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ENHANCING WATER USE EFFICIENCY OF COTTON CROP BY APPLYING POTASSIUM AT DIFFERENT GROWTH STAGES

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Abstract
As a glycophytic crop, cotton shows higher abiotic and biotic stress tolerance compared to other crops. However, under severe stress conditions, its growth and productivity are adversely affected. Potassium (K) could diminish the decrease caused by drought, but the mechanism associated with this alleviation effect is not clear. We evaluated the effect of K in alleviating the stress caused by drought at four different growth stages i.e. seedling stage, flower bud stage, ball formation stage, and ball opening stage. The layout was designed as per RCBD design in triplicates. The maximum and minimum plant height were observed in control; T9 (29.1 cm) and deficit irrigation at boll formation stage; T3 (19.7 cm). The number of leaves was greatly affected by water stress at the boll opening stage; T4 (27.2). The Maximum number of bolls plant $^{-1}$ (10.9) was observed in T5; 10% addition of K with deficit irrigation at seedling stage. The maximum seed cotton yield (78.7 maunds ha^{-1}) was obtained in treatment T8; deficit irrigation at ball opening + 10% addition of K with previous irrigation. It is concluded that treatment T8 (Deficit irrigation at ball opening + 10% addition of K with previous irrigation) performs better among all treatments in terms of cotton yield.

Introduction
Water is a critical resource for sustainable economic development of Pakistan and in this viewpoint irrigated agriculture is of great importance in the socio-economic life of the country. It provides linkages and ripple effects though which growth in other sectors is motivated. Pakistan's agriculture primarily depends upon irrigation and irrigated lands supply more than 90% of the total agricultural production, account for about 25% of GDP, and employ around 50% of the labour force (GOP, 2023). They supply most of the country's needed food-grain and are the source of raw materials for major domestic industries and exports. The availability of irrigation water at time greatly influences crop production and yields. In order to meet agricultural needs, proper management of scarcely available water and its judicious & efficient use for sustainable irrigated agriculture is the need of hours to address food security issues and comply with United Nation Sustainable Development Goals.

Cotton (*Gossypium hirsutum* L.) is considered as the most valuable cash crop of Pakistan, Cotton provides 35 % of the total fiber produced worldwide (Abdelraheem et al., 2019). As a glycophytic crop, cotton shows higher abiotic and biotic stress tolerance compared to other crops. However, under severe stress conditions, its growth and productivity are adversely affected (Hou et al. 2024). Rapid changes in environmental conditions have pronounced effects on growth and fiber length and other developmental processes (Hou et al., 2024). Potassium (K) could diminish the decrease caused by drought, but the mechanism associated with this alleviation effect is not clear. We evaluated the effect of K in alleviating the stress caused by drought at four different growth stages i.e. seedling stage, flower bud stage, ball formation stage, and ball opening stage.

Materials and Methods

The Deficit irrigation was applied to cotton crop with and without Potash fertilizer at four different growth stages (i.e. seedling stage, flower bud stage, ball formation stage, and ball opening stage) to evaluate the water stress and potash effect on water productivity.

Soil characterization

The physico-chemical properties of soil used in this experiment are presented in Table 1 and analyzed in accordance to Page et al. (1982). Briefly, soil texture was determined using hydrometer method in dispersed soil solution (Bouyoucos, 1962), pH from saturated soil paste and electric conductivity (EC) from saturated soil paste's extracts by using pH and EC meters and EC meter, respectively (Anderson and Ingram, 1993), total N by following Jackson's method (Jackson, 1962), and organic matter by Walkley-Black method (Nelson and Sommers, 1982).

Table 1: Physico-chemical properties of soil used in experiment

Characteristics	Unit	Cotton Experiment
Texture	-	Loam (40% sand, 38.6% silt, 21.4% clay)
EC	dS m^{-1}	1.66
pH	-	7.99
Organic matter	%	0.84
Available P	mg kg^{-1}	7.20
Available K	mg kg^{-1}	177
Total N	mg kg^{-1}	350

Crops Husbandry, Treatments and Analysis

The Research studies were conducted at Water Management Research Farm, Renala Khurd Okara (30.8556° N, 73.5444° E). The cotton crop (*Gossypium hirsutum* L.) was sown to evaluate the effect of Potassium (K) application under drought (skipped irrigation) at four different growth stages on crop yield and water productivity. After land preparation, DAP and SOP @ 50 kg/acre was applied as basal dose. While Urea @ 75 kg/acre were split into three for its proper utilization and minimized losses. NIAB-787 variety was sown on beds. The layout was designed as per RCBD design. Nine treatments were tested including Treatment-1 (T1); Deficit irrigation at seedling stage, Treatment-2 (T2); Deficit irrigation at flower bud stage, Treatment-3 (T3); Deficit irrigation at ball formation, Treatment-4 (T4); Deficit irrigation at ball opening, Treatment-5 (T5); Deficit irrigation at seedling stage + 10% addition of K with previous irrigation, Treatment-6 (T6); Deficit irrigation at flower buds stage + 10% addition of K with previous irrigation, Treatment-7 (T7); Deficit irrigation at ball formation + 10% addition of K with previous irrigation, Treatment-8 (T8); Deficit irrigation at ball opening + 10% addition of K with previous irrigation; and T9; Control. All agronomic practices were followed as per standards. There were three pickings during the whole growth period. The amount of

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water/irrigation applied was measured by using cut-throat flume. All the obtained data (e.g. plant height, number of Sympodial Branches per plant, number of leaves per plant, number of bolls per plant, boll diameter and cotton yield) was statistically analyzed for Analysis of variance (ANOVA) technique using computer-based software; STATISTIX 8.1®. Tukeys HSD (Honestly Significance Difference) test was applied at 5% probability level to check treatment significance (Lewicki and Hill, 2006).

Water productivity was calculated as given below (Usman et al., 2012):

$$\text{Water Productivity (kg m}^{-3}) = \frac{\text{Grain Yield } (kg)}{\text{water applied } (m^3)}$$

Results

There exists a significant difference ($P \leq 0.05$) in plant height and number of leaves per plant (Table 2). The maximum and minimum plant height were observed in control; T9 (29.1 cm) and deficit irrigation at boll formation stage; T3 (19.7 cm). The number of leaves was greatly affected by water stress at the boll opening stage; T4 (27.2). The number of sympodial branches was not affected significantly by water stress as compared to potassium application. Overall, potassium applications help in alleviating water stress at all stages (Table 2). The Maximum number of bolls plant $^{-1}$ (10.9) was observed in T5; 10% addition of K with deficit irrigation at seedling stage, however it is non-significant with the value of number of bolls plant $^{-1}$ obtained in control (10.9) (Figure 1).

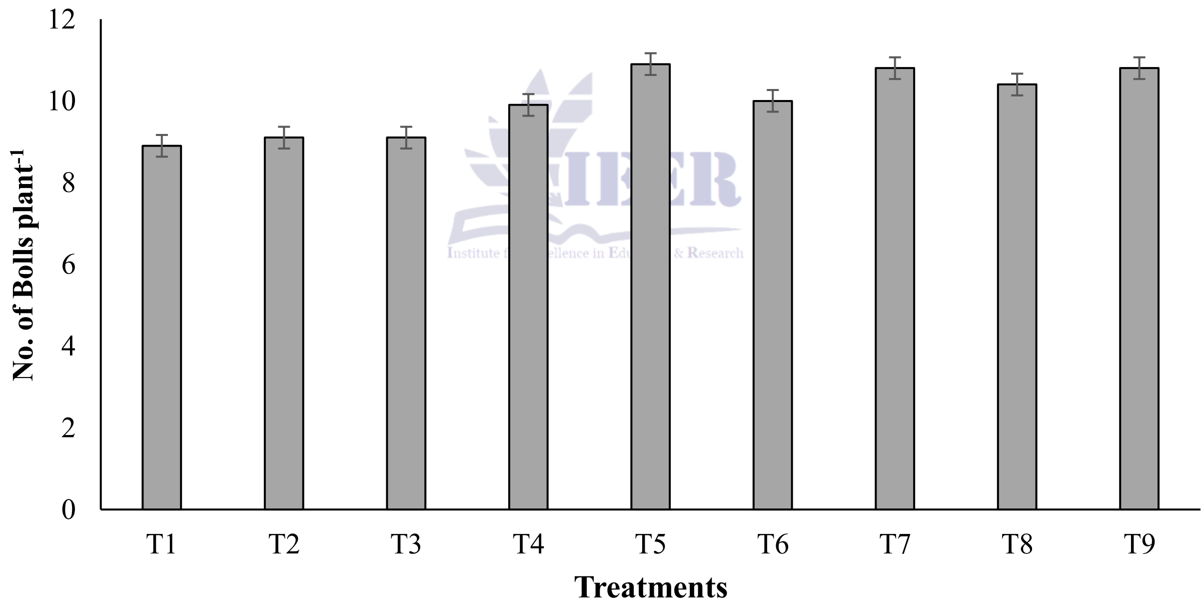

Figure 1: Number of bolls plant^{-1} of cotton crop grown with K application at different growth stages under water stress

Where T1; Deficit irrigation at seedling stage, T2; Deficit irrigation at flower bud stage, T3; Deficit irrigation at ball formation, T4; Deficit irrigation at ball opening, T5; Deficit irrigation at seedling stage + 10% addition of K with previous irrigation, T6; Deficit irrigation at flower buds stage + 10% addition of K with previous irrigation, T7; Deficit irrigation at ball formation + 10% addition of K with previous irrigation, T8; Deficit irrigation at ball opening + 10% addition of K with previous irrigation; T9; Control

When comparing the seed cotton yield, the maximum seed cotton yield (78.7 maunds ha^{-1}) was obtained in treatment T8; deficit irrigation at ball opening + 10% addition of K with previous irrigation (Figure 2), while the minimum seed cotton yield (47.1 maunds ha^{-1}) was observed in treatment T1; deficit irrigation at seedling stage. The addition of 10% K with deficit irrigation at all growth stages helps in mitigation of the water stress.

Discussion

A significant amount of ROS species was induced in plants as a result of drought stress causing oxidative damage (Mahmood et al., 2020) leading to cell death. In response, plants activate enzymatic and non-enzymatic antioxidant defense mechanisms to mitigate ROS. Drought stress can also reduce dry matter accumulation, leaf area and transpiration rate due to shedding of leaves and fruiting structures ultimately leads to yield loss (Pettigrew, 2004). Potassium (K) is famous for quality related nutrients. It participates in many important physiological activities, especially in enzyme activation and significantly improves drought resistance (Zörb et al., 2014). Studies have revealed that K application could enhance the ability of carbon assimilation and photosynthate transfer to cotton bolls (Hu et al., 2017). We also observed the increase of plant height, number of leaves per plant, number of bolls per plant with the application of potassium at critical growth stages (Table 2, Figure 1). The Maximum number of bolls plant $^{-1}$ (10.9) was observed in T5; 10% addition of K with deficit irrigation at seedling stage (Figure 1).

Table 2: Growth- and growth-related attributes of cotton crop grown with K application at different growth stages under water stress

Treatments	Plant Height (cm)	No. of leaves plant^{-1}	Boll diameter (mm)	No. of Sympodial Branches plant^{-1}
T1	22.9	42.0	2.36	6.60
T2	21.9	38.8	2.24	6.20
T3	19.7	32.3	2.08	5.37
T4	21.8	27.2	2.01	4.87
T5	24.5	32.2	2.10	4.80
T6	25.5	36.1	2.27	4.67
T7	26.9	44.2	2.30	4.83
T8	27.3	56.2	2.35	4.90
T9	29.1	65.2	2.39	4.87

The data are the average of three replication and each replication is the average of five consecutive plants.

Where T1; Deficit irrigation at seedling stage, T2; Deficit irrigation at flower bud stage, T3; Deficit irrigation at ball formation, T4; Deficit irrigation at ball opening, T5; Deficit irrigation at seedling stage + 10% addition of K with previous irrigation, T6; Deficit irrigation at flower buds stage + 10% addition of K with previous irrigation, T7; Deficit irrigation at ball formation + 10% addition of K with previous irrigation, T8; Deficit irrigation at ball opening + 10% addition of K with previous irrigation; T9; Control

Summarily, seed cotton yield and fiber strength formation is mainly a process of carbohydrate transformation. Therefore, drought may affect the seed cotton yield and fiber strength. Our results support the hypothesis that potassium (K) can increase the seed cotton yield and fiber strength under drought condition (Figure 2). There is an increase of 31.1% of cotton yield under treatment T8; deficit irrigation at ball opening + 10% addition of K with previous irrigation compared to the same deficit irrigation stress without K application (T4) (Figure 2).

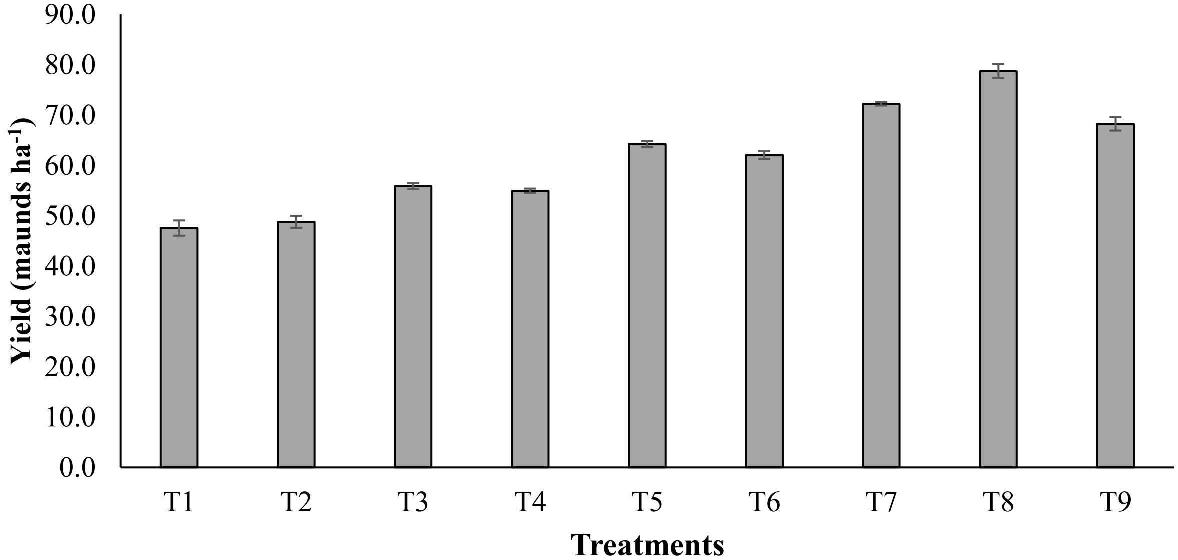

Figure 2: Yield of cotton crop grown with K application at different growth stages under water stress

Where T1; Deficit irrigation at seedling stage, T2; Deficit irrigation at flower bud stage, T3; Deficit irrigation at ball formation, T4; Deficit irrigation at ball opening, T5; Deficit irrigation at seedling stage + 10% addition of K with previous irrigation, T6; Deficit irrigation at flower buds stage + 10% addition of K with previous irrigation, T7; Deficit irrigation at ball formation + 10% addition of K with previous irrigation, T8; Deficit irrigation at ball opening + 10% addition of K with previous irrigation; T9; Control

Conclusion

It is concluded that treatment T8 (Deficit irrigation at ball opening + 10% addition of K with previous irrigation) performs better among all treatments in terms of cotton yield. However, the underlying mechanism needs to be explored under each growth stage for better understanding and future breeding ventures.

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Author Contributions

Hafiz Muhammad Bilal executed experiments and wrote original draft (lead), Humayun Raza and Mazhar Iqbal compiled data and analyzed samples (equal), Muhammad Mohsan, Shafiq ur Rehman and Asif Iqbal conceived the idea and supervised the work (equal), Mujahid Ali and Habib ur Rehman performed statistical analysis (equal).

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This study did not receive any specific funding.

Conflict of Interest

Authors declare no conflict of interest.

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