with net photosynthesis, rate of transpiration, stomatal conductance, substomatal conductance CO_2 concentration and water use efficiency of the maize ($p < 0.05$). Similarly, root K concentration also had the significant positive correlation with the parameters mentioned above ($p < 0.05$).

Table 6 - Correlation of shoot K concentration to various physiological parameters and WUE of maize plants grown in rain protected wire house

	Root K conc.	Pn	E	g_s	Ci	WUE
Shoot K conc.	0.94**	0.78**	0.8**	0.89**	0.83**	0.53*
P-value	0.00	0.00	0.00	0.00	0.000	0.42

*Correlation is significant at 0.05 level; **Correlation is significant at 0.01 level

Table 7 - Correlation of root K concentration to various physiological parameters and WUE of maize plants grown in rain protected wire house

	Shoot K conc.	Pn	E	g_s	Ci	WUE
Root K conc.	0.94**	0.82**	0.79**	0.88**	0.82**	0.56*
P-value	0.00	0.00	0.00	0.00	0.000	0.03

*Correlation is significant at 0.05 level; **Correlation is significant at 0.01 level

DISCUSSION

Potassium fertilization helps to improve yield and quality of crops. In the current studies it was observed that increased K fertilization enhanced the root length, shoot length, dry and fresh weight of root and shoot significantly (*Table 2*). Tzortzakis (2010) reported significant improvement in root length when treated with 10 mmol/L potassium sulphate (K_2SO_4) solution. Egilla *et al.* (2001) found maximum shoot length when they amended the Hoagland's nutrient solution with 10 mM K. Potassium can enhance the total dry weight accumulation in alfalfa (Peoples and Koch, 1979), while K starvation reduced plant dry weight of tomato (Del Amor and Marcelis, 2004). Umer (2006) observed that significant increase in root dry weight by the increase in K application rate. Çelik *et al.* (2010) found that increased potassium level enhanced roots and shoot dry weight of the maize crop when applied at the rate of 8 Mm. Wakeel *et al.* (2002) observed that the K application at the rate of 150 ppm per pot showed maximum fresh root and shoot weight in maize. Nawaz *et al.* (2006) found that high shoot dry weight production was a function of high K uptake under stress conditions. Root: shoot dry weight ratio decreased with increase in K^+ application (*Fig. 1*). The reason for reduced root: shoot ratio is that increased K^+ application improved uptake of K^+ from the soil and hence improved photosynthesis in shoots rather in roots. Higher photosynthetic activity improved shoot development hence reducing root: shoot ratio. Similar results were observed by Warncke and Barber (1974) in maize under N-fertilization. Lower root: shoot weight ratios enhanced the availability of assimilates to the shoot resulting in improved grain production and water use efficiency in cereals (Passioura, 1983). Potassium application improved physiological attributes of maize crops (*Table 5*), as it has osmotic role in plant body, so more K application facilitated more uptake of K^+ by roots and shoots of maize, resulting in large leaf area formation (Behboudian and Anderson, 1990) and improved photosynthesis, rate of transpiration and stomatal conductance. Duli *et al.* (2001) observed high photosynthetic rate under K application. Bednarz and Oosterhuis (1998) stated that K deficiency decreased net photosynthesis, stomatal conductance and substomatal CO_2 concentration and reduced photosynthetic efficiency in maize and sugar beet (Terry and Ulrich, 1973). Jayasekara *et al.* (1991-1993) observed high transpiration rate and stomatal conductance when high concentration of K^+ was applied. Egilla *et al.* (2005) also studied that adequate potassium application increases rate of transpiration significantly. It was also observed that increase in potassium concentration enhanced water use efficiency of maize (*Fig. 2*) because K acts as osmotic solute in plant body. More K application increased the K^+ uptake by maize plants generating more cell turgor. Similar results were found by Fanaei *et al.* (2009). They stated that K fertilization improved physiological characteristics of crop under drought stress condition, and enhanced WUE of the crops. Same results were also found by Egilla *et al.* (2005) and Marschner (1995). Significant improvement in nutrient uptake and concentration in roots and shoots was observed with increased K application (*Tabs. 3 and 4*). More K fertilization increased the physiological traits and shoot development resulting in more removal of nutrients from soil. Mengel *et al.* (1976) used labeled $NH^{4-}N$ of a solution with N^{15} and observed that higher potassium concentration in that solution increased translocation of labeled N from the roots to the shoots. Johnson *et al.* (1997) found that N uptake efficiency of maize was improved with increasing soil K concentration.

Potassium fertilization enhanced nutrient uptake improving growth parameters, physiological traits and nutrient uptake significantly. There was a significant positive relationship between root and shoot nutrient concentration with physiological traits and WUE of maize.

CONCLUSION

Potassium fertilization improved growth and physiological characteristics of maize. Furthermore, it enhanced WUE and reduced root: shoot dry weight ratio of maize. In this way it increases nutrient uptake in water deficit condition. These all parameters finally results in high yield with minimum water usage. So, potassium should be included in all fertilization strategies of maize crop to get optimum yield. It could prove a tool to solve food scarcity problem in developing world.

Acknowledgment. This research was supported by the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan.

REFERENCES

Akhtar M.E., M.T. Saleem, M.T. Stauffer, 2003 - Potassium in Pakistan Agriculture. Pakistan Agricultural Research Council, Islamabad, pp. 80.

Allison L.E., C.D. Moodie, 1965 – Carbonate, pp.1379-1396. *In:* Black C.A. (ed.) Methods of soil analysis, Part 2: Chemical and microbiological properties. ASA, Madison, WI, USA.

Anonymous, 2009-'10 - Agricultural Statistic of Pakistan. Ministry of Food and Agriculture and Livestock. Government of Pakistan, Islamabad.

Bednarz C.W., D.M. Oosterhuis, 1998 - Leaf photosynthesis and carbon isotopes discrimination of cotton in response to potassium deficiency. Environ. Exp. Bot., 39:131-139.

Behboudian M.H., D.R. Anderson, 1990 - Effects of potassium deficiency on water relations and photosynthesis of the tomato plant. Plant Soil, 127:137-139.

Bhattacharyya B.K., 2000 - Response to applied potassium in important crops and cropping systems in West Bengal. Workshop Proc. PPIC-IP, Calcutta, pp: 55-60.

Bouyoucos G.J., 1962 - Hydrometer method improved for making particle size analysis of soils. Agron. J., 53:464-465.

Çelik H., B.B. Aşik, S. Gürel, A.V. Katkat, 2010 - Effects of potassium and iron on macro element uptake of maize. Žemdirbystė, 97:11-22.

Chapman H.D., 1965 - Cation-exchange capacity, 9:891-901. *In:* Black, C.A. (ed.) Methods of soil analysis - Chemical and microbiological properties, Agronomy.

Del Amor F.M., L.F.M. Marcelis, 2004 - Regulation of K uptake, water uptake, and growth of tomato during K starvation and recovery. Sci Hortic-Amsterdam, 100:83-101.

Dowswell R.C., R.L. Paliwal, R. Cantrell, 1996 - Maize is the third world Winrock Development-Oriented Literature Series, West view Press, Boulder, Colo., p. 268.

Egilla J.N., F.T. Davies, M.C. Drew, 2001 - Effect of potassium on drought resistance of *Hibiscus rosa-sinensis*cv. Leprechaun: plant growth, leaf macro- and micronutrient content and root longevity. Plant Soil, 229:213-224.

Egilla J.N., F.T. Davies, T.W. Boutton, 2005 - Drought stress influences leaf water content, photosynthesis, and water-use efficiency of *Hibiscus rosa-sinensis* at three potassium concentrations. Photosynthetica, 43:135-140.

Fanaei H.R., M. Galavi, M. Kafi, A.G. Bonjar, 2009 - Amelioration of water stress by potassium fertilizer in two oilseed species. Int. J. Plant Prod., 3:41-54.

Hamza M.A., W.K. Anderson, 2003 - Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. Aust. J. Agr. Res., 54:273-282.

Hsiao T.C., R.H. Hagemen, E. H. Tyner, 1970 - Effects of potassium nutrition on protein and total free amino acids in *Zea mays.* Crop Sci., 10:78-82.

Heckman J. R., E. J. Kamprath, 1992 - Potassium accumulation and corn yield related to potassium fertilizer rate and placement. Soil Sci. Soc. Am. J., 56:141-148.

Igras J., V. Danyte, 2007 - Potassium concentration in tissue water as an indicator of crop potassium require. Proceedings of International Conference Plant Nutrition and its prospects, Brno, Czech Republic, pp. 47-51.

Jackson M.L., 1962 - Nitrogen determination from soils and plant tissues. *In:* Soil Chemical Analysis.

Constable and Company, Ltd. London, pp. 183-204.

James W.B., 2004 - Wheat irrigation, water quality and irrigation management. Extension service, Washington State University, USA.

Jayasekara C., R.G. Mudalige, C.S. Ranasinghe, 1991-1993 - Effect of N, K, Cl on photosynthesis and water relations of open pollinated tall *(typica)* coconut seedlings. COCOS, 9:30-39.

Johnson J.W., T.S. Murrell, H.F. Reetz, 1997 - Balanced fertility management: a key to nutrient use efficiency. Better Crops 81:3-5.

Lean G., D. Hinrichsen, A. Markham, 1990 - WWF atlas of the environment. New York, Prentice Hall Press, pp: 25-28.

Marschner H., 1995 - Mineral nutrition of higher plants. 2nd ed., Academic Press, New York, USA.

Mason J.L., 1963 - Flame-photometric uetermination of potassium in unashed plant leaves. Anal. Chem., 35:874-875

Mengel K., M. Viro, G. Hehl, 1976 - Effect of potassium on uptake and incorporation of ammonium-nitrogen of rice plants. Plant Soil, 44:547-558.

Nawaz I., Zia-ul-Hassan, A.M. Ranjha, M. Arshad, 2006 - Exploiting genotypic variation among fifteen maize genotypes of Pakistan for potassium uptake and use efficiency in solution culture. Pak. J. Bot., 38:1689-1696.

Nelson D.W., L.E. Sommers, 1982 - Total carbon, organic carbon and organic matter. pp. 570-571. In*:* Methods of soil analysis. Part 2: Chemical and microbiological properties. Agronomia, Mongr. 9; SSSA, Madison, WI, USA.

Parsons K.J., V.D. Zheljazkov, J. MacLeod, C.D. Caldwell, 2007 - Soil and tissue phosphorus, potassium, calcium and sulfur as affected by dairy manure application in a no-till corn, wheat and soybean rotation. Journal of Agronomy, 99:1306-1316.

Passioura J.B., 1983 - Root and drought resistance. Agriculture Water management, 7: 265-280.

Peoples T.R., D.W. Koch, 1979 - Role of potassium in carbon dioxide assimilation in *Medicago sativa* L. Plant Physiol., 63:878-881.

Pingali P., S. Pandey, 2002 - Meeting world maize need: Technological opportunities and priorities for public sector. CYMMIT world maize facts and trends, pp: 1-9.

Rengel Z., M.P. Damon, 2008 - Crops and genotypes differ in efficiency of potassium uptake and use. Physiol. Plantarum, 133:624-636.

Richard L.A., 1954 - Diagnosis and improvements of saline and alkali soils. U.S. Salinity Laboratory DA. U.S Dept. Agri. Hand Book No. 60: 60-160.

Roshani G.A., G. Narayanasamy, 2010 - Effects of potassium on temporal growth of root and shoot of wheat and its uptake in different soils. Int. J. Plant Prod., 4:25-32.

Terry N., A. Ulrich, 1973 - Effects of potassium deficiency on the photosynthesis and respiration of leaves of Sugar beet. J. Plant Physiol., 51:783-786.

Steel R.G.D., J.H. Torrie, D. A. Dickey, 1997 - Principles and procedures of statistics: a biometrical approach. 3rd ed. McGraw Hill Book Co., Inc. New York, pp: 400-428.

Tzortzakis N.G., 2010 - Potassium and calcium enrichment alleviate salinity-induced stress in hydroponically grown endives. Hort. Sci. (Prague), 37:155-162.

Umar S., 2006 - Alleviating adverse effects of water stress on yield of sorghum, mustard and groundnut by potassium application. Pakistan J. Bot., 38:1373-1380.

Wakeel A., A. Hassan, T. Aziz, M. Iqbal, 2002 - Effect of different potassium levels and soil texture on growth and nutrient uptake of maize. Pakistan

Journal of Agricultural Science, 39:99-103.

Warncke D.D., S.A. Barber, 1974 - Root development and nutrient uptake by corn grown in solution culture. Agron. J., 66:514-516.

Watanabe F.S., S.R. Olsen, 1965 - Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. Soc. Am. Proc., 29: 677-678.

Zhao D., D.M. Oosterhuis, C.W. Bednarz, 2001 - Influence of potassium deficiency on photosynthesis, chlorophyll content, and chloroplast ultrastructure of cotton plants. Photosynthesis. 39:103-109.

http://dx.doi.org/10.1023/A:1012404204910