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EXPLOITING GENOTYPIC VARIATION AMONG FIFTEEN MAIZE GENOTYPES OF PAKISTAN FOR POTASSIUM UPTAKE AND USE EFFICIENCY IN SOLUTION CULTURE

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Abstract

Potassium (K) status of Pakistani soils is rapidly decreasing at an alarming rate. Thus, the exploitation of genotypic variation among the major crops of Pakistan could be helpful for future breeding of K-efficient genotypes. Fifteen maize genotypes were grown under K adequate (AK) and deficient (DK) conditions in hydroponics. Substantial variation was observed in the biomass accumulation, allocation and K uptake and use efficiency among genotypes at two contrasting levels of K. K deficiency decreased the biomass and increased the RSR of the maize genotypes. K uptake was highly correlated with shoot dry weight (SDW) production at DK and hence could be utilized as a selection criterion for K-efficient genotypes.

Keywords: Maize, genotypic variation, potassium, biomass, KUE, RSR

Introduction

Low nutrient use efficiency is a major problem in modern agriculture and its enhancement is very important both for reducing cost of agricultural production and for protecting the environment (Zhang *et al.* 1999). Plant genotypes respond differently in their uptake, translocation, accumulation, and use of mineral elements. Efficient plant cultivars could have better fertilizer use efficiency (Epstein & Bloom, 2005) and hence reduce input cost and conserve environment (Baligar *et al.,* 2001). For that, it is very important to identify the genotypes efficient in K use to offer the best opportunities for future breeding research towards low input, sustainable and environment friendly agriculture. Genotypic variation for potassium use efficiency (KUE) in Pakistan and elsewhere was reported in lentil (Ashraf *et al.,* 1997), wheat (Zhang *et al.,* 1999), rice (Yang *et al.,* 2003), chickpea (Gill *et al.,* 2005), cotton (Makhdum *et al.,* 2007) and maize (Minjian *et al.,* 2007).

In Pakistan, soil K status is rapidly decreasing at an alarming rate. National K balance during 1985-86 was –20 kg ha^{-1} which became –25.8 kg ha^{-1} during 1995-96 (Ahmad & Rashid, 2003), making the net draining rate even steeper (300 g ha^{-1} yr^{-1}). This may be greatly due to the negligible (0.8 kg ha^{-1} yr^{-1}) use of K in Pakistan as compared to world average K use (15.1 kg ha^{-1}) (MINFAL, 2007). In such a scenario, K may be the limiting factor especially for those major crops of Pakistan that require this nutrient in high amounts. According Hoeft (2007), a maize crop yielding about 12 t ha^{-1} averagely uptakes even more K (6.9 kg ha^{-1} day^{-1}) than N (5.5 kg ha^{-1} day^{-1}) and P (1.6 kg ha^{-1} day^{-1}).

Keeping in view the above information, it is imperative to exploit the maize genotypes of Pakistan which possess high KUE and could be utilized as potential

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candidates under soil K stress. The present study was aimed at exploring the genetic variation among fifteen maize genotypes for their KUE and biomass production under adverse soil K environment.

Material and Methods

A solution culture experiment was carried out in the rain-protected glass house of the Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, during July-August, 2005. The seeds of fifteen maize genotypes, viz. C53, C58, C77, C78, C84, C104, C107, C108, C110, C113, C115, C116, C120, C121, C122 were obtained from Maize Section, Ayub Agricultural Research Institute, Faisalabad, Pakistan. Seeds were germinated in plastic tubs (28″ x 14″ x 12″) containing pre-washed sand. Separate tubs were used for the germination of each genotype. Distilled water was sprinkled over these tubs to maintain optimum moisture contents for seed germination and seedling establishment. Fifteen days after sowing uniform sized seedlings were transplanted in foam plugged holes of thermopal sheets floating on continuously aerated 100 L half strength modified Johnsons's solution (Johnson *et al.*, 1957) in four polyethylene lined iron tubs (1 m x 0.5 m x 0.3 m). The basal composition of nutrient solution (mM) was: N 6.0, P 0.2, K 3.0 (adequate) or 0.3 (deficient), Ca 2.0, Mg 1.0, S 3.5, Cl 50.0, B 25.0, Mn 2.0, Zn 2.0, Cu 0.5, Mo 0.5 and Fe-EDTA 50.0.

The experiment was laid out in completely randomized factorial design with six repeats (one plant per repeat). Forty five plants were maintained in each tub by randomly repeating 3 plants of each cultivar in equally spaced numbered holes. In total, two tubs contained solution with adequate level of K (3.0 mM) and two tubs contained the solution modified to the deficient level of K (0.3 mM). The pH of nutrient solution was daily monitored and maintained at 5.5±0.2 using H_2SO_4 and/or Ca $(OH)_2$.

Plants were harvested 35 days after transplantation in tubs. Harvested plants were washed thoroughly with distilled water, blotted dry using blotting paper and separated into shoots and roots. The shoot and root samples were dried at 70°C for 2 d in a forced air-driven oven to a constant weight. Dry weights (g plant^{-1}) of shoot (SDW) and root (RDW) were recorded on a digital top-loaded balance (Setra BL-4100S, Setra System Inc., USA). The SDW and RDW were summed up to compute total dry weight (TDW). Root:shoot ratio (RSR) was calculated by dividing the RDW with SDW. The samples were then ground in a Wiley Mill. K concentration (mg g^{-1} dry weight) of shoot (SKc) and root (RKc) was determined from a 0.5 g sample digested in a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$), in the ratio of 3:1 (Miller, 1998). K concentration was determined using a flame photometer (Jenway PFP-7). K uptake (mg plant^{-1}) of shoot (SKu) or root (RKu) was calculated by using the formula, SKu or RKu = SKc or RKc (mg g^{-1} dry weight) × SDW or RDW (g plant^{-1}). KUE (g^2 SDM mg^{-1} shoot-K) was calculated by dividing the SDW (g plant^{-1}) with SKc (mg g^{-1} dry weight). Relative reduction in various parameters was calculated by using the formula: 100 ─ [(parameter value at DK/parameter value at AK) × 100].

Statistical analysis: Data were subjected to statistical analyses according to standard procedures (Steel & Torrie, 1980) using 'MSTAT-C' (Russell & Eisensmith, 1983), and the methods described by Gomez & Gomez (1984). Completely randomized factorial design (factorial CRD) was employed for analysis of variance (ANOVA). The separation of treatment (P-level) means was done by using Duncan's New Multiple Range test (DMRT). The means of cultivars at each level of P were separated using DMRT at each cultivar level by employing completely randomized design. The relationship between various parameters and SDW was determined by performing correlation by utilizing the data analysis tool pack of computer spreadsheet software MS-Excel (Microsoft®).

Results

Dry weights of shoots of different genotypes of maize grown at adequate or at deficient K^+ regimes showed that there was a significant inhibitory effect of low K on shoots dry weight of all maize genotypes except in C53, C115, C116 and C120. Furthermore, low K^+ regime enhanced the shoot dry weight in C116 only while in other maize genotypes it remained almost unchanged (Table 1; Fig 1). In contrast, low K regime did not significantly change the root dry weight. Since genotypes and the interaction term Genotype x K level were significant, it was legitimate to compare the mean root dry weight of each genotype at different K regimes. From mean data, it is obvious that root dry weight was only enhanced in C116 when grown at low K^+, while in C58, C77, C84, C120, and C122 it reduced significantly. However, root dry weight in other maize genotypes remained unchanged (Table 1; Fig 1). Data for total plant dry weight also showed genetic variation at adequate or deficient level of K. Low K enhanced the total dry weight in C116 only while in other genotypes either it remained unchanged or decreased (Table 1, 2; Fig 1). However, maximum total dry matter was observed in C107 and C108, whereas at low K regime same was true for C116 followed by C121 and C120. Data for root:shoot ratio showed that both K regimes had inconsistent effect on this growth attribute of all genotypes. In most of maize genotypes, low K enhanced the root:shoot ratio (Table 2; Fig 1). However, the minimum root:shoot ratio was found in C116, C120 and C121 at low K regime, whereas the same was true for C107 at adequate K regime. Likewise, C58, C78, and C84 had highest root:shoot ratio at deficient level of K, whereas the same was true for C53 followed by C58 and C115 (Fig. 1).

Table 1. Mean squares for analysis of variance of various parameters of maize genotypes.

Parameter	K-level (K)	Genotype (G)	K x G
SDW	181.38**	43.46**	68.54****
RDW	0.15NS	1.96**	4.08****
TDW	171.1**	51.17**	91.56****
RSR	0.17****	0.017**	0.02***
KUE	0.09NS	0.18***	0.07NS
SKU	649761****	127362****	85027****
RKU	59648****	2848****	6012****
TKU	1103144****	123552****	114295****

, * and **** significant at 0.01, 0.001 and 0.0001 level, respectively; NS = non-significant

Table 2. Average performance of maize genotypes at deficient and adequate K-levels and relative reduction in various parameters at deficient relative to adequate K-level (considered 100) in solution culture.

Parameter (unit)	Adequate K	Deficient K	Relative reduction
SDW (g plant^{-1})	18.66±0.59	16.20±0.71	13
RDW (g plant^{-1})	6.76±0.12	6.84±0.17	-1
TDW (g plant^{-1})	25.42±0.67	23.03±0.79	9
RSR	0.38±0.01	0.45±0.02	-18
KUE (g^2 SDW mg^{-1} shoot K)	0.64±0.03	0.70±0.04	-9
SKU (mg plant^{-1})	564.12±19.5	416.95±29.7	26
RKU (mg plant^{-1})	84.02±6.09	39.43±2.57	53
TKU (mg plant^{-1})	648.14±19.8	456.38±31.7	30

Table 3. Relationship of various parameters of maize genotypes with shoot dry matter at deficient and adequate levels of K in solution culture.

Parameter	Adequate K	Deficient K
RDW	0.66***	0.39NS
RSR	-0.77***	-0.77****
KUE	0.82***	0.36NS
SKU	0.54*	0.87****
RKU	-0.10NS	0.85***
TKU	0.53*	0.88***

, * and **** significant at 0.01, 0.001 and 0.0001 level, respectively; NS = non-significant

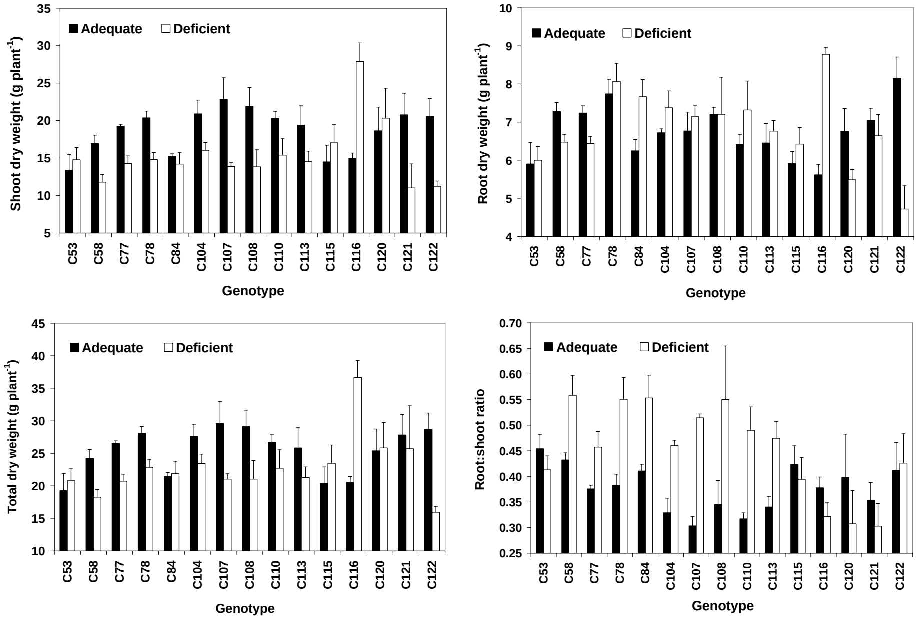

Fig. 1. Biomass production and allocation of maize genotypes at adequate and deficient K-levels in solution culture.

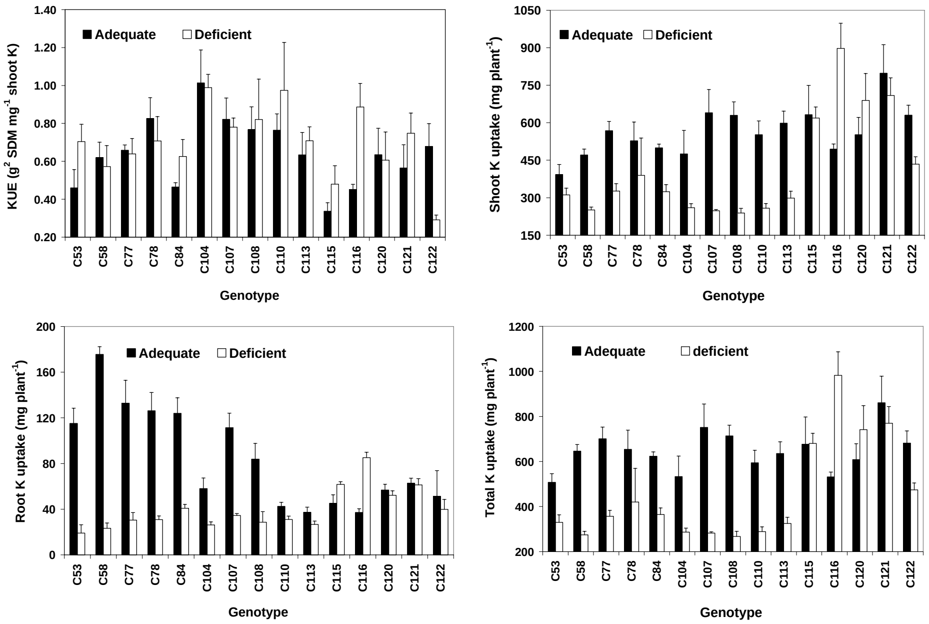

Fig. 2. K use efficiency (KUE) and K uptake of maize genotypes at adequate and deficient K-levels in solution culture.

In case of KUE, highly significant differences were found among maize genotypes; however, these differences were non-significant for K-levels and K x genotype interaction (Table1). Mean KUE at AK was 0.64 g^{2} SDW mg^{-1} shoot K while at DK 0.70 g^{2} SDW mg^{-1} shoot K. K stress increased the KUE by 9% (Table 2). At AK.,the minimum (0.34 g^{2} SDM mg^{-1} shoot K) KUE was exhibited by C115 while the maximum (1.01 g^{2} SDM mg^{-1} shoot K) by C104. At DK, the minimum (0.29 g^{2} SDM mg^{-1} shoot K) KUE was achieved by C122 and the maximum (0.90 g^{2} SDM mg^{-1} shoot K) by C104 (Fig. 2).

K uptake of maize genotypes was significantly affected by all the sources of variation (Table 1). Mean SKu at AK was 564.14 mg palnt^{-1} while at DK it was 416.95 mg plant^{-1}. A large reduction (26%) was noted in SKu due to K stress relative to control (Table 2). At AK., the maximum SKu (798.30 mg plant^{-1}) was observed for C121 while the minimum (392.62 mg plant^{-1}) for C53. At DK, the maximum SKu (897.25 mg plant^{-1}) was found for C116 whereas the minimum (239.03 mg plant^{-1}) for C108 (Fig.2). Mean RKu at AK was 84.02 mg plant^{-1} and at DK was 39.43 mg plant^{-1}. RKu proved to be the most badly affecting parameter due to K stress by exhibiting a reduction of 53% at DK relative AK (Table 2). At AK., RKu was minimum (37.23 mg plant^{-1}) for C116 and maximum (175.57 mg plant^{-1}) for C58. At DK., RKu was maximum (85.10 mg plant^{-1}) for C116 and minimum (19.07 mg plant^{-1}) for C53 (Fig. 2). Mean TKu at AK was 648.14 mg plant^{-1} while at DK it was 456.38 mg plant^{-1}, resulting in a steep decrease of 30% due to K stress relative to its adequacy (Table 2). At AK, minimum TKu (507.82 mg plant^{-1}) was found for C53 while the maximum (861.13 mg plant^{-1}) for C12. At DK, the minimum TKu (267.61 mg plant^{-1}) was observed for C108 and maximum (982.36 mg plant^{-1}) was achieved by the cultivar C116 (Fig. 2).

The relationship of various parameters (Table 3) revealed highly significant correlation between SDW and K uptake at both the levels of solution K, except that RKu did not relate significantly with SDW at AK. Moreover, a highly significant correlation between SDW and RSR was observed at both the levels of solution K. The RDW and KUE significantly contributed towards SDW at AK but their relationship with SDW at DK was non-significant.

Discussion

Although low K regime of the rooting medium had an adverse effect on the growth of most of genotypes, root growth of most genotypes was generally enhanced. Furthermore, considerable genetic variation exists among maize genotypes for growth at different K regimes. From the results of the present study, it is obvious that genotypes showing higher growth had lower root biomass at adequate level of K or at deficient level of K except C116 which had greater shoot and root biomass at low K regime. This view is further supported by the fact that high biomass producing genotypes (C120, C121) at low K level had minimum root:shoot ratio. Thus, differential growth responses of these genotypes to different K regimes were due to differences in pattern of biomass accumulation in shoots or roots. These results are similar with those of Peuke *et al*. (2002) who found that in *Ricinus communis* K deficiency inhibited the shoot growth particularly younger leaves at the expense of root growth. By contrast, in genotype C116 both shoot and root growth was enhanced at low K, which may have been due to its low K requirement. It is widely accepted that all mineral nutrients are taken up through the root which required energy from photo-assimilates and K deficiency cause accumulation of soluble sugars in K deficient plant parts (Epstein & Bloom, 2005). There was another possibility that K deficiency enhanced N uptake which may have been contributed in higher root growth as has earlier been observed in sweet potato (Osaki *et al*., 1995). In view of this information, it is suggested that K deficiency may have caused the accumulation of sugars or stimulated nutrient uptake which resulted in higher root growth at the expense of shoot growth. However, this is in contrast to what have suggested by Hermans *et al*. (2006) in an extensive review that K deficiency causes the accumulation of sugars in both roots and shoots but higher accumulation of soluble sugars did not improve the root growth. Thus, the deep insights how K deficiency enhance the root growth needs to be elucidated.

The present study was also aimed to examine genotypic variation in some maize genotypes of Pakistan for their suitability to become potential candidates in offering best possible yields under K stress conditions. We found substantial variation among maize genotypes for biomass production, allocation, and K uptake and use efficiency, clearly indicating the existence of genotypic variation that could be utilized in K stressed low input agriculture. Earlier studies also reported genotypic variation for biomass production at different K levels and a decrease in growth/biomass production due to K deficiency in wheat (Zhang *et al.,* 1999), sweet potato (Melvin *et al.,* 2002), rice (Yang *et al.,* 2003), chickpea (Gill *et al.,* 2005) and maize (Minjian *et al.,* 2007). KUE and K uptake of maize genotypes also reflected considerable variation that could be used for the selection of K-stress tolerant genotypes. Earlier workers also found such genotypic variation for KUE and K uptake in cotton (Bednarz *et al*., 1999), wheat (Zhang *et al.,* 1999), *amaranthus* (Shuxin *et al*., 2000), sweat potato (Melvin *et al*., 2002), rice (Yang *et al*., 2003) and chickpea (Gill *et al.*, 2005). Thus, our results clearly demonstrated that maize genotypes vary in their biomass production and allocation and, irrespective of K level in the nutrient medium. However, higher growth at K deficient level was due to higher K uptake. Thus, K uptake efficiency could be effectively utilized as an index for selecting K-efficient maize genotypes.

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