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Full Length Article

Response of Rice (*Oryza sativa*) Genotypes Varying in K Use Efficiency to Various Levels of Potassium

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ABSTRACT

Wide spread potassium (K) deficiency in soils of Pakistan is one of the major reasons for relatively low rice yield. The use of K-efficient genotypes to combat this issue is most viable and sustainable strategy. A pot experiment was conducted to study the response of rice genotypes to various levels of K. The air-dried soil was mixed with the N, P and Zn fertilizers (applied @ 130, 70 & 12.5 kg ha^{-1} as urea, diammonium phosphate and $ZnSO_4$ [33%], respectively). Different K rates (0, 30, 60, 90 & 120 kg ha^{-1}) were applied to three rice genotypes previously screened and categorized for their K use efficiency *viz* IR-6 (low K-use efficient), Super basmati (medium K-use efficient) and genotype 99509 (high K-use efficient). Significant improvement in grain yield and yield components was observed with K application albeit with different degree of efficacy. Low K-use efficient genotype (IR-6) responded poorly in terms of grain yield to application of K. High K-use efficient genotype (99509) remained unaffected, whilst medium K-use efficient genotype (Super basmati) behaved moderately. Optimum K rate for maximum rice grain yield was found as 60 kg ha^{-1} for all the three rice genotypes and application beyond 60 kg K ha^{-1} had no further positive impact on various growth and yield parameters. However, using the quadratic model, the optimum K rate for maximum rice grain yield was found 70 kg ha^{-1} for IR-6, while 62 kg ha^{-1} was found for genotype 99509 as well as Super basmati. The results implied that K-use efficient genotypes used the tissue K more efficiently.

Key Words: Rice genotypes; K-use efficiency; K fertilizer; Quadratic model

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most favored world cereals and is staple food for over half of the world's population for fulfilling their food needs (Dowling *et al.*, 1998; Itani *et al*., 2002). Approximately 90% of the world's rice is grown in less developed countries, especially in Asia, including Pakistan (Mae, 1997), to assure food security for burgeoning population of the world (Anonymous, 2002). In Pakistan, it is providing people with their daily sustenance more than any other cereal. Rice is also a major cash crop, generating 20% of the foreign exchange for Pakistan. The sustainability as well as high yields of rice are needed for food security in many of the subsistence farming systems in Asia (Marschner, 1995; Fageria & Baligar, 1997; Cooper, 1999). However, for the last three decades rice yields have been almost stagnant. Thus there is need to strive for increases in its production to feed the rapidly growing population.

Potassium (K) is one of the three essential macronutrients required in large amounts for plant growth. This versatility of K nutrition is well documented in enhancing yield and quality of rice (Jagadeesh *et al.*, 2006; IRRI, 2007; Srivastava & Singh, 2007) and in sustainable production of other crops (Munson, 1985; Fageria & Baligar, 1997). With intensive cropping and increased application of nitrogen and phosphorus fertilizers in recent years, K deficiency has become a limiting nutritional factor for increasing rice yield (Dobermann & Fairhurst, 2000; Yang *et al*., 2003). Rice needs higher K application as compared to other cereals, as about 56-112 kg of K is taken out from the soils by each harvest of 4-8 tones rice yield per hectare and annual K demand for irrigated rice would be 9-15 × 10^6 tones by 2025 (Dobermann *et al*., 1998). With continuous K soil mining, has significantly depleted in K. Widespread K deficiency (>35%) in the soils of Pakistan has been reported, which is an alarming situation in the years to come (Akhtar *et al*., 2003).

The exogenous application of K has direct effects on the growth and total biomass allocation in rice (Samejima *et al*., 2005). Thus, the enhancement in the K use efficiency (KUE) is essential for increasing rice production to meet the food requirements of the growing population (Yang *et al*., 2004). Potassium efficiency defined as the ability of plant species to obtain relatively high yields of biomass in the

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presence of a low K supply as compared to non-efficient plants (Steingrobe & Claassen, 2000). Use of efficient plants thus could get high yields with a low K application (Brouder & Cassman, 1990). This research was conducted with the objective of evaluating different K rate in three genotypically varying rice genotypes in pots under rain protected wire house conditions.

MATERIALS AND METHODS

A pot experiment was conducted in the rain-protected wire house, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad to investigate how three rice genotypes differentially efficient in K utilization (selected from a preliminary study under hydroponic experiment) behaved to exogenously apply varying levels of K in soil. The air-dried soil (Typic Calciargids) was filled in pots (23 cm diameter, 26 cm height) with the 40 mesh sieved soil (12 kg soil pot^{-1}), mixed with the N, P and Zn fertilizers (applied @ 130, 70 & 12.5 kg ha^{-1} as urea, diammonium phosphate & $ZnSO_4$ [33%], respectively). The soil sample was taken before sowing the crop for basic soil analysis. The N, P and Zn fertilizers were applied in all the treatments as a basal dose. The soil was thoroughly mixed with different rates of potassium fertilizer (K_2SO_4) before filling the pots. Nitrogen (urea) was applied in three splits during the growth period (1st at transplanting, 2nd at tillering, & 3rd at panicle initiation). Twenty-eight days old seedlings (6 plants per pot with 2 plants per hill) of three selected rice genotypes i.e., IR-6 (low K-use efficient), Super basmati (medium K-use efficient) and genotype 99509 (high K-use efficient) were transplanted in each pot. The pots were randomly arranged with four replications at ambient temperature and light. After transplanting the rice nursery, the pots were flooded by using canal water [electric conductivity = 0.66 dS m^{-1}, sodium adsorption ratio = 3.75 (m mol L^{-1})$^{1/2}$, residual sodium carbonate = 0.0 meq L^{-1}] which was fit for irrigation as per criteria given by Ayers and Westcot (1985).

The recommended production and protection technology of standard rice management (SRM) was followed throughout the crop period. The data were recorded for yield and its attributes (number of tillers and panicles, 1000-grain weight & grain yield) at maturity. Plant analysis was done for the determination of total K uptake and KUE. Optimum rate of K for maximum grain yield was calculated using the quadratic model. The treatments in addition to equal rates of N, P and Zn, were: No K (control), 30, 60, 90 and 120 kg K ha^{-1}.

The data were subjected to statistical tests (Steel & Toori, 1980) for the analysis of variance (ANOVA), using statistical software Statistix version 8.1 (Analytical Software©, 1985-2005). Turkey's honestly significant difference (HSD) test was employed to separate the treatment means at alpha 0.05. Completely randomized design was employed for analysis of variance.

RESULTS AND DISCUSSION

Number of tillers (NOT) and number of panicles per pot (NOP): Analysis of variance showed significant (P<0.05) effect of K levels (K), rice genotypes (G) and their interaction (K×G) on this parameter (Table II). It is evident from the data that the response of the three genotypes to exogenous K application was almost similar for both NOT and NOP parameters (Table I). In case of IR-6 and 99509, maximum NOT and NOP pot^{-1} was recorded with 60 kg K ha^{-1}, while in case of Super basmati, 30 kg K ha^{-1} resulted in maximum NOT and NOP. A further increase in the level of K application did not improve NOT and NOP in none of the three selected genotypes. As expected, the genotype with low KUE (IR-6) responded poorly to the exogenous K application, whereas the high K-use efficient genotype (99509) was medium responsive for these parameters. On the other hand, Super basmati with medium KUE trait was least affected for these parameters with the exogenous application of K. Overall, the performance of the three genotypes was ranked in the order: Super basmati > 99509 > IR-6. An increase in these growth parameters with the increasing K fertilizer application has been reported by many others (Dunn & Stevens, 2005; Awan *et al*., 2007; Bahmaniar & Ranjbar, 2007).

1000-grain weight (TGW) and grain yield (GY): Data showed a significant (P<0.05) difference for TGW and GY recorded in all treatments over control in three rice genotypes. Sixty kg K ha^{-1} was sufficient to produce maximum TGW in all genotypes whilst higher doses of applied K had a non-significant effect on TGW. Interestingly, the performance of low K-use efficient genotype IR-6 for TGW was good and surpassed that of Super basmati and genotype 99509, indicating the best responsiveness of IR-6 to exogenous application of K for TGW, while Super basmati (medium K-use efficient) followed it. On the other hand, high K-use efficient genotype (99509) was poor in its response to K application for TGW (Table III). A gradual increase in GY was observed in the tested genotypes with increasing level of K up to 60 kg K ha^{-1} implying that 60 kg K ha^{-1} was sufficient to maximize the grain yield of rice genotypes. Application of K @ 30 kg ha^{-1} produced grain yield very close to that of 60 kg K ha^{-1}. This suggested that 30 kg K ha^{-1} was an economical level of K to maximize the productivity of Super basmati. An increase in yield attributes with the increasing application of K fertilizer has been reported by many others (Kalita *et al*., 1995; Ojha & Talukar, 2002; Dunn & Stevens, 2005; Awan *et al*., 2007; Bahmaniar & Ranjbar, 2007). The contrasting results regarding the influence of K nutrition on rice yield parameters may be attributed to the genetic make-up of the rice genotypes, which is reported to greatly influence yield (Horie *et al*., 2004). No remarkable response of rice genotypes beyond 60 kg K ha^{-1} might be due to a disturbance in the balanced proportions of nutrients as well as the potential nutrients

Table I: Effect of K levels on the number of tillers and number of panicles of rice genotypes (pot trials)

K Levels (kg ha^{-1})	Number of tillers per pot				Number of panicles per pot			
	IR-6	Super basmati	99509	Mean	IR-6	Super basmati	99509	Mean
Control	29	38	34	34C±4.5	23	30	27	27D±3.5
30	31	47	36	38B±8.1	25	36	29	30C±5.6
60	37	43	41	40A±31	29	36	35	33A±3.8
90	35	40	39	38B±2.6	26	35	30	30BC±4.5
120	36	39	39	37B±1.7	27	35	33	32B±4.2
Mean	34C±3.5	42A±3.7	37B±2.8		26±2.2	34A±2.5	31B±3.2	

Table II: Effect of K levels on 1000-grain weight and Grain yield (g pot^{-1}) of rice genotypes (pot trials)

K levels (kg ha^{-1})	1000-grain weight (g)				Grain yield (g pot^{-1})			
	IR-6	Super basmati	99509	Mean	IR-6	Super basmati	99509	Mean
Control	21	18	16	19BC±2.5	32.9	34.9	35.8	34.6D±1.5
30	23	20	18	20B±2.5	37.7	40.5	38.7	39B±1.4
60	24	22	19	21A±2.5	39.6	40.8	40.8	40.4A±0.7
90	22	20	17	20BC±2.5	37.5	38.4	39.0	38B±0.8
120	22	19	17	19C±2.5	36.6	37.2	37.5	37C±0.5
Mean	22A±1.1	19.7B±1.5	17.5C±1.1		36.9B±2.5	38.4A±2.4	38.4A±1.9	

requirement of the crops (Mengel, 1983; Dixit & Singh, 1986; Dilbaugh *et al*., 1986; Ahamad, 1988; Awan *et al*., 2003).

K uptake and use efficiency: The analysis of variance showed significant effects according to genotype (G), K levels (K), and their interaction (G×K). There was a gradual increase in plants' total K uptake with an increase in K application up to 60 kg K ha^{-1} in both Super basmati and 99509, while it went up to 90 kg K ha^{-1} in IR-6. Data further revealed that the application of K @ 90 and 120 kg K ha^{-1} resulted in a sharp decrease in total K uptake in 99509, while no significant difference in total K uptake was observed in Super basmati (Fig. 1). Moreover, medium K-use efficient genotype, Super basmati, responded strongly against the exogenous application of K, high K-use efficient genotype 99509 remained poor in K uptake whereas response of the low K-use efficient, IR-6, was moderate towards total K uptake. These results suggest that although 99509 up took lesser K, it produced maximum grain yield among all genotypes. The uptake of K by Super basmati was higher, but its yield was medium; in IR-6, whose total K uptake was medium, the yield increment was poor.

With significant (*P*<0.05) difference in the genotypes, K levels and their significant (*P*<0.05), the KUE of grain + shoot dry matter of the selected rice genotypes calculated against varying levels of K revealed a gradual increase in KUE with increase in K levels up to 60 kg K ha^{-1} in both, IR-6 and 99509, which declined thereafter. In Super basmati, the maximum KUE was noted at 30 kg K ha^{-1} then gradually decreased with increases in K level. Interestingly, KUE was reduced at higher levels of K as compared to lower levels in all three genotypes. It was noted that the KUE of 99509 was higher (1.04) as compared to the Super basmati and IR-6 at 60 kg K ha^{-1} and at the same time the yield of 99509 at this level was also maximum. Furthermore, KUE of 99509 at zero level of K application (control) was also higher as compared to Super basmati and IR-6. This indicated that 99509 kept its consistency in performance for K utilization under pot trials too, while on the other hand, IR-6, as expected, remained poor in its performance in both K utilization and grain formation. On the basis of KUE, the genotypes were ranked in the order of 99509 > Super basmati > IR-6. The significant differences in KUE are an indication of the existence of genetic variation among the selected genotypes.

Maximum total K uptake was noted in IR-6 (low K-use efficient) as compared to other high and medium K-use efficient genotypes. This may imply that although total K uptake was more in IR-6 but its utilization for more grain formation was poor, thus showing its lower efficiency in K utilization. On the other hand, Super basmati with less total K uptake had higher grain yield, thus showing high KUE in terms of grain yield (Fig. 1). Generally, K uptake increases with the increase application of K (Bohri *et al*., 2000). The response to more K uptake might be due to the satisfactory availability of applied K (Rehman *et al*., 2006). However, Sarkar and Malik (2001) claimed that increase in paddy and straw yields by K application might be attributed to more N utilization in the plant system, resulting in more chlorophyll synthesis and efficient translocation of assimilates to reproductive parts. Bahmaniar and Ranjbar (2007) elucidated that K uptake in shoot and grain was significantly affected by cultivar and K interaction. The K absorption by grains increased with the increase of K level (Sheng *et al*., 2004). K uptake was mainly dependent on the dry matter yield and K content of the straw. Efficient plants produce more biomass per unit of nutrient absorption: particularly under nutrient stress conditions (Yang *et al*., 2003). Interestingly, KUE of grain + straw (g^2 total weight mg^{-1} K) was lesser at higher levels of K than at lower levels in all three genotypes (Fig. 2). The same was also noted in rice crop by Fageria *et al*. (1988) and Blair and Wilson (1990).

Table III: Optimum K rate for maximum yield using quadratic model

Variety	Quadratic equation	R^2	Optimum K rate (kg ha^{-1})
IR-6	$y = -0.0012x^2+0.1706x+33.233$	0.91	70.0
Super basmati	$y = -0.0013x^2+0.1628x+35.554$	0.82	63.0
99509	$y = -0.001x^2+0.1315x+35.853$	0.94	62.0

Fig. 1: Effect of K levels on the total K uptake of rice genotypes

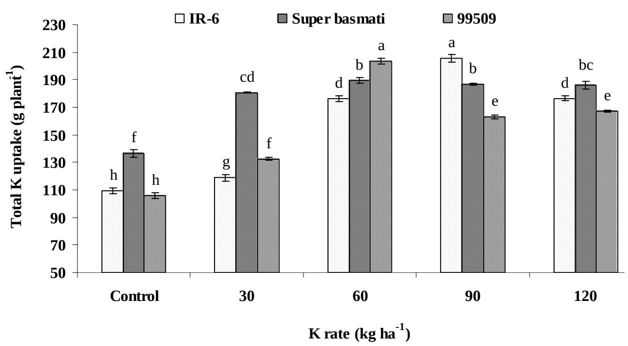


Fig. 2: Effect of K levels on the K use efficiency of rice genotypes

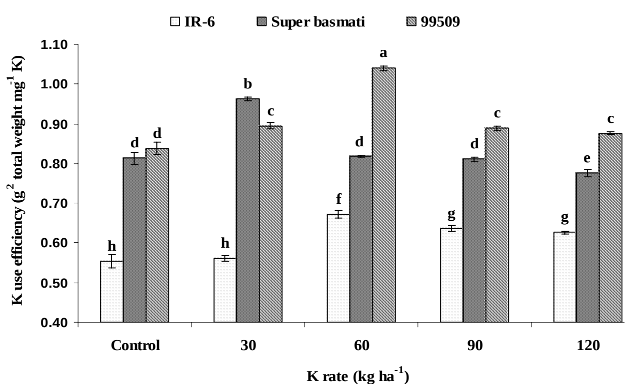
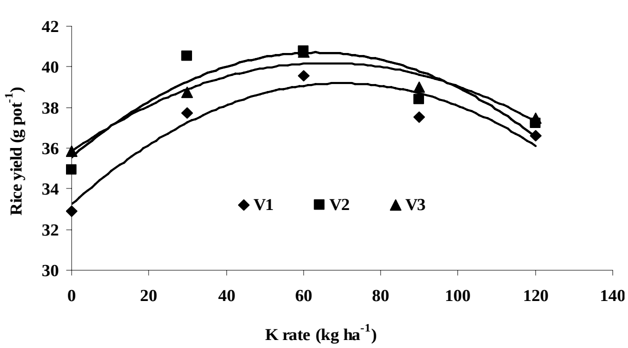


Fig. 3: Optimum K rate for maximum grain yield of rice genotypes



Optimum K rate for maximum grain yield: Optimum K rate for each genotype was determined using the quadratic model (Fig. 3). Optimum K rate (kg ha^{-1}) for maximum grain yield was 70 for IR-6, 63 for Super basmati and 62 for genotype 99509. The coefficients of determination for regression equations were 0.91 for IR-6, while 0.94 for 99509 (P<0.05). In the case of Super basmati, R^2 was 0.82 (P=0.10) (Table V). It is clear from this study that a higher level of K needs to be applied for IR-6 than for Super basmati or 99509. There was almost no difference with respect to optimum K rate for both Super basmati and 99509 genotypes. It was notable that the optimum K rate (kg ha^{-1}) determined for each of the selected genotypes almost matched with the standard rates established for rice cropping (Nazir *et al.*, 1994). The results of pot trials revealed that the maximum grain yield was obtained at 60 kg K ha^{-1} in all three genotypes. Grain yield was decreased at higher levels of K i.e., 90 kg K ha^{-1} and 120 kg K ha^{-1}, respectively.

Optimizing grain yield along with reduction in production cost are considered very important in rice production worldwide (Koutroubas & Ntanos, 2003). Judicious application of fertilizer is important to boost up agricultural production to a desirable level (Panaullah *et al.*, 1998). Awan *et al*. (2007) also reported that a rate of 62.5 kg K ha^{-1} maximized rice yield to 4.73 tones ha^{-1}. The differences in optimum K level might be due to differential phenotypic variation of rice genotypes to the various levels of K (Ali *et al*., 2005; Zhang & Wang, 2005; Zaman *et. al.*, 2007; Islam *et al*., 2008).

CONCLUSION

K application significantly improved grain yield and yield components in the three genotypically varying rice cultivars. High K rate of 70 kg ha^{-1} was found for low K-use efficient genotype (IR-6), while same K rate (62 kg ha^{-1}) was observed both for high K-use efficient genotype (99509 & Super basmati, respectively). There is a need to establish optimum K rate for all the rice cultivars (cultivar specific K rate) in extensive field trials.

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