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Differential response of rice genotypes at deficient and adequate potassium regimes under controlled conditions

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Abstract

Potassium (K) deficiency in the soils of Pakistan is spreading rapidly and thus has become one of the most nutritional limiting factors for increasing rice yield to feed the overgrowing population. Exploitation of genetic potential through screening could be an important technique to find out K efficient rice genotypes which might perform better under deficient K regime. In this study, 26 rice (Oryza sativa L.) genotypes were tested in rain protected environment under nutrient solution at low (0.3 mM) and adequate K (3.0 mM) levels to examine the various growth attributes like shoot fresh weight (SFW), root fresh weight (RFW), total fresh weight (TFW), root shoot ratio (RSR) and K stress factor (KSF). The crop was harvested at 25 days after transplanting. SFW ranged from 0.52 to 4.18 g 2plant^{-1} (deficient K level) and 1.65 to 11.53 g 2plant^{-1} (adequate K level). RFW ranged from 0.07 to 0.30 g 2plant^{-1} (deficient K level) and 0.10 to 0.57 g 2plant^{-1} (adequate K level). Contrasting variation in KSF was observed in 49807 (32%) and 81% in 527773-2. Marked differences for biomass production were observed among all the rice genotypes indicating a wide genotypic variation which may imply an opportunity for the genetic improvement under low K status. The two rice genotypes 99509 and 49818 performed best under deficient K level with respect to all growth parameters and therefore, can be used for future breeding purposes and field experimentation.

Key words: Rice, genotypic variation, potassium deficiency

Introduction

Rice is a staple food for more than half of the world population, and about 95% of the world rice is grown in less developed countries, especially in Asia including Pakistan (Mae, 1997). Potassium (K) is one of the three essential macronutrients required in the largest amount for plant growth and yield because it plays a vital role in sustainable crop production systems (Munson, 1985; Marschner, 1995; Fageria and Baligar, 1997). Due to intensive cropping and increased application of nitrogen and phosphorus fertilizers in recent years, K deficiency has become the most nutritional limiting factor for increasing rice yields (Dobermann *et al*., 1996; Liu and Yang, 2000; Yang *et al*., 2003). Continuous K mining resulted in severe depletion of the element. Wide spread K deficiency (>30%) in the soils of Pakistan has been reported which is alarming situation in the years to come (Akhtar *et al*., 2003).

Selection and identification of crop genotypes best adapted to the adverse soils with low nutrients particularly in K is one of the key strategies for the sustainable intensification of agricultural systems (Fageria and Baliagr, 1997; Baligar *et al.,* 2001). Genotypic differences in K nutritional applications in rice tolerance to low K were reported by many researchers (Liu *et al*., 1987; Li and Xie, 1991; Liu *et al*., 2000; Yang *et al*., 2003, 2004b).

K application is directly related to growth and total biomass allocation in rice (Samejima *et al*., 2005). Flexibility in biomass allocation, root morphology and root distribution pattern has been found to be an important adaptive mechanism to acquire nutrients (Rengel and Marschner, 2005; Yang *et al*., 2005; Xie *et al*., 2006; Lynch *et al*., 2007). At the same time being a major organ for nutrient uptake, the root plays an important role in soil-plant system (Lynch *et al*., 2007) because a high root:shoot ratio is characteristically associated with plants growing in K deficient soils (Yang *et al*., 2004a).

Currently, there is no suitable index of crop response to K deficiency for breeding purpose, which is a major limitation to crop improvement. Therefore, the selection of genotypes that perform best under deficient K conditions are extremely important. Little information are available on genotypic variations in rice cultivars with respect to biomass allocation in response to K application. The objective of this study was to investigate the genotypic differences for biomass production and allocation among 26 rice genotypes under rain protected net house conditions.

Materials and Methods

The solution culture experiment was conducted under controlled conditions during June 2005-2006 at University of Agriculture, Faisalabad to examine genotypic differences for biomass production and allocation under adequate and

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deficient K levels. Seeds of 26 rice *(Oryza sativa* L.) genotypes were obtained from the Rice Research Institute, Kala Shah Kaku, Punjab. Seeds were surface-sterilized with 0.5% NaClO and germinated in sand in an iron tray lined with polyethylene. The sand washed with dilute HCl followed by three to four washings with deionized water. Seeds were irrigated with distilled water regularly. At the 2-leaf-stage, plants were transplanted in a nutrient solution to foam plugged holes in 200-L capacity iron tubs lined with plastic sheets containing half strength Johnson's solution (Johnson *et al.*, 1957). The composition of the nutrient solution was 5.5 mM NH_4SO_4, 2.0 mM Ca $(NO_3)_2.4H_2O$, 0.5 mM $NH_4H_2PO_4$, 0.5 mM $MgSO_4.7H_2O$, 1.0 µM each of KCl, H_3BO_3, $MnSO_4.H_2O$, $ZnSO_4.7H_2O$, $CuSO_4.5H_2O$, H_2MoO_4 and Fe –EDTA. The solution was modified to maintain deficient (0.3 mM) and adequate (3.0 mM) K levels using K_2SO_4.

Sixteen seedlings of each genotype were planted at a density of 10 x 10 cm. A randomized complete block design with two factor factorial was used with each treatment replicated four times. The pH of nutrient solution was maintained at 5.50±0.5 with 0.1M HCl or 0.1M NaOH. The plants were harvested 25 days after transplanting. The harvested plant were washed with distilled water, blotted dry with tissue paper and separated into shoots and roots. The data recorded were root fresh weight, shoot fresh weight, and total fresh weight. Root shoot ratio and potassium stress factor were also calculated.

Results and Discussion

In hydroponics study, biomass production is a basic criterion to evaluate the growth response of any cultivar under a given set of nutritional conditions. There were significant genotypic differences in SFW, RFW and TFW as was evident from the analysis of variance conducted on the growth attributes of the 26 rice genotypes in hydroponics study (Table 1). At adequate K level, shoot fresh weight (SFW) was maximum (11.53 g $2plant^{-1}$) for KSK-412 and minimum (1.65 g $2plant^{-1}$) for IR-6, with a mean SFW of 5.53 g $2plant^{-1}$. Under deficient K condition, the rice genotype 99509 produced maximum SFW (4.18 g $2plant^{-1}$) while the genotype Bas-2000 had the lowest SFW (0.52 g $2plant^{-1}$), with a mean SFW of 2.14 g $2plant^{-1}$. There was an inhibitory effect of low K on shoot biomass of all the genotypes. The interaction (G × K) for SFW was also found significant. Earlier workers reported similar results for rice genotypic variations for shoot biomass production (Yang *et al.*, 2003; Jia *et al.*, 2008).

The RFW ranged from 0.10 g $2plant^{-1}$ (00518) to 0.57 g $2plant^{-1}$ (KSK-406) with an average of 0.28 g $2plant^{-1}$ under adequate K regime. The same parameter ranged from 0.07 g $2plant^{-1}$ (Bas-2000 and IR-6) to 0.3 g $2plant^{-1}$ (99513) with an average of 0.16 g $2plant^{-1}$ under deficient K regimes (Table 1).

Genotype (G), K level and G × K interaction were significant for RFW (Table 1). RFW was increased under adequate K level depicting positive response to K application in all of the genotypes except KSK-133, PK-3717-12 and 00518. High RFW at low K level reflected the tolerance of a genotype to low K stress (Table 1) which may be associated with certain physiological mechanisms of the rice genotypes. Similarly, the increased biomass allocation to roots under K deficiency stress was recently reported in maize (Nawaz *et al.*, 2006). However, total maximum biomass (12.0 g $2plant^{-1}$) was observed in KSK-412 and (4.36 g $2plant^{-1}$) in 99509 of rice cultivars at adequate and low K regimes, respectively. TFW for K×G at both K levels was found significant (Table 1).

There were significant differences among rice genotypes for RSR both at low and adequate K levels. In the present study (Table 2) mean RSR enhanced form 0.05 (adequate K) to 0.08 (deficient K). Hermans *et al.* (2006) suggested contrasting results in an extensive review that K deficiency causes the accumulation of sugars in both roots and shoots but higher accumulation of soluble sugars did not improve the root growth. Earlier too, it is widely accepted that roots require energy from photo-assimilates for nutrient uptake but K deficiency restricts this translocation from leaf to root by accumulating soluble sugars in K deficient plant parts. Epstein and Bloom (2005) nonetheless, the work of Peuke *et al.* (2002) revealed that K deficiency inhibited the shoot growth in *Ricinus communis* particularly younger leaves at the expense of root growth. In sweet potatoes, Osaki *et al.* (1995) also found higher root growth under K deficiency which was related to the enhanced uptake of nitrogen. Similarly, the increased biomass allocation to roots under K deficiency stress was recently reported in maize (Nawaz *et al.* (2006). Inconsistent behavior on this growth attribute was observed in three genotypes viz. 99509, 49818 and Super-Basmati. Only one genotype (49731) exhibited no change in RSR at both K levels. These findings highlighted that the contribution of root morphology and physiology is very important aspect in biomass production (Samejima *et al.*, 2005; Yang *et al.*, 2003). This indicated that these genotypes were tolerant under deficient K conditions because these produce higher biomass as compared to the other genotypes, but the mechanisms behind tolerance of rice genotypes to K deficient needs further experimentations.

Potassium stress factor (KSF) is a measure of relative reduction in biomass production due to K stress (Mahmood, 1999). There were significant differences among rice genotypes with respect to KSF at both deficient and

Table 1. Biomass production of rice genotypes at tillering stage under K deficient (DK) and adequate levels (AK) in hydroponics

Genotype	Shoot Fresh Weight		Root Fresh Weight (g 2plant[-1])		Total Fresh Weight	
	DK	AK	DK	AK	DK	AK
KSK-406	2.78	10.55	0.25	0.57	3.03	11.12
KSK-407	1.42	7.11	0.11	0.31	1.52	7.42
KSK-410	1.00	3.39	0.11	0.22	1.11	3.61
KSK-412	2.98	11.53	0.18	0.47	3.16	11.99
KSK-413	1.79	7.06	0.20	0.26	1.99	7.32
KSK-301	1.40	5.12	0.08	0.23	1.48	5.36
99704	2.30	6.54	0.13	0.32	2.43	6.85
KSK-282	2.30	6.21	0.20	0.36	2.50	6.57
99513	2.81	4.30	0.30	0.36	3.11	4.66
99417	2.91	8.34	0.28	0.53	3.19	8.87
49731	3.75	6.77	0.23	0.43	3.99	7.20
99509	4.18	8.08	0.19	0.43	4.36	8.51
49818	4.08	7.81	0.17	0.42	4.25	8.23
00518	1.64	3.68	0.12	0.10	1.75	3.78
Bas-385	1.99	4.33	0.14	0.25	2.13	4.58
Super-Bas	1.63	3.01	0.14	0.27	1.77	3.28
Bas-2000	0.52	2.22	0.07	0.15	0.59	2.37
IR-6	0.72	1.65	0.07	0.13	0.79	1.77
IR-9	0.74	2.39	0.10	0.12	0.84	2.51
KSK-133	1.55	3.61	0.15	0.12	1.70	3.73
PK-3717-12	2.15	3.62	0.16	0.12	2.31	3.75
49807	2.99	4.37	0.14	0.16	3.13	4.53
Bas-370	3.00	7.24	0.19	0.23	3.19	7.47
40265	3.10	6.12	0.22	0.27	3.32	6.39
52773-2	0.78	4.17	0.10	0.31	0.87	4.48
33608	1.25	4.60	0.09	0.19	1.34	4.79
Minimum	0.52	1.65	0.07	0.10	0.59	1.77
Maximum	4.18	11.53	0.30	0.57	4.36	11.99
Mean	2.14	5.53	0.16	0.28	2.30	5.81
Standard error	0.21	0.49	0.01	0.03	0.22	0.51
HSD $G_{0.05}$	2.21	3.7	0.20	0.25	2.3	3.84
HSD $KxG_{0.05}$	3.1942		0.2429		3.3192	

HSD: Honestly significant differences
DK and AK: Deficient and adequate potassium level, respectively

Table 2. Root shoot ratio at the tillring stage of rice genotypes under deficient (DK) and adequate K (AD) in hydroponics

Genotype	Root : Shoot	
	DK	**AK**
KSK-406	0.09	0.05
KSK-407	0.07	0.04
KSK-410	0.11	0.07
KSK-412	0.06	0.04
KSK-413	0.11	0.04
KSK-301	0.06	0.05
99704	0.06	0.05
KSK-282	0.09	0.06
99513	0.11	0.08
99417	0.09	0.06
49731	0.06	0.06
99509	0.04	0.05
49818	0.04	0.05
00518	0.07	0.03
Bas-385	0.07	0.06
Super-Bas	0.08	0.09
Bas-2000	0.13	0.07
IR-6	0.10	0.08
IR-9	0.14	0.05
KSK-133	0.10	0.03
PK-3717-12	0.07	0.03
49807	0.05	0.04
Bas-370	0.06	0.03
40265	0.07	0.04
52773-2	0.13	0.07
33608	0.07	0.04
Minimum	0.04	0.03
Maximum	0.14	0.09
Mean	0.08	0.05
Standard error	0.01	0.003
HSD G $_{0.05}$	0.095	0.043
HSD KxG $_{0.05}$	NS	

HSD: Honestly significant differences
DK and AK: Deficient and adequate potassium level, respectively

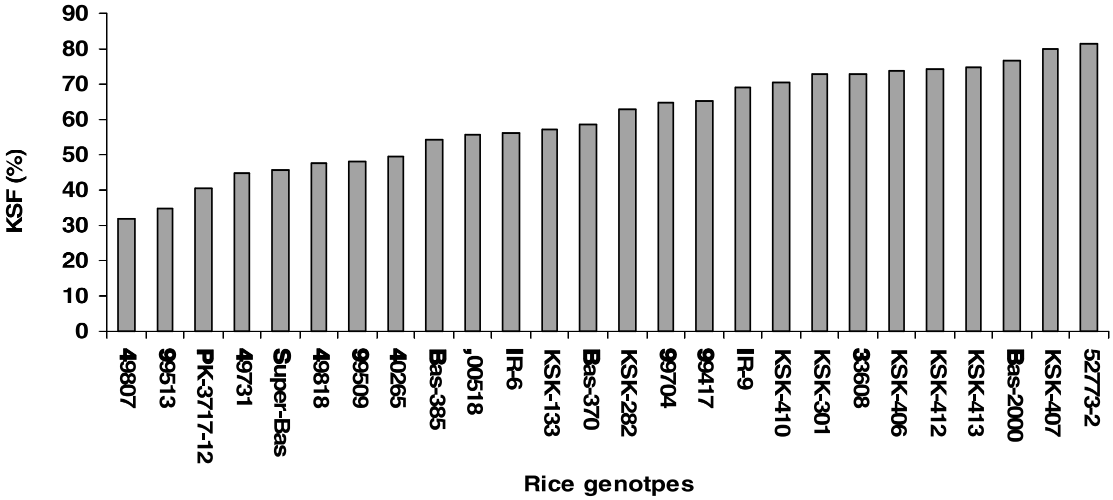

Figure 1. Potassium stress factor of selected rice genotypes

adequate K level. KSF ranged from 32% in genotype 49807 to 81% in genotype 52773-2 with an average of 60% (Figure 1). Present study showed that a considerable variation among rice genotypes for K application is present which could be utilized for future breeding in rice genotypes under low input K agriculture (Wang *et al.*, 2005; Zou *et al.*, 2001).

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