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Potassium Deficiency-Stress Tolerance in Wheat Genotypes II: Soil Culture Study

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ABSTRACT

Identification of nutrient efficient cultivars as low cost, low input technology is considered as one of the most efficient approaches for improving crop production in resource-poor environment. A pot experiment was conducted to evaluate nine wheat genotypes for their relative efficiency to utilize K under deficient and adequate K supply. A basal dose of nitrogen and phosphorous (as P) was applied @ 100 and 50 mg kg^{-1} in both the treatments while potassium was applied @ 50 mg kg^{-1} only to adequate K treatment. The effect of K levels; genotypes and their interaction were statistically significant for almost all the parameters studied. Potassium deficiency substantially decreased grain yield, straw yield, total biomass, K concentration in cell sap, grain and straw and K uptake in grain, straw and total K uptake. Whereas, K utilization efficiency in straw increased at deficient K supply and there was no change in mean harvest index at both K levels. Genotype Dirk produced maximum grain at both K levels. Grain yield had a significant positive correlation with potassium utilization efficiency and total K uptake (r = 0.82, 0.62, respectively n = 27). It was concluded from this experiment that wheat genotypes differ in growth responses when grown at deficient and adequate K levels. The cultivars, which proved to be efficient for K utilization and accumulation, gave maximum yield under deficient and adequate K supply.

Key Words: Wheat; Potassium deficiency; Genotype

INTRODUCTION

Potassium is the third major element in plant nutrition and is vital for many important metabolic functions. After nitrogen, plants require K in larger amounts than any other element. Its total reserves in the soil are generally adequate and it is the seventh most abundant element in the soils of world (Ellington, 1980). Fertilizer use in Pakistan has increased several folds since its introduction in 1950's. However, the use of fertilizer has mainly been confined to the application of nitrogen and phosphorus, while ignoring K, due to the general consensus that soils of Pakistan contain sufficient amounts of potassium due to the dominance of illite in their clay fraction. However, its availability is governed by the equilibrium between different forms of K in the soil system and influenced by many physical and biological factors. But even under conditions in which soil tests indicated relatively high K availability, plant growth and crop yield demonstrated pronounced positive responses to applied potassium (Walker, 1979). Because of aforesaid facts crops are responding to K fertilization. In soils of Pakistan, although total soil K is quite high but its release fails to meet the immediate K requirement of crops. Additionally, the increase in cropping intensity and introduction of high yielding varieties have also resulted in depletion of soil K reserves which in turn caused an annual deficit of 0.265 million tones of K from Pakistan soils. Under such conditions (i.e., when K availability impose a limit upon plant growth) it might be anticipated that competition for the available K, arising from the interaction of two or more genotypes growing in close proximity, might have a strong influence on growth. Therefore, the identification of germplasm better adapted to low K conditions would be useful in areas where soils are low in K and K fertilizer are too costly or unavailable.

The objective of the present study was to study growth behavior and K relations of the selected genotypes with regard to non-limiting and limiting K supply in soil and relate them to the behavior of these genotypes sand culture experiment.

METERIALS AND METHODS

Pot experiment was conducted to evaluate the behavior of the nine wheat genotypes (Khyber-79, Punjab-81, Kohinoor-83, Rawal-87, Yecora, Zarghoon-79, Maxipak, Inqulab-91 and Dirk) to K deficiency stress in soil as a growth medium. Plastic pots lined with polyethylene bags were filled with 3.2 kg air dried K deficient loamy sand having an ECe: 0.25 d Sm^{-1}; pHs: 8.1; NH_4OAc extractable-K, 70 ppm). Ten seeds of the genotypes were sown in each pot. After germination, seedlings were thinned to three plants with uniform height per pot. The experimental layout was completely randomized factorial with three replications for each treatment. Basal dose of nitrogen and phosphorus (as P) was applied @ 100 and 50 mg kg^{-1} soil to both the treatments. Potassium was applied @ 50 mg K kg^{-1} soil in half the pots while other half pots received no K. At tillering stage, 3rd leaf from three plants from each pot was collected to determine K concentration in the leaf sap.

Frozen fresh leaf samples were thawed and crushed using a stainless steel rod with tapered end. The sap was collected in other polypropylene tubes by Gilson pipette and centrifuged at 6500 rpm for 10 minutes. The supernatant sap was stored in dilution tubes at freezing temperature until K determination on appropriate dilution of the sap. Plants were harvested at maturity and grain and straw was weighed separately. Potassium from straw and grain samples was determined by wet ashing in di-acid mixture of HNO_3: $HClO_4$ (3:1) and by analyzing the samples on flame photometer. Potassium stress factor (KSF) for genotypes was calculated as $\{(SDW_{adeq} - SDW_{def\ K}) / (SDW_{adeq})\}*100$. Potassium utilization efficiency (KUE) in genotypes was calculated as (1/K conc. in shoot mg g^{-1}) x SDW g/plant (Siddiqui & Glass, 1981).

RESULTS AND DISCUSSION

All growth related parameters at maturity of nine wheat genotypes were significantly affected by K treatment, genotypes and their interaction. Table I shows the results of growth parameters measured at maturity. Plants in the pots with K supply had 35% higher mean grain yield (average of nine genotypes) than those at low K supply. Dirk and Inqulab yielded 20 and 7% higher mean grain yield compared to mean grain yield of all cultivars grown with deficient K level. Maxipak and Rawal-87 which had the lowest grain yield at deficient K, showed maximum response to K application and their grain yield was almost doubled with K addition, implying that both these genotypes were highly responsive to K addition.

The differences in straw yield among the genotypes were significant only under adequate K treatment but were narrower compared with grain yield of the genotypes (Table I). Potassium supply resulted in 52% increase (as against 34% increase in grains) in mean straw yield compared to deficient-K treatment straw yield of the genotypes. Dirk had significantly the highest straw yield compared to other genotypes (except Zarghoon 79) in adequate K treatment.

The magnitude of increase in mean total biomass yield of the genotypes with adequate K compared to deficient K treatment was similar to that of straw yield (52%). The differences in total biomass among the genotypes were significant in both K treatments. Similar to straw yield, these differences though significant, were smaller among the genotypes. In deficient K treatment, total biomass of Khyber-79 was the highest compared to other genotypes. However, in adequate K treatment, total biomass of Dirk was significantly higher compared to all other genotypes.

Harvest index (HI) remained unaffected by K treatment (Table I). Maxipak was the only genotype among the nine, whose HI was improved considerably (200%) by K addition to soil. The HI varied between 37 to 48% among wheat genotypes.

KSF for grain and total biomass is presented in Table III. Differences among the genotypes for KSF (grain) were about 3-fold. The highest KSF as observed in Maxipak while the lowest in Khyber-79. KSF for total biomass followed the same trend as for grain; however, it increased (50%) in Yecora and decreased in Maxipak (20%). High value of KSF shows the relative responsiveness of the genotypes to K supply.

Measurement of inorganic ion concentration in leaves is a potential diagnostic tool and might enable us to determine soil nutrient supplies more accurately. Data regarding K concentration in leaf cell sap is presented in Table I. There was a significant effect of K levels, genotypes and their interaction on K concentration in cell sap. Potassium concentration in cell sap of K deficient genotypes ranged between 75 to 158 mmol L^{-1} with a mean value of 113 mmol L^{-1} and was lower than the critical limit of K in sap (130 mmol L^{-1}) suggested by Barraclough (1993). The data clearly indicated that these plants were deficient in K at vegetative growth stage. Mean value of K in genotypes given adequate K was 181 mmol L^{-1} with a range of 148 – 213 mmol L^{-1} in the genotypes. However, K

Table I. Total biomass, grain yield, straw weight and potassium concentration in plant sap and straw of genotypes at deficient and adequate K levels

Varieties	Total Biomass (g pot^{-1})		Grain Yield (g pot^{-1})		Straw Weight (g pot^{-1})		K in Cell Sap (mM L^{-1})		K conc. in straw (mg g^{-1})	
	Def. K	**Adeq. K**	**Def. K**	**Adeq. K**	**Def. K**	**Adeq. K**	**Def. K**	**Adeq. K**	**Def. K**	**Adeq. K**
Khyber 79	19.15 ab	23.06 e	7.80 abc	9.39 d	11.35$^{N.S.}$	13.67 cd	88.4 bc	173.9 ab	13.03^{NS}	21.10^{NS}
Punjab 81	17.11 bc	25.30 cde	8.07 ab	11.35 c	9.05	13.97 bcd	119.3 abc	147.7 ab	16.07	24.70
Kohinoor 83	16.98 bc	24.02 de	7.60 bc	9.73 d	9.38	14.29 bcd	123.4 abc	150.5 b	11.53	18.93
Rawal 87	15.08 c	25.61 cde	6.13 d	11.48 c	8.96	14.13 bcd	129.0 ab	213.9 a	13.80	18.40
Yecora	16.97 bc	24.83 cde	7.95 abc	10.35 cd	9.02	14.48 bcd	109.4 abc	201.9 ab	12.83	22.20
Zarghoon 79	15.65 c	26.52 bcd	6.47 cd	10.27 cd	9.17	16.26 ab	158.9 a	199.9 ab	14.37	20.27
Maxi Pak	16.36 bc	27.85 bc	6.03 d	12.87 b	10.33	14.99 bc	93.5 bc	183.2 ab	11.83	22.20
Inqlab 91	17.63 abc	28.71 b	7.94 abc	13.59 b	9.69	14.82 bcd	116.8 abc	182.3 ab	13.23	23.10
Dirk	17.27 abc	33.07 a	9.33 a	15.28 a	11.13	17.79 a	75.7 c	167.3 ab	12.20	20.57
Mean	17.39 B	26.55 A	7.48 B	11.62 A	9.79 B	14.93 A	112.9 B	180.1 A	13.21 B	21.27 A

Mean with different letter (s) differ significantly according to Duncan's Multiple Range test (P = 0.05)

Table II. Potassium concentration and uptake in grain, K uptake in straw, total K uptake and K utilization efficiency of wheat genotypes at Deficient and adequate K levels

Varieties	K conc. in grain ($mg\ g^{-1}$)		K Uptake In Straw (mg)		K Uptake In Grain (mg)		Total K Uptake (mg)		KUE (g^2 grain weight mg^{-1} K	
	Def. K	Adeq. K	Def. K	Adeq. K	Def. K	Adeq. K	Def. K	Adeq. K	Def. K	Adeq. K
Khyber 79	5.00 NS	6.67 NS	150.6 NS	286.2 bcd	39.02 bc	62.43 d	189.6 NS	348.6 cd	1.56 ab	1.42 d
Punjab 81	5.00	6.00	143.8	344.9 a	40.66 bc	67.96 d	184.4	412.9 ab	1.65 a	1.89 bc
Kohinoor 83	5.00	6.67	108.4	270.4 cd	38.02 bc	64.52 d	146.4	334.9 d	1.52 ab	1.48 cd
Rawal 87	6.00	7.00	124.4	259.9 d	36.76 bc	79.93 bc	161.2	339.8 cd	1.02 c	1.67 bcd
Yecora	5.67	6.33	112.5	320.0 abc	45.44 ab	64.76 d	158.0	384.8 bcd	1.40 abc	1.66 bcd
Zarghoon 79	5.67	7.00	132.3	325.3 ab	36.30 bc	71.51 cd	168.6	396.8 bc	1.18 bc	1.50 cd
Maxi Pak	5.33	6.33	121.9	331.8 ab	32.43 c	81.76 bc	153.8	413.5 ab	1.13 bc	2.04 ab
Inqlab 91	5.33	6.00	128.6	342.1 a	42.17 bc	83.34 b	170.7	425.5 ab	1.51 ab	2.31 a
Dirk	6.00	6.33	135.7	365.8 a	55.96 a	96.63 a	191.6	462.4 a	1.50 ab	2.43 a
Mean	5.44 B	6.48 A	128.6 B	316.6 A	40.75 B	74.75 A	169.4 B	391.0 A	1.39 B	1.82 A

Mean with different letter (s) differ significantly according to Duncan's Multiple Range test (P = 0.05)

Table III. Potassium utilization efficiency (KUE), harvest index (HI) and stress factor for grain and total biomass of wheat genotypes at deficient and adequate K levels

Varieties	KUE (g^2 straw weight (mg^{-1} K)		Harvest Index (HI))		Grain KSF (%)	Total KSF (%)
	Def. K	Adeq. K	Def. K	Adeq. K		
Khyber 79	0.83 abc	0.62 abc	0.41 ab	0.41 bc	17 c	17 b
Punjab 81	0.61 c	0.56 c	0.47 a	0.45 abc	29 b-e	32 a
Kohinoor 83	0.83 abc	0.70 abc	0.45 a	0.41 bc	21 cde	29 ab
Rawal 87	0.65 bc	0.77 abc	0.41 ab	0.45 abc	47 ab	41 a
Yecora	0.79 abc	0.59 bc	0.47 a	0.42 abc	20 de	30 a
Zarghoon 79	0.65 bc	0.83 ab	0.41 ab	0.39 c	37 a-d	40 a
Maxi Pak	0.96 a	0.68 abc	0.36 b	0.46 ab	53 a	41 a
Inqlab 91	0.71 abc	0.65 abc	0.45 a	0.48 a	43 ab	39 a
Dirk	0.91 ab	0.87 a	0.46 a	0.46 ab	39 abc	38 a
Mean	0.77 A	0.72 B	0.43	0.44	34	34

Mean with different letter (s) differ significantly according to Duncan's Multiple Range test (P = 0.05)

concentration in grain and straw (at maturity) did not differ significantly among the genotypes but differences were significant due to K levels only. Potassium concentration in straw at harvest also clearly showed that plants were K starved in K deficient treatments (critical limit in straw; 2 – 5% K). Potassium concentration in grain of the genotypes in adequate K treatment was 19% higher than that of deficient K treatment. As against grain, the straw of adequate K genotypes had 61% K concentration than that of deficient K treatment. Concentration of K in straw was about 2 to 3-folds higher than K concentration in grain (Table I).

The differences in K uptake (content) were significant both due to genotypes, K treatments and their interaction (Table II). Dirk had the highest total and grain K content in deficient K treatment. The lowest total K content as well straw K content was observed in Kohinoor-83. Potassium content in straw was 3 to 4-folds higher than K contents in grain

Potassium utilization efficiency (KUE) also differed significantly due to genotypes, K treatments and their interaction. KUE in the straw was significantly lower in adequate K compared to deficient K treatment while the reverse is true for KUE in grain (Table III). However, KUE was about 2-fold higher in grain compared to straw. Wider differences in terms of KUE were found in genotypes in grain as compared to straw in both K treatments.

Under K deficiency, significant differences between genotype in grain yield as well as total biomass clearly indicate that wheat genotypes have differential K requirement for their growth and yield. Other authors have also reported variability among genotypes in grain yield under K stress. This variability was also found for K uptake and utilization efficiency (Gill *et al*., 1997; Woodend, 1987; Fidgore *et al.,* 1987). Grain yield had significant correlation with total K uptake (r = 0.60, n = 27) and K utilization efficiency (r = 0.82, n = 27). Since grain yield is related to K use efficiency and K uptake, these can be used to characterize genotypes as K efficient or inefficient. A low yield was associated with low K uptake and medium utilization efficiency (Maxipak). A high yield was obtained either with high K uptake and medium K utilization efficiency (Dirk) or a medium uptake and high K utilization efficiency (Inqlab-91, Table I & III). Plants with a combination of the observed highest K uptake and the highest K utilization efficiency reached a grain yield that was 25% higher than average grain yield of all cultivars. This study suggests that there is a sufficient genetic variability in K uptake and utilization for further progress to be made by breeding. This approach was also recommended by Sattlemachar *et al*. (1994).

Overall KUE was higher in grain than straw (Table III) in both K deficient and adequate treatment plants. However, KUE in straw was significantly higher in genotypes grown at deficient K compared to plants at adequate K level. The reverse was the case in case of grain, KUE was higher in plants grown at adequate K compared to deficient K plants. Woodened (1987) reported that K utilization efficiency at the vegetative stage correlated with grain yield or grain utilization efficiency. He also proposed that selection for improved potassium utilization efficiency in wheat should be based on grain production rates rather than on vegetative characteristics. However, this relationship cannot be validated in this study since plants were not harvested at vegetative stage to measure KUE.

Regarding K content of shoots, Punjab 81 and Dirk topped under both K levels. While, Yecora lost its position at low K level. On the other hand Maxipak improved its rank position at high K level. Potassium uptake in grain of K deficient genotypes did not relate with K uptake in straw of these genotypes ($r = 0.09$, $n = 27$). This supports the conclusion reported by Haeder and Beringer (1984). They showed that long distance transport of K to grain was not dependent on K nutrition of wheat plant and was proportional to the K in treatment solution. However, K uptake in grain of adequate K treatment, significantly positively correlated with it K uptake in straw ($r = 0.533$, $n = 27$). This did not agree with the conclusion of Haeder and Bermger (1984) reported above. It is suggested that the genotypes may transport K from straw to the grains according to the K content of their shoot when grown with adequate K nutrition in their growth medium.

Potassium in leaf sap of K deficient wheat genotypes had a significant positive correlation with K concentration in straw at maturity ($r = 0.485$, $n = 27$). However, this relationship did not hold true for the genotypes grown with adequate K. It is suggested that measurement of K in leaf sap may be used to determine K nutrition status of wheat genotypes. As yet, not much work has been reported for evidence of genetic variation in field experiments, particularly for K. However, there are lot of reports of field studies showing genotypic differences for P requirement of many crops (Vose, 1960).

It is concluded from this study that wheat genotypes differ in their K requirement. The cultivars, which proved to be efficient for K utilization and accumulation, gave maximum yield under deficient and adequate K supply.

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