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Effect of Deficit Irrigation and Potassium Fertilizer on the Growth and Yield of Maize (*Zea mays* L.)

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ABSTRACT

Potassium (K) and irrigation both plays a key role in the growth and yield attributes of maize crop. Though present in large quantities in soil, but mostly in an unavailable form and hence optimizing K levels in maize field is crucial. . The current study adopted a synergistic approach for optimizing K and irrigation levels for maize crop in agroclimatic conditions of Sindh, Pakistan. The experiment consists of three replicated randomized complete blocks (net plot size of 30 m²). Four irrigation levels, i.e. (no irrigation, 2 irrigations, 4 irrigations and 6 irrigations) and five potassium applications (0, 25, 50, 75 and 100 kg/ha) were employed. Among all treatments, six irrigation along with 100 kg ha⁻¹ application exhibited significantly higher yield attributes. Specifically, grain per cob was 301.81, seed index or 1000-grain weight was 433.4, biological yield was 45104 kg ha⁻¹, grain yield was 4832.8 kg ha⁻¹. Similarly, the vegetative growth performance in terms of plant height (221.81 cm), stem girth (10.04 cm), and number of leaves (17.55) was prominent and significantly higher than the rest of the treatments. The findings may further contribute the better maize cultivation and boosting the national economy and self-sufficiency for this important cereal crop.

KEYWORDS: Agroclimatic, Deficit Efficiency, Grain Yield, Irrigation, Potassium, Water, *Zea mays*

INTRODUCTION

Maize (*Zea mays* L.) is a major cereal crop cultivated globally, ranking third in production after wheat and rice (FAO, 2021). Due to its high yield and nutritional value, maize is considered highly desirable worldwide (Mohapatra et al., 2020). Leading producers include South Africa, China, India, and Russia (Kandil et al., 2020; Abdul Mohsin & Farhood, 2023). Besides serving as a staple food, maize is crucial for livestock feed, industrial products, and biofuels, contributing significantly to economic growth and food security (Mahmood et al., 2017; FAO, 2021). Nutrient management, particularly the provision of potassium (K), plays a vital role in enhancing maize yield and soil health while minimizing environmental pollution (Mohapatra, 2020; Mahmood, 2017; Gezahn, 2021). Water scarcity is a major abiotic stress limiting maize productivity, especially in semi-arid and arid regions where drought can reduce yields by up to 40% (Ul-Allah et al., 2020; Molla et al., 2019). Drought affects plant growth by reducing shoot and root development, photosynthesis, and chlorophyll content (Wasaya et al., 2021; Maqsood et al., 2012). Efficient irrigation scheduling, which maintains optimal soil moisture, improves plant water status and significantly enhances water productivity and crop yield (Farrag et al., 2021; Shahrokhnia & Zare, 2022). However, increasing

irrigation frequency beyond six times per season does not always lead to higher yields, emphasizing the need for optimal water management (Mubeen et al., 2013; Gheysari et al., 2021; Rasool et al., 2020).

Potassium application further supports maize growth by regulating water uptake, enhancing photosynthesis, and improving drought tolerance (Soleimani, 2018; Oosthuis, 2013; Aslam, 2013; Martineau, 2017; Mosa et al., 2022). Potassium fertilizers such as potassium chloride and potassium sulfate are essential either as a pre-planting treatment or as a side dressing during crop growth (Nisa, 2021). Despite its importance, limited studies have addressed the combined effects of irrigation scheduling and potassium fertilization on maize. Therefore, this study aims to evaluate the impact of irrigation levels and potassium application rates on maize growth and yield under the agro-ecological conditions of Tandojam, Sindh, Pakistan.

MATERIALS AND METHODS

Experimental site: The experiment was conducted at the Experimental Farm, Sindh Agriculture University, Tandojam during the spring season of 2021-2022 (GPS coordinates: 25°42'03" N, 68°53'83" E). Tandojam is situated at an elevation above sea level in a Subtropical desert climate. The district's yearly temperature is 33.61°C (92.5°F), which is 12.72%

higher than Pakistan's average. Tandojam typically receives 16.51 millimetres (0.65 inches) of precipitation annually, with 20.65 rainy days (5.66% of the time) (Sabito et al., 2022). The meteorological

data, including mean temperature, humidity, and rainfall, for the period of 2021-22, is shown in the graph below Figure 1.

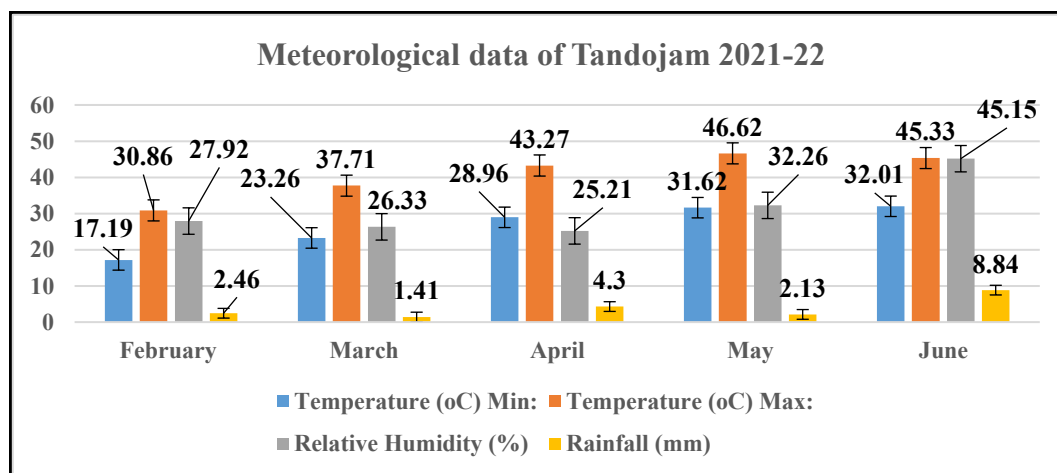


Figure 1. Meteorological Data of Tandojam (2021-22) Showing Temperature (°C), Relative Humidity (%), and Rainfall (mm) Across Different Months.

Experiment design



Figure 2. Experimental Design Layout of the Trial Showing the Maize Plot with Different Irrigation and Potassium Levels.

The experimental trial was conducted using a Randomized Complete Block Design (RCBD) with three replications Figure 2. The size of the main plot was 30 m², and two maize varieties (Akbar and Neclan) were used to study different agronomical parameters. This factorial experiment utilized two factors: Irrigation and Potassium.

The irrigation levels were I₁ = Control (no irrigation), I₂ = 2 irrigations, I₃ = 4 irrigations. For potassium, five levels were applied: K₁ = Control (no potassium), K₂ = 25 kg ha⁻¹, K₃ = 50 kg ha⁻¹, K₄ = 75 kg ha⁻¹, K₅ = 100 kg ha⁻¹ (Potassium was applied in the form of K₂O). Irrigation and potassium were applied as factors A and B, respectively, to observe their individual and interactive effects on the growth and yield of maize varieties.

MAP (Mono Ammonium Phosphate) and AS (Ammonium Sulphate) were applied to fulfill the required quantity of nitrogen and phosphorus for

plants. The recommended dose of nitrogen and phosphorus was applied at a rate of 200 kg ha⁻¹ (50% at the 30-40 cm sowing stage and 50% at the vegetative stage). The recommended dose of nitrogen and phosphorus for maize was applied at 200 kg ha⁻¹ and 100 kg ha⁻¹ at 50% (at the 30-40 cm sowing stage and 50% at the vegetative stage), respectively.

Data collection procedure:

Plant population per square meter (m²) was measured using a meter square frame placed in the experimental block. Plants within the frame were counted and then averaged.

Plant height (cm) was recorded at maturity of the crop by measuring the height of the selected plants in all plots using a measuring tape.

Stem girth (in centimetres) was measured using contiguous measurements at the maturity of the plant. The number of leaves per plant was counted

at maturity and randomly selected in each plot, then averaged.

Grains per ear were counted from randomly selected plants after harvesting and averaged. For the seed index, 1000 seeds from all plots were weighed using an electronic top-loading balance.

Biological yield was measured in kg per hectare using the formula: biological yield (kg/plot size (m²)) × 10,000 after maturity. The biological yield of maize from all plots was weighed. Grain yield was also observed in kg per hectare by using the

formula: grain yield (kg/plot size (m²)) × 10,000. Maize crops from each plot were harvested and weighed.

Data on biological yield were recorded after harvesting crops from each plot. The harvested material was dried to constant weight, weighed with a spring balance, and converted into biological yield in kg ha⁻¹. The material was then threshed, the seeds were cleaned, weighed, and then converted into grain yield in kg ha⁻¹.

Table 1. Important physical and chemical properties of soil analysis are used in the experiment.

Soil properties	Values
Soil pH	7.4
Soil EC, dS m ⁻¹	3.9
CEC, Cmolc kg ⁻¹ soil	8.04
Soil N, %	0.5
Soil P, mg kg ⁻¹	9.32
Soil K, mg kg ⁻¹	180
Ca, %	12.09
Na, %	3.28
Soil Texture	Sandy loam

Soil analysis of the experimental field: Soil was collected before sowing from the top 30 cm from five different locations within the experimental field. Soil samples were taken to the laboratory of Soil Science at Sindh Agriculture University, Tandojam, for physicochemical analysis. The soil was air-dried and sieved through a 5 mm sieve.

The soil was analyzed for texture by the hydrometer method (Pansu & Gautheyrou, 2006). Soil pH and soil EC were measured on a 1:1 soil: water suspension

(McLean, 1982; Rhoades, 1982, respectively) Fig 3. Total nitrogen was measured by the Kjeldahl method (Nelson & Sommers, 1980); available phosphorus was extracted using sodium bicarbonate (Olsen et al., 1954); exchangeable potassium and calcium were extracted with 1 M NH₄OAc (Thomas, 1982). Cation exchange capacity (CEC) was determined using the method of Palemio and Rhoades (1977). The major soil characteristics are presented in Table 1.

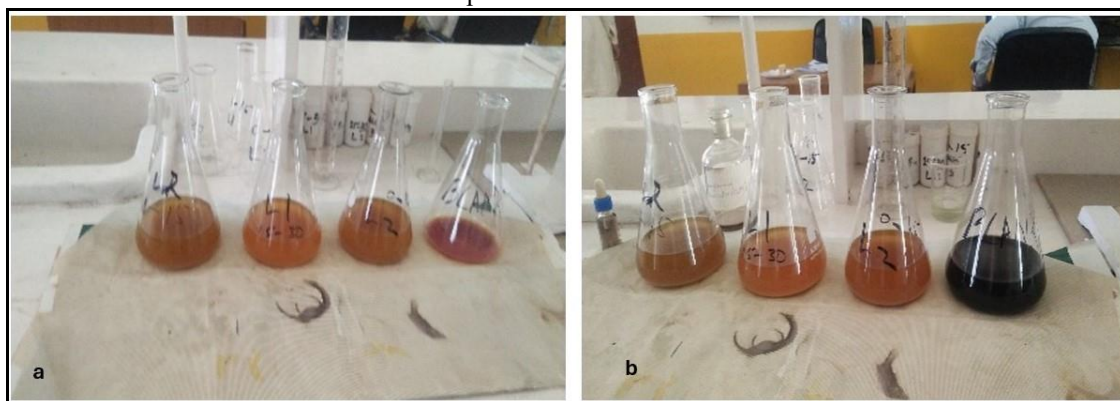


Figure 3. Photo of NPK Analysis in Soil Samples during the Field Trial.

Statistical analysis: Statistical analysis was conducted to analyze data using appropriate variance techniques for a randomized complete block design with a split-plot arrangement. Means of the treatments were compared using the Least Significant Difference (LSD) test at the 5% probability level. Analysis of variance (ANOVA) was applied to evaluate the data, and the means were compared through the LSD test at the 5% significance level.

RESULTS AND DISCUSSION

Plant height is an important factor reflecting the active growth attained during the crop's life cycle. An increase in irrigation numbers significantly increased the plant height of maize, while short-height plants were recorded in non-irrigated plots. The possible reason might be that water availability at the desired crop growth stage improved water uptake and increased photosynthesis and photosynthates, resulting in better growth. Similar results were reported by Anjum et al. (2014), who reported taller maize plants with an optimum supply of irrigation water. Babar et

al. (2015) also reported increased plant height by applying optimum irrigation water. The findings of Pettigrew (2008) and Cheema et al. (1999) agree with our results, which stated an increase in plant height with increasing application of K fertilizers. Simi Increasing irrigation frequencies and potassium application levels increased plant height. Maqsood et al. (2001) and Ayub et al. (2002) also stated that plant height increased with increasing potassium fertilizer application. Irrigation frequencies and K levels significantly affected the plant height of maize. Increasing the number of irrigations from 2 to 6 significantly increased plant height over non-irrigated plots, and thus, taller plants were recorded in plots irrigated six times. Likewise, plant height increased with increasing K levels; however, a maximum increase in plant height was noted with the application of 100 kg K ha⁻¹. Short-stature plants were observed in plots where no K was applied Table 2. The

interaction between irrigation frequencies and K levels was also found to be significant. larly, Stone et al. (2001) and Pandey et al. (2000) also stated that increasing irrigation frequencies and potassium application levels increased plant height. Maqsood et al. (2001) and Ayub et al. (2002) also stated that plant height increased with increasing potassium fertilizer application. Irrigation frequencies and K levels significantly affected the plant height of maize. Increasing the number of irrigations from 2 to 6 significantly increased plant height over non-irrigated plots, and thus, taller plants were recorded in plots irrigated six times. Likewise, plant height increased with increasing K levels; however, a maximum increase in plant height was noted with the application of 100 kg K ha⁻¹. Short-stature plants were observed in plots where no K was applied. The interaction between irrigation frequencies and K levels was also found to be significant.

Table 2. Plant Height (cm) of Maize as Affected by Different Irrigation and Potassium Application Levels.

Irrigation levels	Levels of Potassium application					Mean
	K 0 kg ha ⁻¹	K 25 kg ha ⁻¹	K 50 kg ha ⁻¹	K 75 kg ha ⁻¹	K 100 kg ha ⁻¹	
No irrigation	60.32	101.18	129.18	136.43	144.43	114.380
Two irrigations	90.81	115.87	135.54	153.62	161.51	131.47
Four irrigations	120.02	138.19	153.82	167.33	187.41	153.354
Six irrigations	141.92	157.17	191.43	201.99	221.81	182.86
Mean	103.26	128.102	152.49	162.84	178.79	

Steam girth (cm): Mean comparison indicated that the effects of different potassium levels on stem diameter were significant. Consumption of potassium at the rates of 25, 50, 75, and 100 kg ha⁻¹ and control did not have significant differences as shown in Tab 3. But both showed significant differences from control on stem girth. So that the highest and lowest stem diameters

were obtained with the consumption of potassium fertilizer at a rate of 100 kg ha⁻¹ and control equal to 8.90 cm and 4.93 cm, respectively. In a study on corn, a decrease in below-epidermis sclerenchyma tissue and xylem vascular cells was reported to occur due to potassium deficiency (Syers, 1998).

Table 3. Stem Girth (cm) of Maize as Affected by Different Irrigation and Potassium Application Levels.

Irrigation levels	Levels of Potassium application					Mean
	K 0 kg ha ⁻¹	K 25 kg ha ⁻¹	K 50 kg ha ⁻¹	K 75 kg ha ⁻¹	K 100 kg ha ⁻¹	
No irrigation	3.26	4.67	4.70	6.25	7.25	5.22
Two irrigations	5.64	6.84	7.08	7.68	8.81	7.41
Four irrigations	6.44	7.88	8.22	8.50	9.51	8.11
Six irrigations	6.38	8.50	8.75	9.03	10.04	8.54
Mean	4.93	6.22	7.43	7.86	8.90	

Number of leaves per plant: Statistical data analysis showed significant effects of irrigation frequencies and K levels on grains cob-1 of maize. An increase in leaves per plant-1 was observed with increasing irrigation numbers, and significantly more leaves per plant-1 (12.95) of maize were recorded under six irrigations, while the fewest leaves per plant-1 (5.88) were recorded with no irrigation. Similarly, potassium at 100 kg ha⁻¹ increased leaves per plant by 12.93, and the lowest grains per cob (5.94) were observed from potassium-controlled plots. The interaction of irrigation frequencies and K levels indicated a linear increase in leaves per plant of maize. Interaction of six irrigations with K 100 kg/ha significantly increased the

leaves plant-1 with (17.55), while the lowest leaves plant-1 (5.94) were recorded where no irrigation and potassium were applied. As in past studies, Akhtar et al. (2019) and Ullasa et al. (2017) reported that the stimulation of numerous enzymes helps in protein production and N uptake and use that are responsible for normal growth, and therefore, maize obtained maximal growth, which is the key explanation for increased growth characteristics at higher K levels (Rehman et al., 2011). According to reports, it is necessary to supply the plants with the K they need throughout subsequent growth phases, which prevents the maize plants' height and leaf area from increasing. However, according to Sadiq et al. (2017) and Moi &

Dutta (2020), maize plant development was affected by decreasing potassium levels. Aslam et al. (2012) stated that when K was applied to maize plants, plant height

and number of leaves increased in comparison to the control as shown in table 4.

Table 4. Number of Leaves per Plant of Maize as Affected by Different Irrigation Levels and Potassium Applications.

Irrigation levels	Levels of Potassium application					Mean
	K 0 kg ha ⁻¹	K 25 kg ha ⁻¹	K 50 kg ha ⁻¹	K 75 kg ha ⁻¹	K 100 kg ha ⁻¹	
No irrigation	3.33	5.53	6.66	6.96	6.92	5.88
Two irrigations	4.33	5.47	6.80	9.20	11.70	7.50
Four irrigations	5.10	7.44	9.67	12.04	15.56	9.91
Six irrigations	9.20	11.86	12.33	13.82	17.55	12.95
Mean	5.94	7.57	8.86	10.50	12.93	

Grains per cob: Statistical analysis of data showed significant effects of irrigation frequencies and K levels on the grains of cob-1 of maize. An increase in grains cob-1 was observed with increasing irrigation numbers, and significantly higher grains cob-1 (198.34) of maize were recorded under six irrigations, while lower grains cob-1 (88.66) were recorded with no irrigation. Similarly, potassium at 100 kg ha⁻¹ increased grain cob⁻¹ by 177.09, and the lowest grain cob⁻¹ (92.11) was observed from potassium-controlled plots. Interaction of irrigation frequencies and K levels indicated a linear increase in grains of cob-1 of maize.

Interaction of six irrigations with K 100 kg/ha significantly increased the grains cob-1 with 301.81, while the lowest grains cob-1 were recorded where no irrigation and potassium were applied Table 5. Kuşçu and Demir (2012) reported higher grain cob-1 with increasing irrigation water compared to non-irrigated plots. Aguilar et al. (2007) stated there were more grains in cob-1 of maize under high irrigation frequencies. Maqsood et al. (2013) stated significantly higher grain cob-1 with higher application of potassium.

Table 5. Grains (Grain Cob-1) of Maize as Affected by Different Irrigation Levels and Potassium Application.

Irrigation levels	Levels of Potassium application					Mean
	K 0 kg ha ⁻¹	K 25 kg ha ⁻¹	K 50 kg ha ⁻¹	K 75 kg ha ⁻¹	K 100 kg ha ⁻¹	
No irrigation	70.6	81.37	91.73	96.43	103.21	88.66
Two irrigations	90.73	115.33	122.23	128.13	137.12	118.70
Four irrigations	99.8	138.87	152.4	159.33	166.22	143.32
Six irrigations	107.33	151.73	186.53	244.31	301.81	198.34
Mean	92.11	121.82	138.22	157.05	177.09	

Seed Index (1000-grains wt. g): Irrigation frequencies and K fertilization significantly varied the thousand-grain weight of maize. Mean values of the data revealed heavier grains in plots supplied with six irrigations, while lower thousand-grain weights were recorded in non-irrigated plots. Likewise, a 100 kg ha⁻¹ application produced heavier grains with higher thousand-grain weight, though lower thousand-grain weight was recorded in K-controlled plots. The interaction of irrigation frequencies and K fertilization indicated that thousand-grain weight increased significantly with increasing irrigation numbers and K levels. Interaction results of six irrigations and 100 kg/ha were observed with the highest thousand-grain weight of maize. However, the fewest results were recorded where irrigation and potassium were both controlled as shown in table 6. This might be due to the

increased translocation of assimilates from leaf to grain. Akhtar et al. (2003) recorded that K increases enzyme activities in the plant, which is important for the accumulation and translocation of assimilates from leaf to grain that resulting in increased grain weight. Potassium has an important role in water use efficiency and improves plant growth conditions and cell division, and makes hydrocarbons and protein and quick transportation toward grains (Horst, 1995). Aguilar et al. (2007) stated a higher thousand-grain weight of maize under high irrigation frequencies. Similarly, Bahrani et al. (2012) also suggested a higher 1000-grain weight of maize with frequent supply of irrigation water at proper intervals. Confirmatory findings were reported by Hussain et al. (2007) and Aslam et al. (2014), who suggested an increase in 1000-grain weight with increasing potassium fertilization.

Table 6. Seed Index (1000-Grain Weight, g) of Maize as Affected by Different Irrigation Levels and Potassium Applications.

Irrigation levels	Levels of Potassium application					Mean
	K 0 kg ha ⁻¹	K 25 kg ha ⁻¹	K 50 kg ha ⁻¹	K 75 kg ha ⁻¹	K 100 kg ha ⁻¹	
No irrigation	106.13	138.4	151.21	172.43	248.53	163.34
Two irrigations	190.73	267.2	240.34	294.33	309.4	260.4
Four irrigations	233.33	299.53	329.33	397.4	412.07	334.332
Six irrigations	292.33	307.6	370.3	421.33	433.4	364.992
Mean	205.63	253.183	272.795	321.373	350.85	

Statistical analysis of data showed significant effects of irrigation frequencies and K levels on the grains of cob-1 of maize. An increase in biological yield was observed with increasing irrigation numbers, and a significant biological yield (31419.4 kg ha⁻¹) of maize was recorded under six irrigations, while a lower biological yield (12288.6 kg ha⁻¹) was recorded with no irrigation. Similarly, potassium at 100 kg ha⁻¹ increased biological yield (28311.7 kg ha⁻¹), and the lowest biological yield (12310.7 kg ha⁻¹) was observed from potassium-controlled plots. The interaction of irrigation frequencies and K levels indicated a linear increase in grains of cob-1 of maize. Interaction of six irrigations with K 100 kg/ha significantly increased the

biological yield by 45104 kg ha⁻¹, while the lowest biological yield (8209 kg ha⁻¹) was recorded where no irrigation and potassium were applied Table 7. Datnoff (2007) reported that K application at higher than optimal levels doesn't increase maize yield and disease resistance. The decrease in maize yield with increasing K levels might be because excessive K fertilization hinders the uptake of other nutrients like zinc, iron, manganese, and magnesium (Zhao et al., 2011). Our results confirm the findings reported by Maqsood et al. (2013) and Bahrani et al. (2012). Our results match the results as recorded by Tabatabaei & Ranjbar (2012) and Hanif (1990).

Table 7. Biological Yield (kg ha⁻¹) of Maize as Affected by Different Irrigation Levels and Potassium Applications.

Irrigation levels	Levels of Potassium application					Mean
	K 0 kg ha ⁻¹	K 25 kg ha ⁻¹	K 50 kg ha ⁻¹	K 75 kg ha ⁻¹	K 100 kg ha ⁻¹	
No irrigation	8209	10645	11758	14916	15115	12288.6
Two irrigations	12604	15584	18093	18816	19916	16562.6
Four irrigations	13216	21573	27140	29416	33112	24451.4
Six irrigations	15214	30551	30923	39304	45104	31419.4
Mean	12310.7	19588.2	21987.5	25613.0	28311.7	

Grain yield (kg ha): Data analysis showed that different irrigation frequencies and K applications brought significant variations in the grain yield of maize. Increasing the number of irrigations increased the grain yield of maize over non-irrigated plots; hence, six times irrigated plots produced higher grain yields (3830.5 kg ha⁻¹) as compared with irrigation-controlled plots, where the lowest grain yields (1027.9 kg ha⁻¹) were recorded. Regarding K fertilization, grain yield increased with increasing K levels. However, a maximum grain yield (2958.5 kg ha⁻¹) was observed with 100 kg of potassium application per hectare, while the lowest grain yield was 1577.2 kg ha⁻¹. Whereas in the interaction between irrigation and K fertilization, the highest grain yield with six

irrigations and 100 kg/ha K (4832.8 kg ha⁻¹) and the lowest results for grain yield (802.6 kg ha⁻¹) were recorded where no irrigation and potassium were applied Table 8. Our results align with Saleem et al. (2011) and Staffer et al. (1995), who reported that grain yield increased with the increase in K level. Water stress increased growth hormone levels, for example, cytokinin, and decreased inhibitor hormones, for example, ABA, but potassium increased cell division, grain number per row, row numbers per row, 1000-grain weight, and grain yield (NeSmith & Ritchie, 1992). Potassium regulates stoma closure and prevents water wasting and osmosis, increasing water use efficiency and improving growth conditions in corn (Wiebold & Scharf, 2006).

Table 8. Grain Yield (kg ha⁻¹) of Maize as Affected by Different Irrigation Levels and Potassium Applications.

Irrigation levels	Levels of Potassium application					Mean
	K 0 kg ha ⁻¹	K 25 kg ha ⁻¹	K 50 kg ha ⁻¹	K 75 kg ha ⁻¹	K 100 kg ha ⁻¹	
No irrigation	802.6	1017.3	1073.7	1108.4	1137.9	1027.9
Two irrigations	1432.5	1743.7	1954.0	2007.7	2147.6	1857.1
Four irrigations	1923.4	2363.1	2774.3	3314.8	3715.7	2818.2
Six irrigations	2152.7	3482.4	4182.5	4501.7	4832.8	3830.5
Mean	1577.2	2151.6	2496.1	2733.1	2958.5	

CONCLUSIONS AND RECOMMENDATIONS

From the results of this study, it was concluded that water stress and a low supply of potassium at each critical crop growth stage drastically decreased the growth and yield of maize. Optimum water supply and potassium applications to crops, considering the crop growth stage, increased the yield of maize. Therefore, among all the treatments, plots that received six irrigations of 2 and 100 kg ha⁻¹ potassium application improved crop yield and yield components compared with the rest of the treatments. Based on results obtained from this research, it is therefore

recommended that efficient water utilization and optimum K applications throughout the life span of the maize crop would be necessary for higher growth and grain yield of the maize crop in the agro-ecological zones of Tandojam, Sindh, Pakistan.

CONFLICTS OF INTEREST

We declare no competing interests affecting the work reported in this study.

AUTHORS' CONTRIBUTION

SB and NS designed and executed the experiments, analyzed the data, and wrote the manuscript. NS and QJ is Supervisor guidance, intellectual input, and throughout the research process. DK. Revised and assisted during manuscript preparation. NS and SAK. Contributed significantly to

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