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Genotypic variation for potassium uptake and utilization efficiency in Wheat (*Triticum aestivum* L.)

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Generally K-deficiency decreased all the growth parameters, root and shoots K-uptake, root and shoot K-concentration and potassium use efficiency (KUE). However, comparatively less relative reduction (%) or potassium stress factor (KSF) was observed in most of the growth parameters in the genotypes NIA-8/7, NIA-MB-I, SD-4085/3 and SD-4047. Absolute growth rate (g day^{-1}) and relative growth rate (g g^{-1}day^{-1}) was increased by 19 % under K-deficient environment in the genotype SD-4085/3, whereas comparatively less relative reduction was exhibited in the RGR in the genotypes NIA-8/7 (11 %), SD-4047 (14 %), SD- 502 (8 %). Root dry weight showed 8.20% increase in the genotype 22-03 under K-deficient environment, whereas no relative reduction was found in the genotype SD-4085/3 and SD-502 under the same environment (K-deficient). The genotypes NIA-8/7 and SD-4085/3 exhibited 2.89 and 26.69% increase, respectively in the shoot dry weight under K-deficient environment. Among all the nine genotypes evaluated in this study, increase in root potassium uptake under K-deficient environment was found in the genotype 22-03 (27%), whereas comparatively less relative reduction was observed in the genotype SD-4085/3 (6%). The genotype SD-4047 exhibited less relative reduction (8.9%) in the shoot potassium uptake. In conclusion the genotypes NIA-8/7 (0.32 g^{-2} SDW mg^{-1} shoot K), NIA-MB-I (0.2703 g^{-2} SDW mg^{-1} shoot K), SD-4085/3 (0.2987 g^{-2} SDW mg^{-1} shoot K) and SD-4047 (0.2567 g^{-2} SDW mg^{-1} shoot K) had higher potassium use efficiency among all the genotypes evaluated. It was concluded from this study that wheat genotypes differ in growth response and potassium use efficiency (KUE) when grown at deficient and adequate K-level.

Key words: wheat genotype, potassium use efficiency, water stress

Introduction

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Wheat (*Triticum aestivum* L.) is one of most important cereal crops in Pakistan. It is the most important staple food of our country and accounts for 75% of total food grain production and covers the largest area (8.5 mha) under any crop in Pakistan. It adds 12.5% to the value added in agriculture and 2.9% to GDP (Muhammad *et al*., 2005). Pakistan is ranked 9th in wheat production (Anon., 2000). According to recent statistics, the average grain yield of wheat in Pakistan is 2379 kg^{ha-1} which is much lower than other wheat growing countries of the world (Sial *et al*., 2003; Malik, 2006). The main causes of low productivity in wheat are, non-availability of certified seed, irrational use of fertilizer, weed infestation, untimely sowing, scarcity and un-timely application of irrigation water, drought prone varieties and genetic instability of new cultivars, lack of proper price incentive, inadequate adoption of technology to achieve genetic potential and continuous use of wheat cotton rotation.

The ability of a cultivar to produce high and satisfactory yield over a wide range of stress and non-stress environments is very important (Rashid and Ahmed*,* 2003). The response of plants to water stress depends on several factors such as developmental stage, severity and duration of stress and cultivar genetics (Beltrano and Marta, 2008).

One of the mechanisms for improving plant tolerance to drought is to apply K which seems to have a beneficial effect in overcoming soil moisture stress. Potassium fertilizer mitigates the adverse effects of moisture stress in plants by increasing translocation and maintaining water balance within plants (Greenwood and K Appoints, 1997). Numerous studies have shown that the application of fertilizer mitigates the adverse effects of drought on plant growth (Ahmad *et al*., 2007).

Plant genotypes differ in their uptake, translocation, accumulation and use of mineral elements. Efficient plant genotypes have better fertilizer use efficiency (Epstein and Bloom, 2005) and therefore reduce input cost and conserve environment (Baligar *et al.,* 2001). Potassium efficient wheat genotypes or the genotypes which have greater ability to uptake more potassium under K stress environment are reported to grow well under drought condition. Therefore K efficient identified verities could be grown under drought condition successfully and growers could be advised to use these genotypes under their drought environment. This will also offer the best opportunities for future breeding programmed for the development of drought tolerant genotypes. Genotypic variation for potassium use efficiency (KUE) and K uptake has been widely reported in Pakistan and elsewhere in lentil (Ashraf *et al.,* 1997), wheat (Zhang *et al.,*1999), rice (Yang *et al.,*2007), chickpea (Gill *et al.,* 2005), and cotton (Makhdum *et al.,* 2007). It is reasonable to assume that genotypic differences in (KUE) exist within all the major crop species.

Although numerous studies have identified inter- and interspecies differences in K use efficiency, relatively few studies have made detailed assessments of the observed differences at a mechanistic level and none has taken a strategic approach towards breeding selection, inheritance or molecular markers for key K efficiency mechanisms.

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 caused an annual deficit of 0.265 million tons of K from Pakistan soils. Therefore under this situation, when K availability imposes a limit upon plant growth, it might be understood 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. As potassium fertilizer is very costly therefore this study was also being useful for poor grower's community as they can grow K efficient genotypes which do not need K- fertile.

Material and methods

Diversified wheat germplasm (genotypes (MSH-14, NIA-8/7, 22-03, NIA-MB-I, SD-4085/3, SD-4047, SD-502, Chakwal-86 and Khirman)) were collected from Plant Breeding and Genetics Division, Nuclear Institute of Agriculture (NIA), Tando jam. Sand culture experiment was conducted by creating two K levels K adequate (3.0 mM) and K deficient (0.3 mM). The basal composition of nutrient solution (mM) was used as described by Johnsons et al., (1957). The experiment was designed for the evaluation of wheat genotypes for potassium uptake and use efficiency. Experiment was conducted in the cemented tanks measuring 2.1 m x 0.6 m in the wire netted pot house and comprised two treatments, i.e. Adequate-K and Deficient-K. The tanks were filled with K-deficient sandy soil having an EC 0.48 dS m^{-1}, pH 7.4, organic matter 0.8% and ammonium acetate (CH_3COONH_4) extractable-K 37.5 ppm. Potassium was applied @ 10 mM K in the farm of KNO_3 (Adequate potassium), while no potassium was applied to other treatment (Deficient potassium). Nutrient solution was applied as and when required. Seedlings were harvested at 21 and 30 days after sowing (DAS).

The experiment was carried out in Completely Randomized Design (CRD) factorial with three replicates. The seedlings were harvested after 20, 30, 45 days after sowing (DAS) and analyzed for growth parameters. Fresh and dry weight of root and shoot was taken and shoot and root samples were dried at 70

^{o}C for 2 days in an oven. Dry weight (g plant^{-1}) of shoot (SDW) and root (RDW) was recorded.

The root and shoot samples were ground and potassium concentration (mg g^{-1} dry wt.) of shoot (SKC) and root (RKC) were determined after digestion in a mixture of HNO_3:$HClO_4$ (1:3) (Miller, 1998) using flame photometer (PFP-7, Jenway). K+ uptake (mg plant^{-1}) of shoot (SKU) and root (RKU) was computed using formula SKC = SKC x SDW and RKC = RKC x RDW (mg g^{-1} dry wt.). Shoot potassium Use Efficiency (SKU) (g^{-2} SDM mg^{-1}) was determined by dividing SDW (g plant^{-1}) with SKC (mg g^{-1} dry wt.) or KUE = (1/K concentration in shoot x SDW) (Siddiqi and Glass, 1981).Shoot potassium stress factor (KSF) was calculated by using the following formula:

Parameter value at AK - parameter value at DK parameter value at AK*100.

Statistical analysis:

The statistical analysis will be carried out by standard procedure (Steel and Torrie, 1980) using computer software MSTAT-C (Russel and Eisensmith, 1983).

Results and discussion

Significant variations were observed among genotypes for absolute growth rate (AGR), relative growth rate (RGR), shoot dry weight (SDW), root dry weight (RDW), root shoot ratio (RSR), allocation and uptake of K at two contrasting level of potassium. Generally K-deficiency decreased all the growth parameters, root and shoots K-uptake, root and shoot K-concentration and potassium use efficiency (KUE). However, comparatively less relative reduction (%) or potassium stress factor (KSF) was observed in most of the growth parameters in the genotypes NIA-8/7, NIA-MB-I, SD-4085/3 and SD-4047.

Absolute Growth Gate (AGR)

Under adequate- K significantly higher AGR (g day^{-1}) was found in the genotype Khirman followed by non-significant variation in the genotype Chackwal-86 as shown in fig.1. Under deficient K- significantly higher AGR was shown by the genotype SD-4085/3 followed by significant variation by Chakwal-86 (Fig.1). It is interesting to note that the genotype SD-4085/3 showed lowest AGR under adequate-K but under deficient-K environment, it increased its AGR and the relative reduction under K-deficit environment as compared to K-adequate environment was -19%.

Plant growth analysis in terms of Absolute growth rate (AGR) and Relative growth rate (RGR) is an explanatory and integrative approach for the interpretation of plant form and function. Relative growth rate (RGR) is termed as efficiency index of plant as it gives a convenient integration of the combined performance of various parts of plant (Hunt, 1982).

The increase in AGR by the genotype SD-4085/3 under deficient-K environment shows that, this genotype is low K- responsive but it has the capability to adapt itself under poor K-environment. This might be due to the fact that some genotypes (which may be rightly regarded as K-efficient) activate a range of mechanism by altering their root morphology and exuding organic compounds (carboxylates, Phenolics, carbohydrates etc) that results in increased nutrient ability in the rhizo sphere, thus efficient genotypes are adapted to environment with low nutrient availability (Rengel and Marschner, 2005).

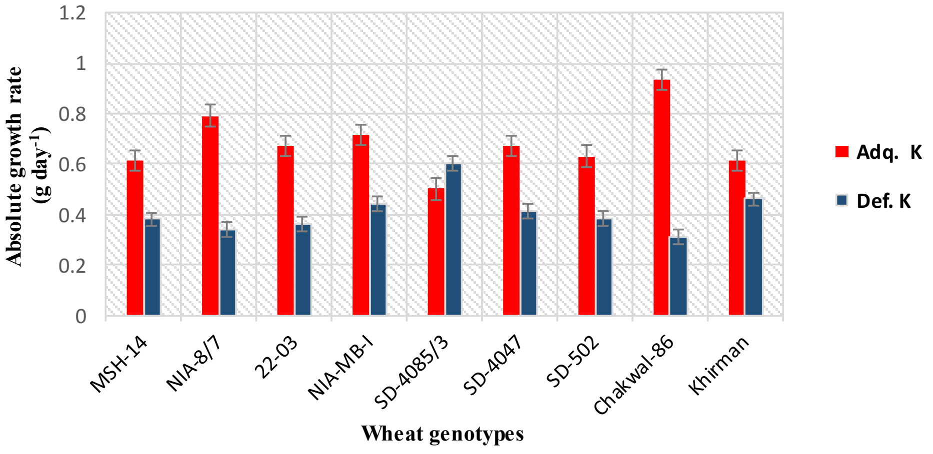
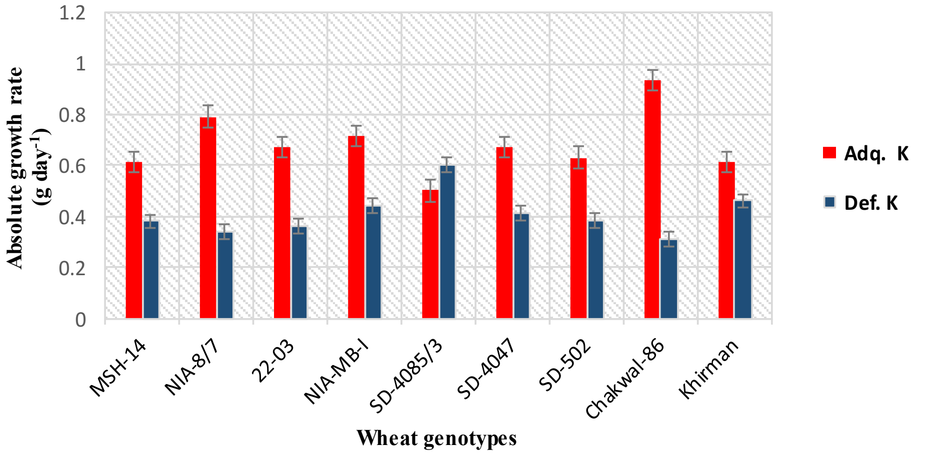


Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K

Relative Growth Rate (RGR)

Significantly higher RGR by NIA- 8/7 at adequate-K and at deficient-K and the less relative reduction of 11 % shows that this genotype is also K–responsive as well as the genotype has the adaptation characteristics under poor K-environment (Fig. 2). Data of RGR shows that the genotype SD-502 is not responsive to K under adequate –K environment, but less relative reduction (8 %) under K-deficient environment suggest that this genotype has also genetic potential for the adaptation under poor K- environment. Similar is the case with SD-4047 with 14 % relative reduction. Significantly ($p < 0.05$) higher RGR was depicted by the genotype NIA-8/7 followed by non-significant variation in the genotype 4085/3. In case of AGR all genotypes except SD-4085/3 showed relative reduction (KSF) of more than 10 % which indicates that these genotypes are K- responsive but not efficient. However data of RGR showed less relative reduction in the genotype NIA-8/7 (11%), SD-4047(14%), and SD-502 (8%), which might also be due to the fact that this genotype has higher potential to work well under K deficient environment.

Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K



Shoot Dry Weight (SDW)

Shoot dry weight (SDW) is considered to be the most sensitive plant response to nutrient deficiency and is supposed to have a pivotal place in screening experiments (Fageria *et al.,* 2001). It is generally used as a selection criterion for evaluating genotypes for nutrient efficiency sat seedling stage.

The data of shoot dry weight (g) showed non-significant variation under K-deficit environment, whereas under adequate-K Khirman showed significantly higher value (Fig.3). Two genotypes NIA-8/7and SD-4085/3 showed higher shoot dry weight under K-deficit environment as compared to K-adequate with the relative reduction of -2.89 and -26.69, respectively. Higher root growth, higher root dry weight of genotypes 22-03 (0.023 g plant^{-1}) and at all no reduction in the genotype SD-4085/3 and SD-502 under K-deficit environment may be due to increased N-uptake (data not presented) which may have contributed to higher root growth as reported by Osaki *et al.,* 1995.

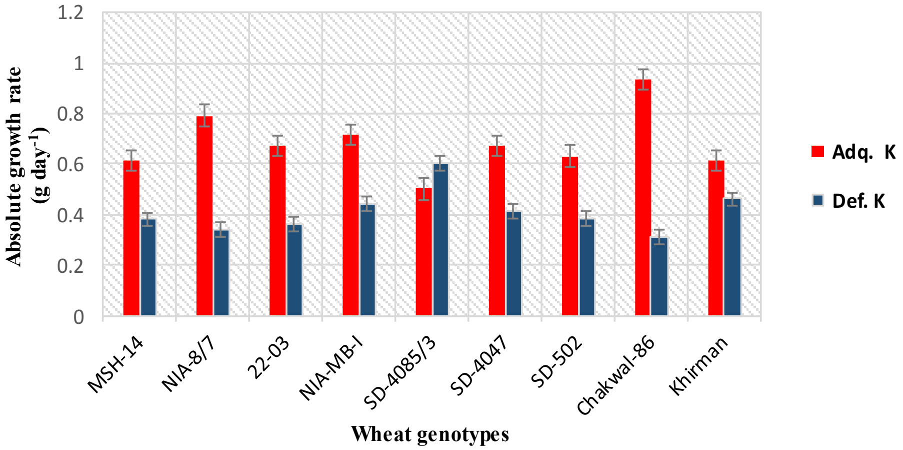


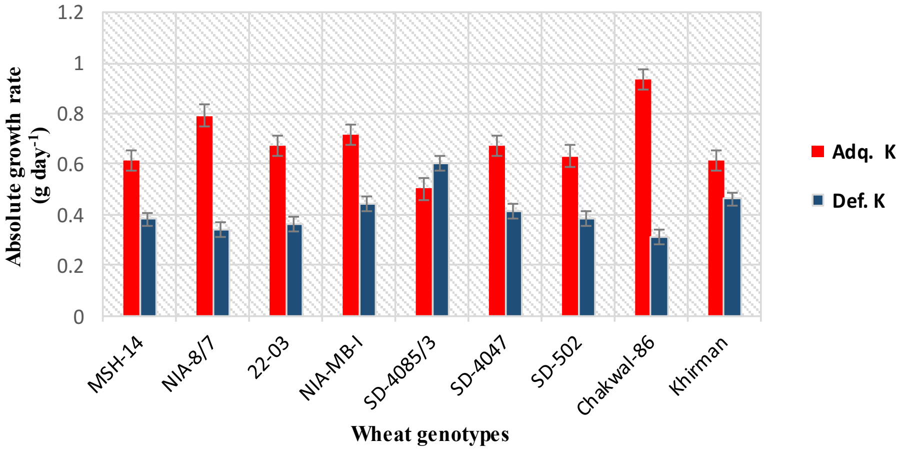
Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K

Root Dry Weight (RDW)

Being a major organ for nutrient uptake, the root plays an important role in soil-plant system (Lynch *et al.,* 2007). Its growth is directly related with the growth and biomass yield of shoots. Flexibility in biomass allocation root morphology and root distribution patter has been found to be an important adaptive mechanism to exquisite nutrients.

The data of root dry weight revealed significant and non-significant variation within the genotypes under two K-level (Fig. 4). Within the genotype under deficient-K environment significantly ($p < 0.05$) higher values were found in the genotype 22-03 followed by non-significant variations in the genotype NIA-8/7, SD- 4085/3 and Chakwal-86. Minimum relative reduction among the genotypes was depicted by the genotype 22-03 (-8.20%) followed by at all no reduction in the genotype SD-4085/3 and SD-502.

Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K

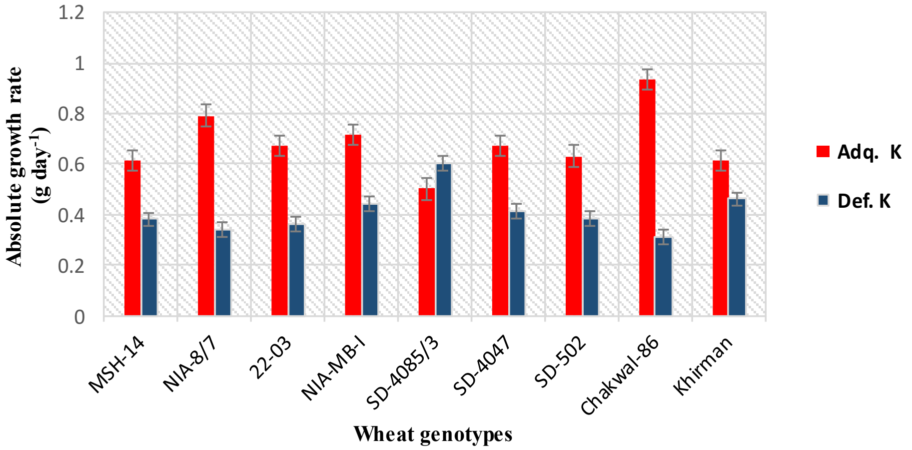


Root Shoot Ratio (RSR)

The root shoot ratio (RSR) is the ratio of the amount of plant tissues that have supportive function (i.e. root) to the amount of those that have growth functions (i.e. shoot). Plants with a higher proportion of roots can compete more effectively for soil nutrients (in our case for K).

The data for root shoot ratio indicated non-significant variation within the genotypes under both potassium levels (Fig.5). The genotype MSH-14 , 22-03 , SD-4047, SD-502 and Chakwal-86 (2.4%) showed comparatively less relative reduction under K-deficit environment absolute growth rate, relative growth rate, root and shoot dry weight of wheat genotypes grown at Adequate-K and Deficient- K (-K) level.

Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K



Root and shoot potassium concentration (mg g^{-1}dry weight)

Maximum root potassium concentrations were found in the genotype Khirman- (17.46 mg g^{-1} dry wt) under adequate K-level with the KSF value of 49 %,whereas, under deficient K-level maximum root potassium concentrations was depicted by MSH-14 with the KSF value of 32% (Fig.6). In all the genotypes KSF value ranges from 26-48, which showed that all genotypes have > 20 % KSF value.

Maximum shoot potassium concentrations (mg g^{-1} dry wt.) under adequate-K exhibited by SD-502 (51.3 mg g^{-1} dry wt.). Whereas under deficient-K maximum shoot potassium concentrations were showed by Khirman (47.33 mg g^{-1} dry wt.) as shown in figure 7. The lowest KSF value of 6% by the genotypes SD-4047 indicates that the genotype has the potential to work well even under K stress environment. Similar, Khirman genotype is also working well under K-deficient even with the KSF value of 11%. However, it is notable fact that root and shoot potassium concentrations has weak correlation with shoot dry weight.

Root and shoot K uptake has positive correlation with shoot dry weight root dry weight affected shoot dry weight by enhancing total K-uptake under deficiency stress. As potassium is diffusion supplied nutrient thus the efficiency of plant to uptake K under its deficiency stress largely depends upon root morphology, root hair, root exudates, and release of K from non-exchangeable pool (Rengel and Demon, 2008).

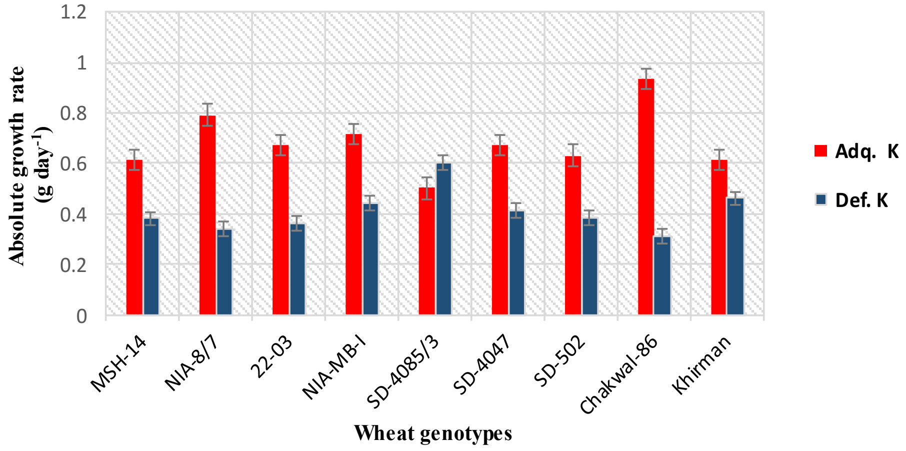


Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K

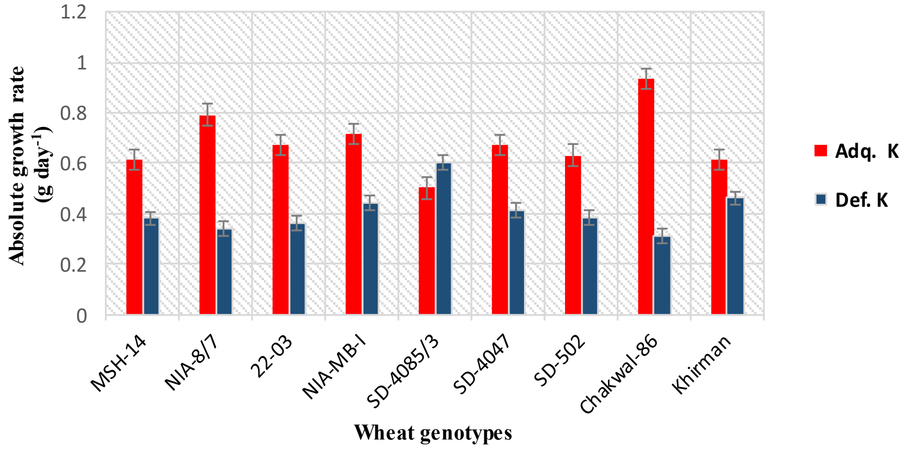


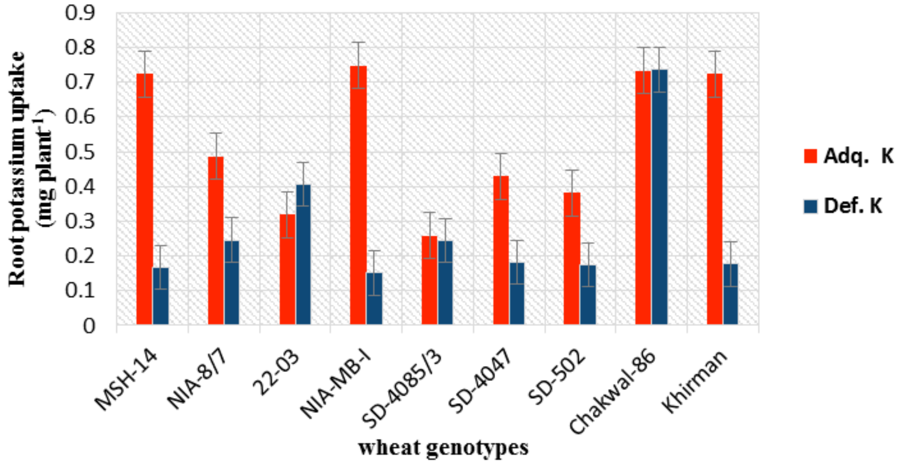
Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K

Root potassium uptake (RKU)

The potassium uptake (mg plant^{-1}) of root and shoot at two contrasting level of potassium are shown in figure 8 and 9. At adequate potassium significantly higher root K-uptake was found in the genotype NIA-MB-I followed by non-significant variation in the genotype Chakwal-86, Khirman and MSH-14 (Fig. 8). The lowest K-uptake at this level (i.e. at adequate-K) was observed in the genotype SD-4085/3. At deficit-K level significantly ($p < 0.05$)

higher root K-uptake, higher, that of adequate-K, was observed in the genotype chakwal-86 followed by significantly low uptake in the genotype 22-03 (0.407 mg plant^{-1}). The lowest K-uptake at this level (i.e. deficient-K) was observed in the genotype SD-4085/3 (0.258 mg plant^{-1}).

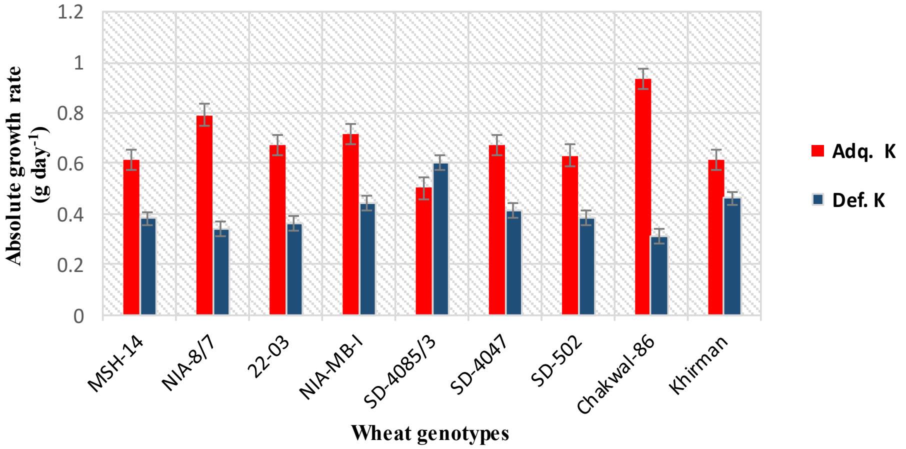
Fig. 8. Root potassium uptake of wheat genotypes grown under adequate-K and deficient-K



Shoot potassium uptake (SKU)

Shoot potassium uptake (SKU) was significantly higher in the genotype Khirman under adequate-K. The lowest shoot k-uptake under this level was depicted by the genotype SD- 4085/3 (Fig. 9). Under K-deficient environments significantly ($p < 0.05$) higher shoot K-uptake was observed in the genotype Khirman followed by non-significant variation in the genotype SD-4047. The lowest K-uptake was shown by the genotype Chakwal-86 followed by non-significant changes by the genotype SD-4085/3 and SD-502. Minimum relative reduction under deficient environment as compared to adequate-K was depicted by the genotype SD-4047 (8.9%).

Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K



Potassium use efficiency (KUE)

Figure 10 showed shoot potassium use efficiency (g^2 SDW mg^{-1} shoot K) of the genotypes evaluated. The highest (KUE) under adequate-K was found in the genotypes Khirman (0.0034 g^2 SDW mg^{-1} shoot K) with the KSF of 41 %. NIA-MB-1 showed less relative reduction or KSF (6 %). The genotypes NIA-8/7(0.0036 g^2 SDW mg^{-1} shoot K), SD-4085/3 (0.0040 g^2 SDW mg^{-1} shoot K) and SD-502 (0.0022 g^2 SDW mg^{-1} shoot K) increased their KUE under deficient-K when compared with adequate-K. The increase in KUE under deficient-K when compared with adequate-K showed that these genotypes have higher KUE as compared to other genotypes. However it was concluded from this study that wheat genotypes differ in growth response and KUE when grown at deficient and adequate K-level.

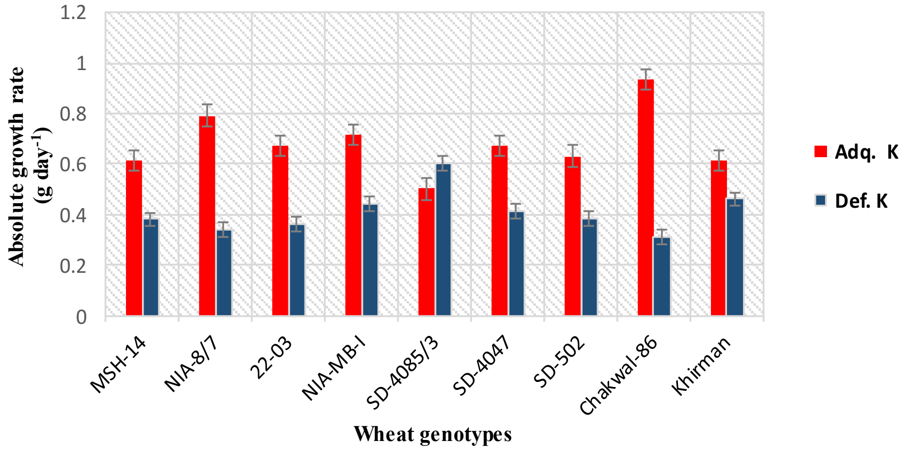


Fig. 1. Absolute growth rate of wheat genotypes grown under adequate-K and deficient-K

The biomass production of crop genotypes under K deficiency stress is associated with their enhanced K uptake and K use efficiency. There exists a strong relationship between these two important plant characters (Rengel and Demon, 2008). In this study, K uptake and K use efficiency equally contributed to wheat biomass production, these results suggest that, under K deficiency stress, K uptake and K use efficiency are the most important characters contributing to shoot dry weight production of wheat genotypes. Furthermore genotypes maintaining high root dry weight are able to use K more efficiently to support biomass production. These results are in good agreement with those reporting the significance of uptake and the use efficiencies in enhancing nutrient use efficiency (Zhang *et al.,* 1999; Rengel and Demon, 2008).

Conclusion

It could be concluded from present data that varieties, treatments and their interaction were highly significant for germination percentage, root and shoot length, root and shoot growth rate, root and shoot fresh and dry weight and root and shoot moisture content. Among the treatments level all the growth parameters were decrease by increasing the halo priming (KCl) concentrations. Among the varieties, SKD-1 recorded highest mean values, while TD-1 showed minimum mean values for all the parameters at different halo priming (KCl) concentrations.

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