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Effect of potassium fertilization on grain attributes of rice under vegetative and reproductive stage water stress

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Abstract
Rice (*Oryza sativa* L.) is a cereal that feeds billions of people and serves as a primary staple food. Its production will be required to increase with the rapid increase in population in the future decades. However, rainfed lowland rice in many places are prone to drought and limiting yield. A field experiment was conducted to evaluate the potentiality of potassium fertilisation on compensating the negative effect of drought on rice grain production. Under water stress at the reproductive stage, rice grain production was more limited than water stress at the vegetative stage and higher dose of potassium application substantially compensates the negative effect of water stress, though the extent of effect of potassium was genotypic dependent.

Keywords: Drought, rice, potassium nutrition

Introduction

Rice (*Oryza sativa* L.) has been farmed for thousands of years and holds great significance as a staple food crop. It plays a crucial role in the global food system and is considered one of the most important cereal crops worldwide. Rice feeds billions of people, particularly in Asia, where it serves as a dietary staple and crucial for ensuring global food security. Drought is the most common and complex natural event that can occur at any time over an extended period, influencing a vast array of plants metabolic processes (Muthurajan *et al*., 2011) [9]. Drought stress is a deficiency in the soil's moisture content that reduces rice plants' growth, development and yield. During vegetative growth, rice can recover from drought, but it cannot recover during the flowering stage, decreasing grain yield (Fukai and Cooper, 1995) [5]. Drought stress reduces the growth by inhibiting cell division or cell elongation, reducing turgor pressure (Egilla *et al*., 2001) [4]. Drought stress has a more significant impact on cell elongation, resulting in stunted growth.

Drought is an environmental catastrophe that has reduced rice production. Drought is a serious issue in many parts of the world that limits crop production and directly affects rice productivity. Genotypic variation in maintaining internal water status was primarily associated with grain yield during the flowering stage under drought conditions. Adaptation rather than desiccation tolerance, i.e., the ability to function in a dehydrated state, is the result of the development of crops to water-limited environments in terms of growth and productivity. Plants are able to respond to and adjust to drought and other abiotic stresses by introducing molecular, cellular and physiological modifications. Fertilizers are the oldest methods for enhancing plant productivity among cultural practices. Potassium's function in plant development is well understood. Growing evidence shows plants experiencing environmental stresses such as drought have a greater internal demand for potassium (Cakmak, 2005) [3]. Potassium plays a significant role in enhancing rice's drought resistance. Diverse mechanisms, such as regulation of stomatal opening, water uptake maintenance and osmoregulation promotion, contribute to potassium's effect on rice's drought tolerance. Multiple studies have demonstrated that potassium application can increase rice's drought tolerance by enhancing physiological and biochemical responses, regulating gene expression and promoting water uptake. The presented experiment was aimed to evaluate the potentiality of potassium fertilisation on compensating negative effects of water stress on different rice genotypes subjected to vegetative and reproductive stage.

Materials and Methods

The field experiment was conducted at Main Rice Research Centre, Navsari Agricultural University, Navsari (20.9248° N latitude and 72.9079 °E longitudes) during the *Summer* season. The field experiment was laid out in a Split - split Plot Design with three irrigation levels, four genotypes and two potassium levels with four replications (Fig. 1). The irrigation was kept normal for control (No stress) for the first level of irrigation, whereas moisture stress at tillering (vegetative) stage was given for the second level of irrigation and moisture stress at the reproductive stage was given for the third level of irrigation by withholding water for 15 days. All treatments received a uniform basal application of half the recommended amount of nitrogen and a full dose of phosphorus. At the stages of active tillering and panicle initiation, the remaining half of the nitrogen was applied in two equal splits. Potassium fertiliser (Muriate of potash) was applied as per treatment 20 kg/ha and 40 kg/ha at the initiation of the tillering phase. The crop received irrigation as needed, up until tillering in every plot, based on crop requirements. Irrigation was administered based on treatment after tillering.

Five panicles were randomly selected from tagged plants and the length was measured from the neck nodes to the tip of the apical grain of a primary panicle; the average length was recorded as panicle length and expressed in centimetres. The total number of grains was calculated by taking five randomly selected panicles from each plot and expressed as the average number of grains per panicle.

The statistical analysis of data recorded for different parameters from each repetition during the experiment was carried out through the procedure appropriate to the Split-split Plot Design of the investigation at the computer centre, department of agriculture statistics, as described by Panse and Sukhatme (1985) [10].

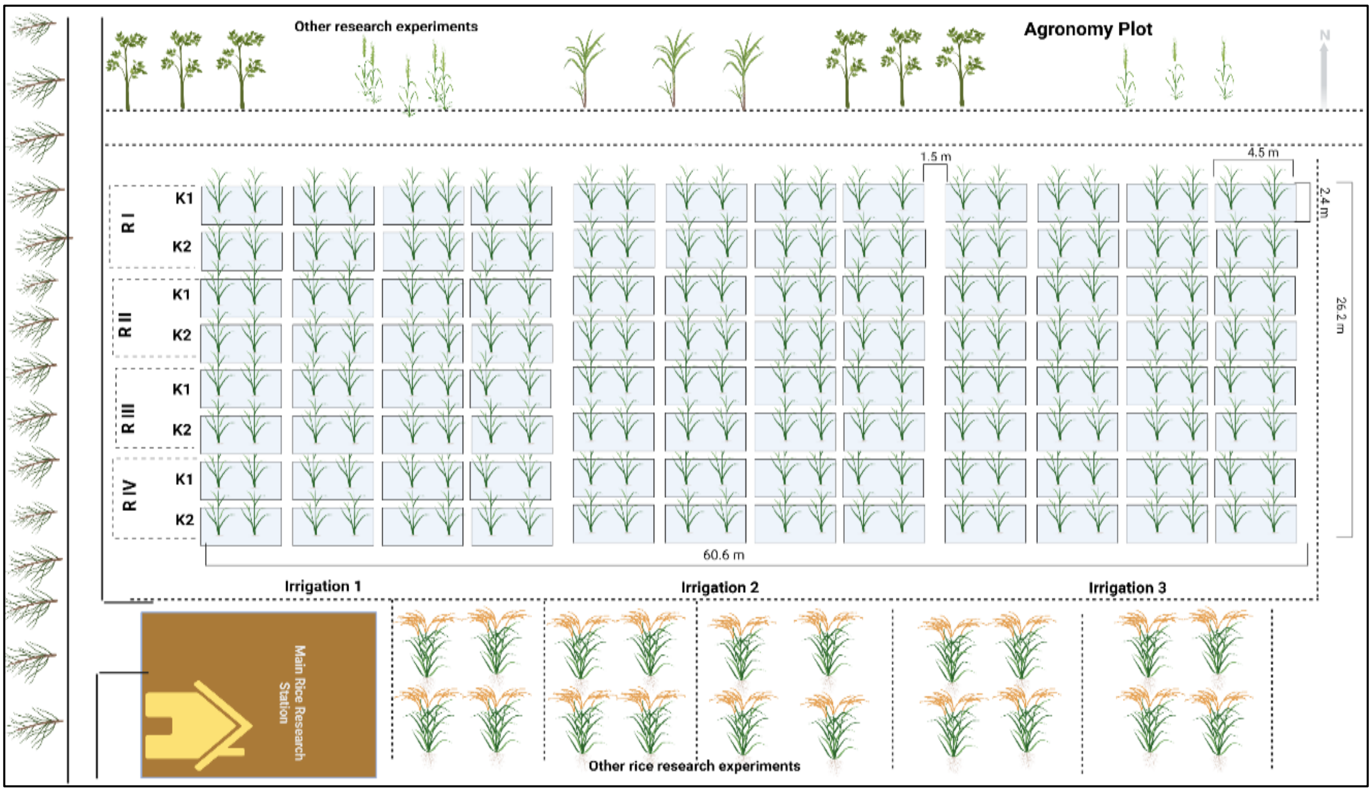

Fig 1: Detailed experiment layout showing treatment distribution

Results and Discussion

The panicle length of rice genotypes was reduced due to water stress, over no water stress conditions and significantly minimum panicle length was observed under water stress at the reproductive stage with a mean length of 23.9 cm, followed by vegetative stage water stress with a mean length of 24.3 cm (Table 1). Significant maximum panicle length was observed for rice plants that were grown under no water stress conditions with a mean length of 25.3 cm. Potassium significantly increased the panicle length and application of 40 kg K_2O/ha (K_2) recorded a significant maximum panicle length with attaining a mean length of 26.0 cm compared to normal does of K (K1), which recorded a mean length of 23.0 cm. The panicle length of different rice genotypes exhibited significant differences and a significant mean maximum panicle length was observed in NAUR 1 (V_4) (26.1 cm) followed by NVSR 467 (V_3) (25.3 cm) and NVSR 476 (V_2) (23.6 cm). A significant minimum panicle length was recorded for IR 28 (V_1) (23.0 cm). Irrigation and potassium availability significantly interacted with each other and with an application of a higher dose of K, panicle length was significantly increased under all three water regimes. However, rice plants grown under non-water stress conditions with a higher supply of K attained a significantly maximum panicle length with a mean length of 27.0 cm compared to the counterpart with a normal K supply, which attained a mean length of 23.5 cm. The same positive effect of K was also reflected under vegetative and reproductive stage water stress where panicle length was significantly higher with mean of 25.6 cm and 25.3 cm, respectively, as compared to their counterpart panicle length under regular K supply, 23.0 cm and 22.6 cm. The panicle length of all rice genotypes was significantly decreased under both water stress regimes over no water stress. However, under reproductive stage water stress, a significant maximum extent of reduction was noticed in all rice genotypes, compared to the extent of reduction observed under vegetative stage water stress, over no water stress condition. The panicle length of rice genotypes was also significantly influenced by potassium levels. A higher dose of K application (K_2) significantly increased the panicle of NVSR 467 (V3) and NAUR 1(V4). In contrast, a significant reduction was noticed in IR 28 (V1) and NVSR 476 (V2) as compared to the panicle length of respective genotypes under a normal dose of K application. The panicle length of rice genotypes was significantly influenced due to the interactive effect of different irrigation regimes and potassium levels. Under all water regimes, the application of a higher dose of K (K_2) significantly increased the panicle length of NVSR 467 (V3) and NAUR 1(V4), whereas significant reduction was noticed in IR 28 (V1) and NVSR 476 (V2) as compared to panicle length of respective genotypes under normal dose of K application in counterpart water regimes.

Water stress significantly decreased the number of grains per panicle over no water stress condition and significantly minimum grains per panicle were observed under water stress at the reproductive stage with a mean number of 161.3 (Table 2). A similar extent of decrease was also observed in vegetative stage-water stress with a mean number of 162.5 and remained at par with reproductive stage water stress. A significant maximum number of grains per panicle was observed for rice plants that were grown under no water stress conditions, with a mean number of 169.7. Potassium significantly increased the grain number of panicles and the application of 40 kg K_2O/ha (K_2) recorded a significant maximum grain number per panicle with attaining mean of 179.7 as compared to a normal dose of K (K_1) which recorded a mean of 149.3. The grain number per panicle of different rice genotypes exhibited significant differences and a significant mean maximum grain number per panicle was observed in NAUR 1 (V_4) (175.8), followed by NVSR 467 (V_3) (170.2) and NVSR 476 (V_2) (157.9). IR 28 (V1) (154.0) recorded a significantly minimum number of grains per panicle. Irrigation and potassium availability significantly interacted with each other and influenced the grain number per panicle of rice. Applying a higher dose of K significantly increased the grain numbers per panicle under all three water regimes. However, rice plants grown under non-water stress conditions with a higher supply of K attained a significant maximum number of grains per panicle with a mean of 185.9 compared to the counterpart with a normal K supply, a mean of 153.5. The same positive effect of K was also reflected under vegetative and reproductive stage water stress where grain number per panicle was significantly higher with mean of 176.5 and 176.6 cm, respectively, as compared to their counterpart with normal K supply, 148.4 and 146.0, respectively. The grain number per panicle of rice genotypes also influenced significantly and differently under varied irrigation regimes. The grain number of panicles of all rice genotypes decreased considerably under both water stress regimes over no water stress. However, under water stress at the reproductive stage, a significant maximum reduction was noticed in all rice genotypes compared to the reduction observed under water stress at the vegetative stage over no water stress condition. Potassium levels also significantly influenced the grain number of panicles of rice genotypes. A higher dose of K application (K_2) significantly increased the grain number per panicle of all rice genotypes over the usual amount of K application. The grain number per panicle of rice genotypes was not influenced significantly due to the interactive effect of different irrigation regimes and potassium levels.

Drought is the major factor during maturation and ripening of cereals while period of water limitation causes large yield losses (Yang *et al.*, 2004) [12]. Drought stress can interrupt floret initiation during the booting stage (Pantuwan *et al.*, 2002) [11]. This causes sterility in the spikelet, which lowers grain numbers and ultimately results in poor paddy yield (Kamoshita *et al*., 2004) [6]. However, positive effect of potassium was observed on these attributes and higher dose of potassium substantially overcome the detrimental effect of water stress on rice genotypes. Our findings also support those of other researchers (Zayed *et al*., 2007) [13], who demonstrated that longer rice panicles with more spikelets per panicle were produced by rising potassium rates. According to (Bahmaniar and Mashaee 2010) [2], potassium aided in the proper filling of seeds, producing a greater number of plump seeds and, consequently, a greater number of grains per panicle.

Water stress significantly decreased the test weight of rice genotypes over no water stress condition and significantly minimum test weight was recorded under water stress at the reproductive stage with a mean test weight of 24.5 g, followed by vegetative stage water stress with a mean test weight of 25.1 g., which remained at par with test weight observed in water stress at the reproductive stage (Table 3). Rice plants grown under no water stress conditions attained the maximum test weight with a mean weight of 25.6 g. Potassium significantly increased the test weight and application of 40 kg K_2O/ha (K_2) recorded a significant maximum test weight with a mean weight of 26.3 g compared to the normal dose of K (K1), which recorded a mean weight of 23.8 g. The test weight per plant of different rice genotypes exhibited significant differences and a significant mean maximum test weight per plant was observed in NVSR 476 (V_2) (26.2 g) followed by IR 28 (V_1) (25.9 g) and NAUR 1 (V_4) (24.3 g). A significant minimum test weight was recorded for NVSR (V_3) (24.0 g). The test weight of rice genotypes was significantly influenced due to the interactive effect of different irrigation regimes and potassium levels. Under all water regimes, the application of a higher dose of K (K_2) significantly increased the test weight over their counterpart with normal K supply in respective water regimes. The test weight of rice genotypes does not influence significantly due to varied irrigation regimes. Potassium levels significantly influenced the test weight of rice genotypes. A higher dose of K application (K_2) significantly increased the test weight of all rice genotypes over the normal dose of K application. The test weight of rice was not significantly influenced due to the interactive effect of different rice genotypes, irrigation regimes and potassium levels. Severe drought stress has been shown to reduce yield by 90% by influencing spikelet sterility, grain width, grain length, and test weight decline (Mohammed *et al*., 2010) [8]. The reduction in grain weight could potentially be caused by the drought-induced reduction in leaf size, disruption of plant-water relations, decreased assimilate partitioning, and ultimately a decrease in grain weight (Anjum *et al*., 2011) [1]. The length of the drought, its intensity, and the crop's growth stage all affect how much grain weight is reduced (Kumar *et al*., 2014) [17].

Table 1: Length of panicle (cm) of rice as influenced by different levels of K fertilizer under water stress condition

Treatments	I1			I2			I3			Mean (K x V)		Mean (V)
	K_1	K_2	Mean (I x V)	K_1	K_2	Mean (I x V)	K_1	K_2	Mean (I x V)	K_1	K_2	
V_1 (IR 28)	23.8	23.3	23.5	23.1	22.8	22.9	22.7	22.5	22.6	23.2	22.8	23.0
V_2 (NVSR 476)	24.7	23.7	24.2	24.1	23.0	23.5	23.5	22.7	23.1	24.1	23.1	23.6
V_3 (NVSR 467)	22.6	30.0	26.3	22.0	27.9	24.9	21.6	27.5	24.6	22.1	28.5	25.3
V_4 (NAUR 1)	23.1	30.9	27.0	22.8	28.7	25.8	22.5	28.5	25.5	22.8	29.4	26.1
Mean (I x K)	23.5	27.0		23.0	25.6		22.6	25.3				

Mean (K)	K_1: 23.0		K_2: 26.0
Mean (I)	I_1: 25.3	I_2: 24.3	I_3: 23.9
ANOVA			
	S. Em ±	CD @ 5%	CV (%)
I	0.14	0.49	Main Plot (I): 3.30
K	0.06	0.20	
V	0.08	0.22	Sub plot (K): 1.81
I x K	0.11	0.35	
I x V	0.13	0.38	Sub-sub plot (V): 1.54
K x V	0.11	0.31	
I x K x V	0.19	0.53	

#I_1- No water stress, I_2 - Water stress at tillering stage, I_3- Water stress at reproductive stage, K_1- 20 kg and K_2 - 40 kg K_2O /ha.

Table 2: Number of grains per panicle of rice as influenced by different levels of K fertilizer under water stress condition

Treatments	I1			I2			I3			Mean (K x V)		Mean (V)
	K_1	K_2	Mean (I x V)	K_1	K_2	Mean (I x V)	K_1	K_2	Mean (I x V)	K_1	K_2	
V_1 (IR 28)	143.5	175.3	159.4	136.5	167.0	151.7	134.1	167.5	150.8	138.0	169.9	154.0
V_2 (NVSR 476)	145.2	177.2	161.2	141.7	172.1	156.9	139.8	171.6	155.7	142.2	173.6	157.9
V_3 (NVSR 467)	161.9	192.3	177.1	154.5	179.9	167.2	152.1	180.7	166.4	156.2	184.3	170.2
V_4 (NAUR 1)	163.4	198.7	181.1	160.7	187.3	174.0	158.1	186.5	172.3	160.7	190.8	175.8
Mean (I x K)	153.5	185.9		148.4	176.5		146.0	176.6				

Mean (K)	K_1: 149.3		K_2: 179.7
Mean (I)	I_1: 169.7	I_2: 162.5	I_3: 161.3
ANOVA			
	S. Em ±	CD @ 5%	CV (%)
I	0.73	2.51	Main Plot (I): 2.50
K	0.29	0.93	
V	0.41	1.16	Sub plot (K): 1.23
I x K	0.50	1.61	
I x V	0.71	2.02	Sub-sub plot (V): 1.22
K x V	0.58	1.65	
I x K x V	1.01	NS	

#I_1- No water stress, I_2 - Water stress at tillering stage, I_3- Water stress at reproductive stage, K_1- 20 kg and K_2 - 40 kg K_2O /ha.

Table 3: Test weight (g) of rice as influenced by different levels of K fertilizer under water stress condition

Treatments	I1			I2			I3			Mean (K x V)		Mean (V)
	K_1	K_2	Mean (I x V)	K_1	K_2	Mean (I x V)	K_1	K_2	Mean (I x V)	K_1	K_2	
V_1 (IR 28)	22.6	30.2	26.4	22.2	29.9	26.1	22.0	28.6	25.3	22.2	29.6	25.9
V_2 (NVSR 476)	22.7	30.7	26.7	22.3	30.5	26.4	22.0	28.7	25.4	22.3	30.0	26.2
V_3 (NVSR 467)	25.8	23.4	24.6	24.7	22.8	23.8	25.0	22.2	23.6	25.2	22.8	24.0
V_4 (NAUR 1)	25.8	23.5	24.6	25.5	23.2	24.3	25.4	22.2	23.8	25.6	22.9	24.3
Mean (I x K)	24.2	26.9		23.7	26.6		23.6	25.4				

Mean (K)	K_1: 23.8		K_2: 26.3
Mean (I)	I_1: 25.6	I_2: 25.1	I_3: 24.5
ANOVA			
	S. Em ±	CD @ 5%	CV (%)
I	0.24	0.83	Main Plot (I): 5.44
K	0.06	0.19	
V	0.08	0.22	Sub plot (K): 1.60
I x K	0.10	0.32	
I x V	0.13	NS	Sub-sub plot (V): 1.51
K x V	0.11	0.31	
I x K x V	0.19	NS	

#I_1- No water stress, I_2 - Water stress at tillering stage, I_3- Water stress at reproductive stage, K_1- 20 kg and K_2 - 40 kg K_2O /ha.

Conclusion
Moisture stress at reproductive stage was more detrimental for rice grain production. However, the availability and sufficiency of potassium, improve plant drought tolerance and showed positive effect on grain attributes of rice. The combined effect of irrigation, K fertilizer and genotypes was more pronounced when the K nutrition became a limiting factor under water stress conditions and its application significantly improved the grain attributes of rice.

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