Pak. J. Bot., 49(6): 2153-2159, 2017.

DIFFERENTIAL RESPONSES OF WHEAT GENOTYPES FOR POTASSIUM UPTAKE AND UTILIZATION EFFICIENCY UNDER ADEQUATE AND DEFICIENT POTASSIUM LEVELS IN SOLUTION CULTURE

MUHAMMAD ALI KHAN[1]*, M.Y. KHUAWER[2], M.U. SHIRAZI[1], S.M. MUJTABA[1], MAQSOOD A. KHASKHELI[3] AND M.A. KHAN[1]

[1*]*Nuclear Institute of Agriculture (NIA), Tandojam, Sindh, Pakistan*
[2]*Institute of Advanced Studies in Chemical Sciences, University of Sindh, Pakistan*
[3]*Department of Agronomy, Sindh Agriculture University, Tandojam, Sindh, Pakistan*
**Corresponding author's email: alipaec@hotmail.com*

Abstract

Identification of nutrient efficient genotypes as low cost, low input technology is considered one of most efficient approaches for improving crop production in poor resource environments. Potassium (K) deficiency in the soils of Pakistan is spreading rapidly and has become one of the most nutritional limiting factors for crop yield. In the present investigation, six wheat genotypes were evaluated for growth, K uptake and utilization efficiency in the Johnson's solution modified to 0.3mM (deficient-K) and 3.0 mM (adequate-K) using K_2SO_4. The experiment was conducted in a factorial, completely randomized design (CRD), replicated thrice. Substantial variation was observed among the genotypes in the biomass accumulation, allocation of K-uptake and -use efficiency in root and shoot at two contrasting K level. Generally, K-deficiency decreased biomass production, K-uptake and K-use efficiency, however higher genetic potential genotypes maintained their growth and K accumulation even at low K-level. Potassium use efficiency was increased almost four folds in the genotype grown at low K and was positively correlated with K accumulation. The genotype SD-222 is responsive to adequate K-supply, while the genotype 22-03 is efficient to low K-supply. It is suggested that these two genotypes could be used in breeding programmes to improve K-efficiency.

Key words: Wheat, Potassium levels, Potassium use efficiency, Potassium stress factor.

Introduction

Pakistan is an agricultural country with a population of about 192×10^6 people. Cereals crops play a vital role in Pakistan's economy whereas wheat is the most important agricultural commodity (Hussain *et al.*, 2012). In Pakistan, it is grown by 80% of the farming community and covers the largest area (9.17 m ha) in the country under any crop (Anon., 2012-13). However, its production is still very low at only about 25 million tons. Pakistan ranks 9th in area under wheat cultivation, 11thin total production and 8th in average yield among the major wheat producing countries of the world (Arshad *et al.*, 2007). Low wheat yields in the country have resulted from drought, salinity, water logging, temperature and various diseases. While most of these research areas are being addressed; the exploitation of nutrient efficient crops has being generally ignored. Recent efforts have been concentrated on exploiting genetic differences in the absorption and utilization of mineral nutrients by crops (Gill *et al*., 1997). Nutrient efficient varieties are likely to have positive environmental effects through reduced impacts of chemicals in agriculture.

Potassium is the third major plant nutrient which is essential for plant metabolic processes. It is known to be involved in the activation of more than 60 enzymes, acts as an osmoticum to maintain turgor pressure and regulates the opening and closing of stomata in plant cells. Its impacts on water relations, photosynthesis, assimilate transport and enzyme activation can have direct consequences for crop productivity (Pettigrew, 2008). Higher crop productivity and improved quality may be achieved by increasing potassium supply or by cultivating varieties with higher K use efficiency (Pettigrew, 2008). Potassium application significantly increases the grain yield of wheat (Bhatti *et al*., 1976, Vengiell, 1982, Malik *et al*., 1990 and Hamayun *et al*., 2011). Ghulam *et al*. (2013) reported 11, 18 and 25% increase in grain with K application of 31, 62 and 93 Kg ha^{-1}, while Tahir *et al*. (2008) reported 4, 9 and 11% increase in grain yield with the same potassium application. In Pakistan high fertilizer costs inhibit the use of K (Zia-ul-Hassan & Arshad, 2008) besides the general impression is that soils in Pakistan have sufficient K due to dominance of illite in the clay fraction (Ranjha *et al.*, 1990). In Pakistan, potassium is being used only @ 0.8 kg ha^{-1} yr^{-1} as compared to the global average of 15.1 kg ha^{-1} (Anon., 2007). Therefore, irrigated soils of Pakistan face an annual deficit of 0.265 million tons of potassium (Bajwa, 1994). At present 40% of soils are K-deficient in the country. Selection of K-efficient wheat genotypes will be fruitful for future breeding programme, focusing on low K-input agriculture (Akhter *et al*., 2009, Wang & Chen, 2012).

The present study was designed to evaluate the K-efficient and K-responsive wheat genotypes of Pakistan to identify potential candidate genotypes for sustainable low K-input wheat production in Pakistan.

Material and Methods

The solution culture experiment was conducted during Rabi season of 2014-15, 2015-16 and 2016-17 under two contrasting potassium level i.e., adequate-K (3.0 mM) & deficient-K (0.3 mM) at Nuclear Institute of Agriculture (NIA), Tandojam. The presented data are the grand mean of three years result. Seeds of six wheat genotypes, viz. NIA-Sundar, SD-222, SD-502, NIA-Sarang, NIA-MB-II and 22-03, were surface sterilized with 0.5% NaOCl (sodium hypochlorite), germinated in 8.5 cm diameter bowls (Anon., 1984-85) in growth incubators (irradiance22 Wm^{-2}). Six d old uniform sized seedlings were transferred in foam-plugged holes of thermocol sheets floating on polyethylene lined iron tubs (0.6m x 0.6 m x 0.15 m) containing, continuously aerated, 20 L half strength Johnson's modified solutions (Johnson *et al.*, 1957). The basal composition of nutrient solution (mM) was N 8.0, P 0.25, Ca2.0, Mg 1.0, S 2.0, B, and 0.025, Zn 0.002, Cu 0.0005, and Mo 0.0005. The solution was modified to maintain deficient (0.3 mM) and adequate (3.0 mM) K levels using K_2SO_4.The experiment was arranged factorially in a completely randomized design (CRD) with three replicates. One tub was filled with nutrient solution of adequate K (3.0mM) and another with deficient-K (0.3mM) level. The pH of nutrient solution was monitored on daily basis and adjusted to 5.5 $\pm$ 0.2 using $Ca(OH)_2$ and/or H_2SO_4.

Plants were harvested 14 days after transplantation and separated into shoots and roots, washed with distilled water and blotted dry. The dry weight of shoots and roots were recorded and the samples were finely ground in a wiley mill to pass through 1 mm (40-mesh) sieve. Uniformly ground samples were digested in di-acid mixture of nitric (HNO_3) and perchloric acid ($HClO_4$) in a 3:1(Miller, 1998). Potassium concentration (mg g^{-1}dry wt.) in shoots and roots were determined through flame photometer (Jenway PFP-7).K relations were determined using the standard formulae as described below:

Shoot/root K accumulation (SKA/RKA) = Shoot/root dry weight × K concentration (Zhang *et al*., 2007).

Potassium use efficiency (KUE) = Shoot dry weight ÷ Shoot K concentration (Glass *et al*., 1981).

Potassium stress factor (KSF) =$SDW_{adeq.}$- $SDW_{def.}$ / SDW_{adeq} X 100 (Siddique & Glass. 1981)

The chlorophyll contents were determined as described by Lichtenthaler (1987).

Fresh leaves were chopped into small pieces and extracted overnight with 80% acetone. The extract was centrifuged at 14000 x g for 5 minutes and the absorbance of the supernatant was measured at 645 and 663 nm using Spectrophotometer. The Nitrate reductase activity was determined following the method of Jordon, (1984). One gm leaf segment was chopped in phosphate buffer (pH 7.5), incubated in dark at 32°C for 1 hr. Added to it, each 0.5 ml sulphanilamide (1%) and N-(1-Naphthy) ethylene diamine dihydrochloridel(0.02 %) and the solution was incubated at room temperature for 20 min and read spectrophotometrically at 542 nm. The activity was represented as µ mol NO_2 g^{-1} F. wt h^{-1}.

The data was statistically analyzed using "Statistix ver. 8.1" (2006) and the means were separated using Tukey's honestly significant test at alpha 0.05 (Tukey $HSD_{0.05}$).

Results

The data for shoot dry weight (SDW), root dry weight (RDW), potassium stress factor (KSF, %),total biomass(TBM) and root shoot ratio (RSR) of six wheat genotypes under two Contrasting K levels are presented in table 1. At adequate-K level (Adeq-K), the genotype SD-222 showed significantly ($p \leq 0.05$) higher shoot and root dry weight (0.27 g $plant^{-1}$ and 0.19 g $plant^{-1}$ respectively), whereas the genotype NIA-Sarang exhibited significantly lower SDW (0.08g $plant^{-1}$) at low or deficient- K (Def-K) level. The genotype 22-03 depicted the lowest KSF (-5.32%) whereas the genotype NIA-Sunder showed the highest KSF (55.49%) value. In case of root dry weight (RDW), again SD-222 showed significantly the highest dry weight (0.189 g $plant^{-1}$) at Adeq- K level. Under low K- availability (Def-K), generally there was reduction in root dry weight of all six genotypes; while two genotypes viz., NIA-Sarang and SD-502 showed comparatively less reduction (15.74 and 11.93% respectively). The genotype 22-03 has increased its dry weight by 37.7%. In case of total biomass (TBM), wide genetic variations were observed among the wheat genotypes at both K-level. Under Adeq-K, the genotypes SD-222, exhibited the highest biomass (0.456 g $plant^{-1}$) while at Def-K, the genotype 22-03 showed significantly the highest biomass (0.291 g $plant^{-1}$). K-deficiency stress caused reduction in total biomass in all the genotypes except 22-03 which enhanced its dry weight by 15%. Maximum reduction (56.26%) due to K- deficiency stress was observed in the genotype NIA-Sundar.

Data for root/shoot ratio (RSR) exhibited differential responses under two K- levels. Under Adeq-K, the genotypes SD-222 showed significantly the highest RSR (0.708), whereas three genotypes viz. NIA-Sarang, 22-03 and SD-502 enhanced RSR under Def- K level (23.57, 30.67 and 12.97 % respectively). Minimum reduction in RSR (4.67%) was found by the genotype NIA-Sundar.

Table 1. Shoot and root dry weight, Potassium stress factor, Total bio-mass and root shoot ratio of wheat genotypes grown at adequate and deficient K level.

Genotypes	SDW (g $plant^{-1}$)		KSF (%)	RDW (g $plant^{-1}$)		RI / RD (%)	TBM (g $plant^{-1}$)		RI / RD (%)	RSR		RI / RD %
	Adeq-K	Def-K		Adeq-K	Def-K		Adeq-K	Def-K		Adeq-K	Def-K	
NIA-Sarang	0.154 f	0.105 e	31.82	0.070 f	0.059 e	15.74	0.224 f	0.164 e	26.77	0.458 e	0.566 c	(23.57)
22 – 03	0.176 c	0.186 a	-5.32	0.076 e	0.105 a	(37.70)	0.253 d	0.291 a	(15.10)	0.433 f	0.565 c	(30.67)
NIA-Sundar	0.173 d	0.077 f	55.49	0.088 c	0.037 f	57.63	0.262 c	0.115 f	56.25	0.510 c	0.486 e	4.67
SD – 502	0.159 e	0.124 d	22.01	0.079 d	0.069 d	11.93	0.238 e	0.190 d	18.62	0.495 d	0.559 d	(12.97)
SD – 222	0.266 a	0.132 c	50.24	0.189 a	0.081 c	56.96	0.456 a	0.214 c	53.03	0.708 a	0.612 b	13.49
NIA-MB-II	0.185 b	0.136 b	26.44	0.128 b	0.086 b	32.71	0.314 b	0.223 b	28.98	0.691 b	0.633 a	8.49
Mean	0.186 A	0.127 B		0.105 A	0.073 B		0.291 A	0.200 B		0.549 A	0.570 A	
Tukey HSD (0.05)												
Genotypic	0.0016	0.0006		0.0012	0.0005		0.0017	0.0010		0.0089	0.0026	
Treatment	0.025			0.023			0.047			0.059		

Means followed by similar letter do not differ significantly at $p \leq 0.05$, Values in the parenthesis shows percentage increase over adequate
SDW = Shoot dry weight, RDW = Root dry weight, RSR = Root shoot ratio, TBM = Total biomass, R.I / R.D = Rel. increase / Rel. dec

Table 2. Shoot and root potassium accumulation (SKA and RKA) and potassium use efficiency (KUE) of wheat genotypes grown at adequate and deficient K level.

Genotypes	SKA (mg plant^{-1})		R.R (%)	RKA (mg plant^{-1})		R.R (%)	KUE (g^2 SDW mg^{-1} K)	
	Adeq-K	Def-K		Adeq-K	Def-K		Adeq-K	Def-K
NIA-Sarang	10.37 bc	1.013 bc	90.23	2.94 d	2.03 b	30.87	0.0023 d	0.0110 bc
22 – 03	9.30 c	1.907 a	79.50	3.36 cd	3.15 a	6.24	0.0037 ab	0.0183 a
NIA-Sundar	10.24 bc	0.720 c	92.97	3.89 c	1.01 c	73.97	0.0029 bc	0.0084 c
SD – 502	9.23 c	1.157 b	87.47	3.05 cd	1.84 b	39.61	0.0028 cd	0.0135 b
SD – 222	18.32 a	1.297 b	92.92	11.21 a	2.06 b	81.59	0.0039 a	0.0138 b
NIA-MB-II	12.26 b	1.367 b	88.85	7.44 b	2.81 a	62.29	0.0028 bc	0.0137 b
Mean	11.62 A	1.243 B		5.316 A	2.15 B		0.0030 B	0.0131 A
Tukey HSD (0.05)								
Genotypic	2.097	0.379		0.905	0.435		0.00055	0.0040
Treatment	1.601			1.551			0.0016	

Means followed by similar letter do not differ significantly at $p \leq 0.05$

SKA = Shoot potassium accumulation, RKA = Root potassium accumulation, KUE = Potassium use efficiency, R.R = Rel. reduction

Shoot potassium accumulation (SKA), root potassium accumulation (RKA) and potassium use efficiency (KUE) of six wheat genotypes are presented in table 2. Potassium accumulation in shoot (mg plant^{-1}) was significantly affected by both contrasting levels of K. All six genotypes showed large reduction due to K stress. Mean K accumulation at Adeq-K level was 11.62 mg plant^{-1} while at Def-K it was 1.243 mg plant^{-1}. At Adeq-K, the genotype SD-222 accumulated significantly more K (18.32 mg plant^{-1}) while at Def-K, the genotype 22-03 accumulated more potassium (1.907 mg plant^{-1}). Potassium accumulation in root (RKA) was also significantly ($p \leq 0.05$) affected by two K-levels. At Adeq-K, significantly higher potassium was accumulated (11.21 mg plant^{-1}) by the genotype SD-222 and significantly lower (3.05 mg plant^{-1}) by the genotype SD-502. At Def-K, the genotype 22-03 coped with the adverse K-environment and accumulated significantly more potassium (3.15 mg plant^{-1}) with the lowest reduction (6.24%). Generally, all six genotype exhibited reduction in root K- accumulation due to K stress.

The chlorophyll contents (Total chlorophyll) (mg g^{-1} fresh wt) and nitrate reductase activity (µ mol NO_2 g^{-1}fresh wt h^{-1}) of wheat genotypes at two contrasting K levels is presented in figs. 1 and 2. The genotype NIA-Sunder (1.333 mg g^{-1} fresh wt) and SD-502 (0.743 mg g^{-1} fresh wt) accumulated significantly ($p \leq 0.05$) higher and lower chlorophyll contents respectively at adq. K level. At def. K level, the genotype NIA-Sunder (1.046 mg g^{-1} fresh wt) maintained its superiority and exhibited significantly higher chlorophyll contents while the genotype NIA-Sarang (0.675 mg g^{-1} fresh wt) showed lower chlorophyll contents. The two genotypes i.e., SD-222 and 22-03 maintained chlorophyll contents at def. K as compared to adq. K and showing less reduction of 3.07 and 6.80% respectively. The genotype SD-502 (0.743 mg g^{-1} fresh wt) accumulated significantly ($p \leq 0.05$) lower chlorophyll contents at adq. K level, however, at def. K level, this genotype increased its chlorophyll contents (0.945 mg g^{-1} fresh wt) by 27.19%, showing the potential of this genotype to cope with the adverse K (def. K) conditions. The genotype NIA-Sarang (0.756µ mol NO_2 g^{-1}fresh wt h^{-1}) exhibited significantly ($p \leq 0.05$) higher nitrate reductase activity (NRA) at adq. K, followed by significantly similar activity of this enzyme in the genotype 22-03 (0.731 µ mol NO_2 g^{-1}fresh wt h^{-1}) and NIA-Sunder (0.681 µ mol NO_2 g^{-1}fresh wt h^{-1}).The genotype NIA-Sarang (0.577 µ mol NO_2 g^{-1}fresh wt h^{-1}) maintained its superiority at def. K and showed minimum reduction (23.68%). All other genotypes showed large reductions (51.32- 63.68%) in NRA under K-deficiency stress.

The results with respect to potassium use efficiency (KUE) (g^2 SDW mg^{-1} k) showed that there was increase in KUE in almost all wheat genotypes due to K deficiency stress. Significant differences among the genotypes at both K-levels were observed. At Adeq-K, the genotypes SD-222 exhibited significantly higher KUE (0.0039 g^2 SDW mg^{-1}K) followed by significantly similar KUE (0.0037 g^2 SDW mg^{-1} k) in the genotype 22-03. The genotype 22-03 also had significantly higher KUE (0.0183 g^2 SDW mg^{-1} k) under Def-K. Generally, K deficiency stress caused increase in KUE in almost all genotypes; however three genotypes namely, NIA-Sarang, 22-03 and NIA-MB-II showed 5 fold increases in KUE.

Discussion

Shoot dry weight is considered to be the most sensitive plant response parameters to nutrient deficiency and given a pivotal place in screening experiments (Fageria *et al.*, 1988). This study revealed considerable genetic variation in SDW production among wheat genotypes at both K-levels. There was an inhibitory effect of low K (Def. K) on shoot and root biomass of all the genotypes except the genotype 22-03 which showed increase at Def-K or low K level. General reduction in root and shoot dry weight in wheat at low K-availability is in accordance with the findings of Tahir (1999); however Ismat *et al.* (2006) found an increase in root dry weight at low K- level in maize at seedling stage. This contrasting behavior of two crop (wheat and maize) may be due to different genetic makeup of two different crops (Joachim *et al.*, 2004). Increase in shoot and root dry weight of the genotype 22-03 at Def. K level reflects the tolerance of the genotypes at low K regime, therefore the genotype 22-03 may be rightly regarded as K efficient genotype under these experimental conditions. Potassium stress factor (KSF), which is a relative reduction in biomass production due to K stress (Tahir 1999) also depicts the lowest/negative KSF (-5.32%) for this genotype (i.e. 22-

03), showing that the genotype is efficient to deficient K supply (Def-K) but non-responsive to sufficient K supply(Adeq-K). Similar trend for KSF for some of the potential genotype (in terms of K-efficiency) was found by Tahir (1999). The mean root shoot ratio (RSR) enhanced from 0.549 (Adeq-K) to 0.569 (Def-K), however, the increase between two K level is statistically ($p \leq 0.05$) non-significant (Table 1). In this study, the genotype NIA-Sarang, 22-03 and SD-502 enhanced their RSR by 23.6, 30.7 and 12.9% respectively while the other three genotypes showed decrease in RSR. The results of increase in RSR is in line with of work of Peuke *et al.* (2002) who found that K deficiency inhibited the shoot growth in *Ricinnus communis* at the expense of root growth. Yang *et al.* (2004) and Shagufta *et al.* (2016) also reported high root: shoot ratio in the plants growing in nutrient deficient soil. Earlier, too, it is widely accepted that all mineral nutrients are taken up through the roots which required energy from photo-assimilates and k deficiency restricts this translocation from leaf to root by accumulating soluble sugars in K deficient plant parts (Epstein & Bloom, 2005). However, inconsistent behavior of this growth attribute among wheat genotypes was observed by Tahir *et al.*, 2008.

Shoot and root potassium accumulation (SKA and RKA) revealed statistically ($p \leq 0.05$) significant differences between two K level. Significantly higher shoot (18.32 mg plant^{-1}) and root (11.21 mg plant^{-1}) potassium accumulation, under adq. K-level, by the genotype SD-222 reflects the higher requirement of this genotype under high K condition, however under low K condition, this genotypes, as with other genotypes, could not cope with the adverse K condition, showing 92.92 and 81.59% reduction in shoot and root respectively (Table 2). Similarly the genotype 22-03 has significantly low requirement of K in shoot (9.30 mg plant^{-1}) and root (3.36 mg plant^{-1}) under Adeq-K, but this genotype , to some extent, managed with the low K condition showing comparatively less reduction (79.50 and 6.24% in shoot and root respectively) as compared to other genotypes. Similar results, as in the case of genotype 22-03, were found by Santa-Maria *et al*. (2015), who suggested that, under conditions of nutrient scarcity, plant can develop efficient internal nutrient economy, which may result from efficient redistribution with the plant and/or lowering requirement of that particular nutrient at functional sites. Apart from the suggestion of Santa-Maria *et al*. (2015) Song (2011) proposed that some genotypes, with small concentrations of certain mineral nutrients and high photosynthetic rate, require least amount of mineral (in our case K) to produce high yield. Jia *et al*., 2008 reported that some genotypes maintain shoot and root K- uptake by modifying their root length under K deficiency stress.

The higher chlorophyll contents (Total chlorophyll) of wheat genotypes at adq. K (genotypic mean: 0.9708 mg g^{-1}.f.wt) as compared to def. K (genotypic mean 0.8204 mg g^{-1}.f.wt)is attributed to the involvement of potassium in many photosynthetic processes i.e., ATP synthesis, activation of some enzymes involved in photosynthesis, uptake of CO_2, electrical charge balance at the site of ATP and acting as the counter ion to light-induced H^+ flux across the thylakoid membranes (Ray Tucker, 2004). Under K deficiency stress, photosynthesis as well as ATP production rates are reduced, which cause decrease in chlorophyll contents (Anon., 1998).The increase in chlorophyll contents by the genotype SD-502 may be due to K deficiency stress tolerance of this genotype as reported by Wang *et al*. (2015) in soybean and Jian *et al*. (2017) in maize. However, SDW (0.124 g plant^{-1}) of this genotype at def. k (Table 1) could not increase accordingly. The maintenance of chlorophyll contents by the genotypes, 22-03 (0.850 mg g^{-1}.f.wt) and SD-222 (0.725 mg g^{-1}.f.wt), at def. K level (Fig. 1) is attributable to comparatively higher KUE of these genotypes (Table 2) (0.0183 g^2 SDW mg^{-1} K and 0.0138 g^2 SDW mg^{-1} K respectively) at the same K level i.e., at def. K. This also reflects the potential of these genotypes (22-03 and SD-222) to cope with the adverse K conditions.

Nitrate reductase is one of the key enzymes in the assimilation of exogenous nitrate (NO_3^-)-the major form of nitrogen available to plants growing in the soil or growth medium. Activity of this enzyme predicts a good estimate of the nitrogen status of the plant and is frequently correlated with growth and yield. With respect to the significance of K for NRA, Pflüger & Wiedemann (1977) augmented that K probably was involved in the activation of this enzyme and that K is essential for synthesis of nitrate reductase. Numerous studies have indicated the importance of K nutrition and its effect on modulating the NRA in many crop plants (Umar & Bansal, 1995; Anuradha & Sarma, 1995; Megda, 2009).As K is highly involved in the synthesis and activation of NR, therefore reduction in the activity of this enzyme in most of the genotypes(Out of six five genotypes showed reduction in NR, Fig. 1) under K deficient environment is clearly understandable and reported by many workers (Venkatesan, & Ganapathy, 2004; José *et al*., 2010**;** Wiedenfeld *et al*., 2009).Maintenance of activity of this enzyme(0.577 µ mol NO_2 g^{-1} fresh wt h^{-1}) by the genotype NIA-Sarang under K-deficiency stress may be speculated due to higher uptake of NO_3^-(substrate)from growth medium as NR is substrate inducible enzyme (Ricardo & Joaquim, 2002). However, comparatively low shoot dry weight (0.105 g plant^{-1}) of this genotype, in spite of higher NRA, might be due to toxic effects of higher NO_3^- accumulation in the leaves. Cody Wrathall (2001) reported that in some genotypes certain genetic or environmental factors inhibit the activityof the nitrate reductase and allow nitrate to accumulate in the plant.

Our study showed that potassium use efficiency (g^2 SDW mg^{-1} K) had significant positive correlation with K accumulation (n= 6, R^2 = 0.968), at def. K (Fig. 3) concluding that these two important plant characters could be used for selection of wheat genotypes better adapted to low K-condition. Similar results of positive correlation between these two parameters in wheat were found by Sattelmacher *et al*. (1994), they advocated this approach for the selection of nutrient efficient crops.

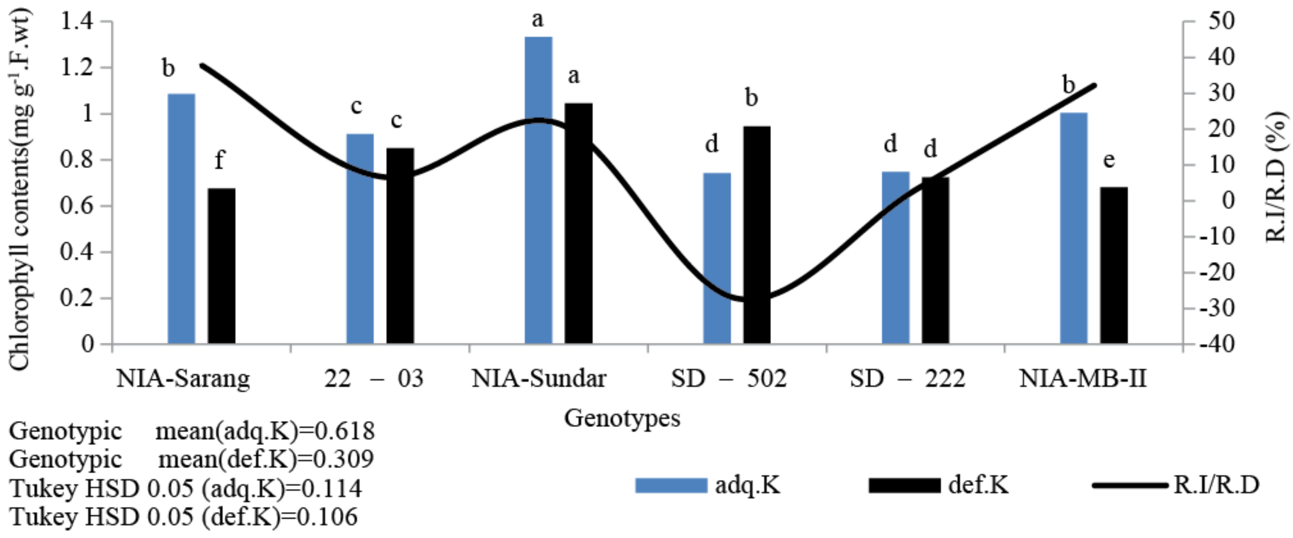

Fig. 1. Chlorophyll contents of wheat genotypes grown under adq. and def. K conditions.
Means followed by similar letters do not differ significantly at $p \leq 0.05$. Genotypic mean is the mean of six genotypes
adq.k = adequate K. def.k = deficient K. R.I/R.D = Rel. increase / Rel. decrease

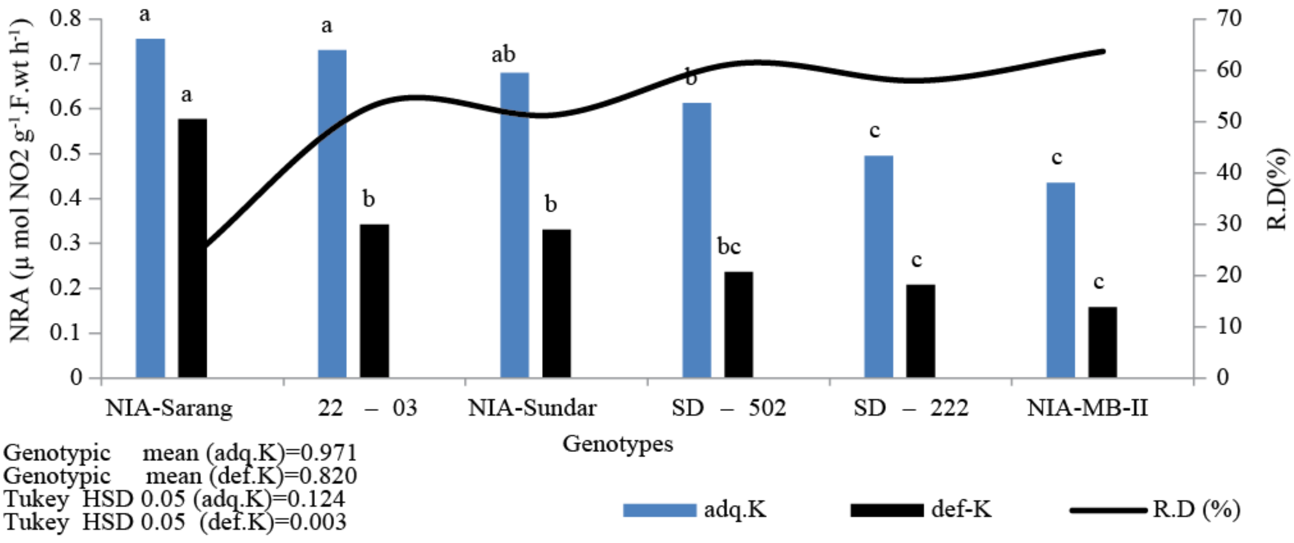

Fig. 2. Nitrate reductase activity (NRA) of wheat genotypes grown under adq. and def. K conditions.
Means followed by similar letters do not differ significantly at $p \leq 0.05$. Genotypic mean is the mean of six genotypes
adq.k = adequate K. def.k = deficient K. R.I/R.D = Rel. increase / Rel. decrease

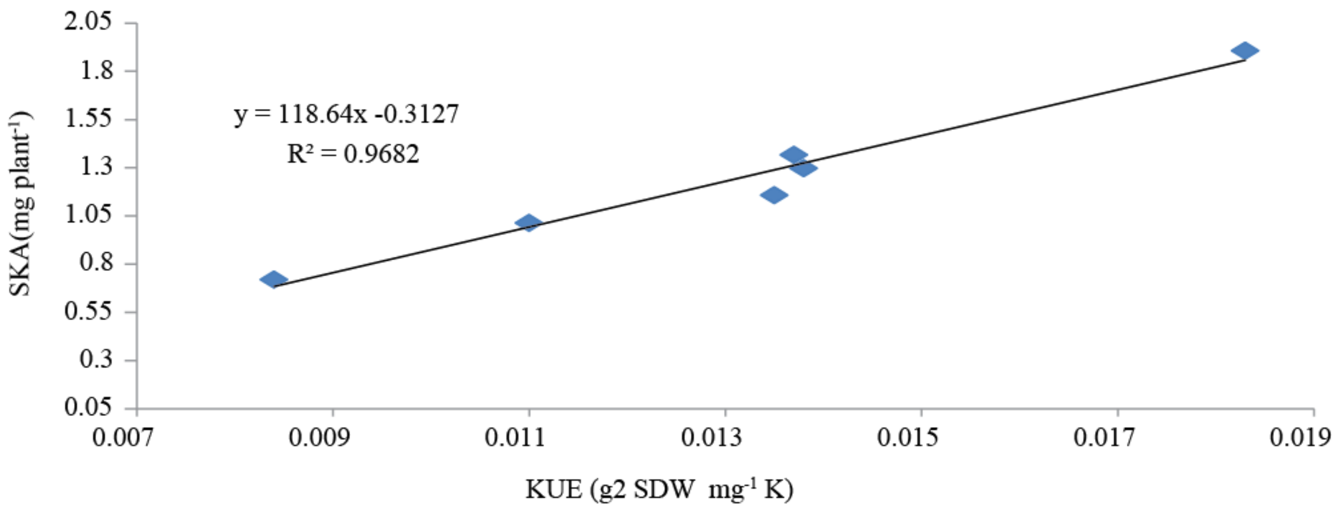

Fig. 3. Correlation of potassium use efficiency (KUE) with shoot potassium accumulation (SKA).

Conclusion

The prime objective of the study was to explore K-efficient and K-responsive wheat genotypes for sustainable low K-input wheat production in Pakistan. The results of the present study showed differential responses of wheat genotypes at two K (adq. K and def. K) levels. However, the genotype SD-222 is proved to be responsive to adequate K-supply (adeq-K) while the genotype 22-03 is efficient to low K-availability (def-K). It is suggested that these two genotypes could be used in the breeding programme to improve K-efficiency.

Acknowledgement

The author is thankful to Head, Plant Breeding and Genetics (PBG)Division, NIA Tandojam for providing wheat germplasm, Mr. Saifullah Baloch (SA-III) for technical assistance , Muhammad Adil Raza (SA-IV) for composing the manuscript and Shafique Ahmed Abro for statistical analysis.

References

Akhter, M.E., M.Z. Khan, S. Ahmad, M. Ashraf and A. Sardar. 2009. Effect of potassium on micromorphological and chemical composition of three cotton (*Gossypium hirsutum* L.) genotypes. *Afr. J. Biotechnol.,* 8(15): 3511-3518.

Anonymous, 1998. Functions of potassium in plants. In: Potassium for Agriculture. (Ed.): Donald L. Armstrong. Vol. LXXXII(82): 1998, No. 3. pp. 4-5.

Anonymous. 1984-85. Annual Report, AEARC, Tando Jam.

Anonymous. 1998. Functions of potassium in plants. In: Potassium for Agriculture. (Ed.): Donald L. Armstrong. Vol. LXXXII(82): 1998, No. 3. pp. 4-5.

Anonymous. 2007. Agricultural Statistics of Pakistan. Government of Pakistan, Ministry of food and agriculture and livestock. Islamabad

Anonymous. 2012-13. Agricultural Statistics of Pakistan. Government of Pakistan, Ministry of National Food Security and Research (Economic Wing), Islamabad.

Anuradha, K. and P.S. Sarma. 1995. Effect of moisture stress and applied potassium on yield and biochemical parameters of soybean in vertisols. *J. Oilseed. Res*., 12: 275-278.

Arshad Farooq, M. Ishaq, S. Yaqoob and K.N. Sadzai. 2007. Varietal adoption effect on wheat crop production in irrigated areas of NWFP. *Sarhad J. Agric*., 23(3): 2007.

Bajwa, M.I. 1994. Soil potassium status, potassium fertilizers, usage and recommendation in Pakistan. *Potash Review*, 20th Suit, No. 3: 18.

Bhatti, A., A.A. Qureshi and S. Rehman. 1976. Effect of nitrogen alone and in combinations with phosphorus and potash on the yield of wheat. *Pak. J. Agri. Res*., 6: 88-92.

Cody Wrathall. 2001. Nitrate Toxicity, Fall 2002 News letter. Editor Dr. Steve Hooser, ADDL Chief of Toxicology.

Epstein, E. and A. Bloom. 2005. Mineral nutrition of plants: *Principles and perspectives.*2nd Edition. Sinauer Association, Sunderland, M.A.

Fageria, N.K., R.J. Wright and V.C. Baligar.1988. Rice cultivar evaluation for phosphorus food production and environment. T. Ando *et al.* (eds.), p. 33-35.

Ghulam, A., J.Z.K. Khattak, G. Abbas, M. Ishaque, M. Aslam, Z. Abbas, M. Amer and M.B. Khokhar. 2013. Profit maximizing level of potassium fertilizer in wheat production under arid environment. *Pak. J. Bot.*, 45(3): 961-965.

Gill, M.A., I. Ahmed and M. Yaseen.1997. Potassium deficiency tolerance and potassium utilization efficiency in wheat genotypes. p. 33-35. In: Plant nutrition for sustainable food production and environment. T. Ando *et al.* (eds.), p.33-35.

Glass, A.D.M. M.Y. Siddiqi and K.I.Giles.1981.Correlation between potassium uptake and hydrogen efflux in barley varieties. *Plant Physiology*, 68: 457-459.

Hamayun, M., S.A. Khan, A.L. Khan, Z.K. Shinwari, N. Ahmad, Y.H. Kim and I.J. Lee. 2011. Effect of foliar and soil application of nitrogen, phosphorus and potassium on yield components of lentil. *Pak. J. Bot*., 43(1): 391-396.

Hussain, M., M. Niaz, M. Iqbal, T. Iftikhar and J. Ahmad. 2012. Emasculation techniques and detached tiller culture in wheat X maize crosses. *J. Agric. Res*., 50(1): 1-19.

Ismat, N., Zia-ul-Hassan, Atta Muhammad Ranjha and Muhammad Arshad. 2006. Exploiting genotypic variation among fifteen maize genotypes of Pakistan for potassium uptake and use efficiency in solution culture. *Pak. J. Bot*., 38(5): 1689-1696.

Jia, Y.B., X.E. Yang, Y. Feng and G. Jilani. 2008. Differential response of root morphology to potassium deficient stress among rice genotypes varying in potassium efficiency. *J. Zhejiang Univ. Sci B.,* 9(5): 427-434.

Jian, W., H. Haijiao, Sen Jia, Xuem ei Zhong, Fenghai li, Kuangye zhang and Zhensheng Shi. 2017. Photosynthesis and chlorophyll fluorescence reaction todifferent shade stresses of weak light sensitive maize. *Pak. J. Bot.,* 49(5): 1681-1 688.

Joachim, M., Arvind K. Bharti, Wojciech M. Karlowski, Heidrun Gundlach, Hye Ran Kim, Yeisoo Yu, Fusheng Wei, Galina Fuks, Carol A. Soderlund, Klaus F. X. Mayer and Rod A. Wing. 2004. Sequence composition and genome organization of maize. *Proceedings of the National Academy of Sciences of the United States of America.* 101(40): 14349-14354, available at www.pnas.org

Johnson, C.M., R.R. Stout, T.C. Broyer and A.B. Carlton.1957. Comparative chlorine requirements of different species. *Plant Soil*, 8: 327-353.

Jordon, J.S. 1984. Optimization of the *In vitro* assay conditions for nitrate reductase in barley (*Hordeum vulgare.*L.CV. Irgi). *J. Sci. Food*, 35: 725-730

José, L.J., S.J. João and A.M. Francisco. 2010. Nitrate reductase activity and spad readings in leaf tissues of guinea grass submitted to nitrogen and potassium rates. *R. Bras. Ci. Solo*, 34: 801-809.

Lichtenthaler, H.K. 1987. Chlorophyll and carotenoids pigments of photosynthetic biomembranes. *Methods Enzymol*., 148: 350-382.

Malik, M.A., S.H. Shah and A. Ali. 1990. Response of two wheat cultivars to different levels of potassium. *Pak. J. Agri. Sci.,* 27(2): 183-186.

Megda, M.M. 2009. Suprimento de nitrogênio e de potássio e características morfogênicas, nutricionais e produtivas do capim-Marandu. Piracicaba, Escola Superior de Agricultura “Luiz de Queiroz”, 84p. (Tese de Mestrado).

Miller, R.O. 1998. Nitric-Perchloric wet acid digestion in an open vessel. In: (Ed.): Y.P. Kalra. *Handbook of reference methods for plant analysis*, CRC Press, Washington, DC.,U.S.A. pp. 57-62.

Perveen, S., M. Iqbal, A. Nawaz, A. Parveen and S. Mahmood. 2016. Induction of drought tolerance in *Zea mays* L. by foliar application of Triacontanol. *Pak. J. Bot*., 48(3): 907-915.

Pettigrew, W.T. 2008. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. *Physiologia Plantarum*, 4(133): 670-681.

Peuke, A.D., W.D. Jeschke and W. Hartung. 2002. Flows of elements, ions and abscisic acid in *Ricinus communis* and site of nitrate reduction under potassium limitation. *J. Exp. Bot.*, 53(367): 241-250.

Pfluger, R. and R. Widemann. 1977. Der einfluss monovalenter kationene auf die nitrate duktion bei *Spinacia oleracia* L. *Z. Pflanzenk. Pflanzen*., 85: 125-133.

Ranjha, A.M., A. Jabbar and R.H. Qureshi. 1990. Effect of amount and type of clay minerals on K fixation in some alluvial soils of Pakistan. *Pak. J. Agri. Sci.,* 27: 187-92.

Ricardo Almeida Viégas and Joaquim Albenísio Gomes Silveira. 2002. Activation of nitrate reductase of cashew leaf by exogenous nitrite. *Braz. J. Plant Physiol*., 14(1): 39-44.

Santa-Maria, G. E., J.I. Moriconi and S. Oliferuk. 2015. Internal efficiency of nutrient utilization: what is it and how to measure it during vegetative plant growth? *J. Exp. Bot*., 66, 3011-3018.

Sattelmacher, B., W.J. Horst and H.C. Becker. 1994. Factors that contribute to genetic variation for nutrient efficiency of crop plants. *Z. Pflanzenernahr Bodenkd*, 157: 215-224.

Siddique, M.Y. and A.D. Glass. 1981. Utilization Index: A modified approach to the estimation and comparison of nutrient utilization efficiency in plants. *J. Plant Nutr*., 4: 289-302.

Song Heng Jin, Jian Qin Huang, Xue Qin Li, Bing Song Zheng, Jia Sen Wu, Zheng Jia Wang,Gen Hua Liu and Miao Chen. 2011. Effects of potassium supply on limitations of photosynthesis bymesophyll diffusion conductance in *Carya cathayensis. Tree Physiology,* 31: 1142-1151

Statistix 8.1. 2006. Analytical software

Tahir, M. Asif Tanveer, Asghar Ali, Muhammad Ashraf and Allah Wasaya. 2008. Growth and yield response of two wheat (*Triticum aestivum* L.) varieties to different potassium levels. *Pak. J. Llife Soc. Sci*., 6(2): 92-95.

Tahir, M.1999. Differential potassium use efficiency and potassium substitution by sodium in wheat genotypes. Ph. dissertation, Soil Science Department, UAF, Faisalabad.

Umar, S. and S.K. Bansal. 1995. Potassium requirement of mustard *(Brass ica juncea* L.) under moisture stress conditions. *Plant Physiol*. *Biochem*., 22: 130-135.

Vengiell, A. 1982. The use of chemical fertilizer on wheat during the systematic use of varying Bletitutim a Larte Bujqesor Tirane, Albania 21: 5-13. *Field Crop Absts*., 36: 2924.

Venkatesan, S. and M.N.K. Ganapathy. 2004. Nitrate reductase activity in tea as influenced by various levels of nitrogen and potassium fertilizers. *Comm. Soil Sci. Plant Anal*., 35: 1283-1291.

Wang Xiao-Guang, Zhao Xin-Hua, Jiang Chun-ji, Li Chun-Hong, Cong Shan, Wu Di, Chen Yan-Qiu, Yu Hai-Qiu and Wang Chun-Yan. 2015. Effects of potassium deficiency on photosynthesis and photoprotection mechanisms in soybean (*Glycine max* (L.) Merr.). *J. Integ. Agri.,* 14(5): 856-863.

Wang, L. and F. Chen. 2012. Genotypic variation of potassium uptake and use efficiency in cotton (*Gossypium hirsutum* L). *J. Plant Nutr. Soil Sci.,* 175(2): 303-308.

Wiedenfeld, B., B.W. Wallace and F. Hons. 2009. Indicators of cotton nitrogen status. *J. Plant. Nutr.,* 32: 1353-1370.

Yang, X.E., W.M. Wang and Z.I. He. 2004. Physiological and genetic characteristics of high nutrient efficiency of plants in acid soils. p. 78-83. In: The Red Soils of China: Their Nature, Management and Utilization. M.J Wilson Z.L.

Zhang, Z., X. Tian, L. Duan, B. Wang, Z. He and Z. Li. 2007. Differential responses of conventional and Bt transgenic cotton to potassium deficiency. *J. Plant Nutr.,* 30: 659-670.

Zia-ul-Hassan and M. Arshad. 2008. Structural equation modeling for biomass production of cotton under potassium stressed hydroponics system. *Soil Environ.,* 27: 58-62.

(Received for publication 12 August 2016)