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# IMPACT OF FOLIAR AND SOIL APPLICATION OF POTASSIUM ON WHEAT GROWTH AND YIELD UNDER FULL AND LIMITED IRRIGATION

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**Article Info**



**Abstract**

Wheat productivity in Pakistan remains below potential due to nutrient deficiencies and limited water availability. The comparative role of soil and foliar applied potassium (K) under different irrigation regimes is not well established. This study was conducted at the Agronomy Research Farm, The University of Agriculture Peshawar, during the 2023–2024 to evaluate the influence of K application on wheat growth and yield under full and limited irrigation. The experiment was arranged in a randomized complete block design with three replications. Two irrigation regimes were imposed: full irrigation (four irrigations at emergence, tillering, booting and grain filling) and limited irrigation (two irrigations at emergence and booting). Treatments consisted of soil-applied K (75, 100 and 125 kg $ha^{-1}$), foliar-applied K (1, 2 and 3%) and a control without K for each replication under both fields, using sulfate of potash (SOP) as the source. Application of 125 kg K $ha^{-1}$ improved emergence (91 $m^{-2}$), plant height (86 cm), spike density (306 $m^{-2}$), grains $spike^{-1}$ (60), thousand grain weight (41.14 g), biological yield (11,322 kg $ha^{-1}$), grain yield (3,377 kg $ha^{-1}$) and harvest index (30 %) comparable with 100 kg K $ha^{-1}$. Foliar K at 2–3% enhanced emergence, leaf area and yield traits with 2% producing maximum thousand grain weight (41.64 g). Full irrigation significantly outperformed limited irrigation, while treated plots consistently exceeded controls. It is concluded that soil K at 100 kg $ha^{-1}$ combined with 2% foliar K is a promising strategy to improve wheat productivity under both irrigation regimes in Peshawar.

**Keywords:**
*Wheat, potassium application, irrigation regimes, foliar spray, yield and yield components.*

## INTRODUCTION

Wheat (*Triticum aestivum* L.) plays a significant part in Pakistan's economy. In Pakistan, approximately 70% of the wheat produced is used in the production of bread, while the remaining 30% is utilized in the manufacturing of various bakery products, such as cookies and cakes (Ahmad et al., 2013). Agricultural statistics from 2023 in Pakistan, wheat was grown on 9.2 million hectares, resulting in a whole annual production of 27.5 million tons. The average seed yield was 2989 kilograms per hectare. In the Khyber Pakhtunkhwa (KPK) province, during the same year, wheat was cultivated on 0.76 million hectares, yielding an annual output of 1.45 million tons, with an average seed yield of 1908 kilograms per hectare (MNFS&R, 2023).

Potassium (K) is an essential macronutrient which regulates a number of significant plant processes (including water regulation, photosynthesis and enzyme activity). It enhances the quality of crops, raises yields and develops stress resistance. Insufficiency leads to retardation in the growth, the reduction of resistance to stress and leaf chlorosis. These processes include enzyme activation, photosynthesis, protein synthesis, osmoregulation, energy transfer, stomatal movement, cation-anion balance and stress resistance (Wang and Wu 2013). Due to its impact on various metabolic pathways and crop quality, it is often referred to as the quality element (Ali et al., 2019). In the context of wheat, potassium holds a critical position in meeting its physiological requirements (Zörb et al., 2014). Wheat's seed size decreases when there is insufficient potassium, leading to an effect on grain filling duration (Ashraf et al., 2011). The intensive production of crop types which are high yielding has accelerated soil potassium (K) leaching and reduced the absorption of other nutrients requisite to maximum crop yields. Moreover, split potassium application during the growth period reduces potassium loss through leaching and enhances the efficiency of applied potassium fertilizers (Romheld and Kirkby 2010). It promotes the supply of sucrose, the accumulation of starch in grains, and ultimately leads to increased grain yield (Xu et al., 2020)

Reports by Choudhary and Suthar (2023) indicated that spraying wheat leaves with potassium enhances wheat productivity significantly in drought-prone growing seasons. Apart from enhancing productivity, foliar K utilization provides protection against environmental stresses. Srivastava et al. (2019) proved that the use of potassium foliar sprays can severely assist wheat in overcoming physiological limitations due to drought. Application of potassium promotes osmoregulation, modulates stomatal behavior, and maximizes water use efficiency in a manner that significantly minimizes the effects of moisture deficits. Adhikari et al. (2019) also demonstrated that the application of potassium boosts water utilization and transport in order to maintain the cells rigid and photosynthesis functioning amidst drought.

The optimum crop nutrition should include both foliar and soil fertilization. Foliar spraying is good in solving deficiencies especially where we are dealing with micronutrients but when the macronutrients (N, P and K) are deficient, soil application is the most desirable. Foliar applications require accurate diagnosis of deficiencies by soil/tissue testing, ample leaf area (LAI>3), and water-soluble formulations of the nutrient, favorable environmental conditions (temperatures of 20-25 o C), and many opportunities to respond to low doses of treatments. The nature of nutrient, the severity of said shortage and affordability also have a bearing on technique choice. Foliar fertilization can complement soil fertilization, and when combined with post emergence herbicides, insecticides, or fungicides, it may enhance yield responses while reducing application costs (Fageria et al., 2009).

The research was based on the following objectives:

1. To investigate the impact soil K application on growth, yield and yield components of wheat under full irrigation (FIF) and limited irrigation (LIF) conditions.
2. To study the foliar K application on growth, yield and yield components of wheat under full irrigation (FIF) and limited irrigation (LIF) conditions.
3. To find out the interactive effect of soil and foliar application of K on growth, yield and yield component of wheat under full irrigation (FIF) and limited irrigation (LIF) conditions.

## Materials and Methods

### Experimental Design and Treatment Details

An experiment was conducted to investigate the impact of foliar and soil application of potassium on wheat growth and yield under full and limited irrigation". The experiment was carried out at Agronomy Research Farm, The University of Agriculture Peshawar in winter season 2023-24. Experiment was done in randomized complete block design (RCBD) having three replications. Each plot size was 3 x 3 $m^2$ with row-to-row distance of 30 cm. The research was conducted under two different field conditions: one field was under full irrigated field which received four irrigations (at emergence, tillering, booting and grain filling stage) and the second field was under limited irrigated condition where only two irrigations were applied (at emergence and booting stage). The experiment was two factors; factor one consisted of three soil applied K levels (75, 100 and 125 kg K $ha^{-1}$) and factor two having three foliar applied K levels (1, 2 and 3 % K), while there will be one control plot. There was one control in each replication under both field conditions where no K was applied.

### Growth and Phonological Observation

Emergence ($m^{-2}$) was calculated by the following formula was converted to $m^{-2}$. Emergence $m^{-2}$= (number of plants counted)/ Row-Row distance x Row length x Number of rows) x 1 $m^2$. For days to maturity, the number of days from crop sowing to crop maturity was simply counted in order to record the data related to days to maturity. For plant height (cm), ten samples in the plot's middle rows were randomly measured to record data relating to plant height one week prior to crop harvest. A single plant's height was measured from the base to the top of the wheat spike awn, and the results were averaged to get a single number. For leaf area ($cm^2$), ten typical plants were chosen, their leaf lengths and widths were measured, and the formula was used to average the results for each tiller. LA (leaf area) = (Length x Width x Correction factor (0.75).

### Yield and Yield Components

For spikes $m^{-2}$, Information pertaining to spikes in a 1-meter row at three random selections in each plot was counted to determine spike $m^{-2}$, which was then converted using the following formula: spikes $m^{-2}$= (number of spikes counted)/ Row-Row distance x Row length x Number of rows) x 1 $m^2$. For grains spike$^{-1}$, five spikes were chosen from each experimental plot, and the grain was manually threshed from each spike before being tallied during harvest. This process was used to count the wheat grains spike$^{-1}$ data. For thousand grain weight (g), after the crop was threshed, a sample of pure grains was randomly chosen for each treatment to weigh 1000 grains of wheat (g). The weight of the counted grains was then determined using a digital scale. For biological yield, cutting three middle rows in each plot allowed for the collection of biological yield data. Plant weight was then calculated and translated to kg ha$^{-1}$ using the following formula: biological yield (kg ha$^{-1}$) = (Biological yield of three rows/ Row-Row distance x No. of rows x Row length) x 10000). For grain yield, the harvested three central rows in each plot were used to calculate the grain yield of wheat. The material was dried and threshed independently and the same formula which was used for biological yield was used to convert the grain yield into kg ha$^{-1}$. For harvest index (%), the following formula was used to calculate data regarding the wheat harvest index (%): Harvest index (Grain yield/ Biological yield) x 100).

**Statistical Analysis**

The recorded data was analyzed regarding to the procedure relevant to the randomized complete block design (RCBD). Least significance differences (LSD) test at (5%) level of Significance was used for mean comparison in term of significance difference (Steel et al., 1997). Multivariate analyses, including Principal Component Analysis (PCA) and correlation, were performed in Origin software to identify key traits contributing to wheat yield and to evaluate interrelationships among yield and yield-related parameters under different potassium and irrigation regimes.

**RESULTS**

**Emergence m$^{-2}$**

The impact of SK and IR was found significant on emergence m$^{-2}$, while FK affect was found non-significant (Table 1). All the interactive impact were found non-significant except IR x SK. The C vs. T had a significant effect on emergence m$^{-2}$ of wheat. Among SK, higher emergence m$^{-2}$ (93) was recorded with 100 kg K ha$^{-1}$, followed by 125 kg K ha$^{-1}$ (91), while lower emergence m$^{-2}$ was noted with 75 kg K ha$^{-1}$ (89). Full irrigated field (FIF) (96) had higher emergence m$^{-2}$ (96) than limited irrigated field (LIF) (86). C vs. The rest plots (91) had more emergence m$^{-2}$ than control plots (87). In case of IR x SK interaction, increasing the K levels under FIF produced higher emergence m$^{-2}$ as compared with LIF.

**Days to Maturity**

Table 1 shows the data of days to maturity of wheat. ANOVA displayed that SK, FK and IR had a prominent impact on days to maturity. All the interactive affect were found non-significant except SK x FK, while C vs. T also had a positive impact on maturity timing. The plots receiving 125 kg K ha$^{-1}$ (158 days) had taken delayed maturity timing which was statistically similar with 100 kg K ha$^{-1}$ (158 days), while earlier maturity timing was found at 75 kg K ha$^{-1}$ (157 days). Among FK levels, applying 3 % K (158 days) took delayed maturity timing was statistically at par with 2 % (158 days), while earlier maturity timing was noted with 1 % (157 days). FIF plots (158 days) recorded delayed maturity timing when compared with LIF plots (157 days). In C vs. T, treat plots (157 days) delayed maturity timing as compared to control plots (155 days).

**Leaf Area ($cm^2$)**

The impact of SK, FK and IR on leaf area of wheat was found significant (Table 1). All the interactive impact were found non-significant while C vs. T had a positive impact on leaf area. In the SK levels, higher leaf area (31 $cm^2$) was noted with 100 kg K $ha^{-1}$ which was statistically at par with 120 kg K $ha^{-1}$ (29 $cm^2$), while lower leaf area was observed at 75 kg $ha^{-1}$ (27 $cm^2$). Those plots receiving 2 % FK had produced higher leaf area (31 $cm^2$) which was statistically similar with 3 % (30 $cm^2$), while lower leaf area was noted with 1 % (27 $cm^2$). In FIF plots (31 $cm^2$) had higher leaf area when compared with LIF plots (27 $cm^2$). In case of C vs. T, treated plots (29 $cm^2$) had produced higher leaf area than control plots (24 $cm^2$).

**Plant Height (cm)**

Table 1 represents the data on plant height of wheat. ANOVA displayed that SK, FK and IR had a prominent impact on plant height. All the interactive impact were non-significant while C vs. T had a positive effect on plant height. In case of SK levels, taller plants (86 cm) were observed with 125 kg K $ha^{-1}$ which was statistically at par with 100 kg K $ha^{-1}$ (85 cm), while shorter plants was observed with 75 kg K $ha^{-1}$ (83 cm). Among FK levels, the plots where 3 % K (87 cm) was given had maximum plant height which was similar with 2 % (86 cm), while lower plant height was noted with 1 % (82 cm). FIF plots (88 cm) had taller plants as compare with LIF plots (82 cm). While in case of C vs. T, treated plots (85 cm) had taller plants than control plots (81 cm).

**Table 1. Emergence $m^{-2}$,days to maturity, leaf area ($cm^2$) and plant height (cm) as impacted by soil and foliar potassium application under full (FIF) and limited irrigation (LIF).**

| Source of Variation | Parameters | | | |
|---|---|---|---|---|
| **Irrigation Regimes (IR)** | **Emergence ($m^{-2}$)** | **Days to maturity** | **Leaf area ($cm^2$)** | **Plant height (cm)** |
| **Full Irrigation (FIF)** | 96 a | 158 a | 31 a | 88 a |
| **Limited Irrigation (LIF)** | 86 b | 157 b | 27 b | 82 b |
| **LSD $_{(0.05)}$** | 2.67 | 0.98 | 3.22 | 4.45 |
| **Soil K (SK) (kg $ha^{-1}$)** | | | | |
| **75** | 89 c | 157 b | 27 b | 83 b |
| **100** | 93 a | 158 a | 31 a | 85 a |
| **125** | 91 b | 158 a | 29 a | 86 a |
| **LSD $_{(0.05)}$** | 1.70 | 0.73 | 1.84 | 2.58 |
| **Foliar K (FK) (%)** | | | | |
| **1** | 90 | 157 b | 27 b | 82 b |
| **2** | 91 | 158 a | 31 a | 86 a |
| **3** | 91 | 158 a | 30 a | 87 a |
| **LSD $_{(0.05)}$** | NS | 0.73 | 1.84 | 2.58 |
| **Planned Mean** | | | | |
| **Control** | 87 b | 155 b | 24 b | 81 b |
| **Treated** | 91 a | 157 a | 29 a | 85 a |
| **Significant Interactions** | | | | |
| **IR x SK** | * | NS | NS | NS |
| **SK x FK** | NS | * | NS | NS |
| **IR x FK** | NS | NS | NS | NS |
| **IR x SK x FK** | NS | NS | NS | NS |

**Notes:**

Within each source of variation and column, means followed by different letters are significantly different according to the Least Significant Difference (LSD) test at $P < 0.05$.

NS, non-significant; * significant at the 5% level of probability.

**Spike $m^{-2}$**

The impact of SK, FK and IR was found significant on number of spike $m^{-2}$ (Table 2). All the interactive effects were found non-significant except IR x SK interaction, while C vs. T was also found significant for spike $m^{-2}$. The highest spike $m^{-2}$ (306) was noted with plots having 125 kg K $ha^{-1}$ which was statistically at par with 100 kg K $ha^{-1}$ (295), while lower spike $m^{-2}$ was observed with 75 kg K $ha^{-1}$ (284). Among FK levels, 3 % (307) produced maximum spike $m^{-2}$ which was statistically at par with 2 % (296), while lower spike $m^{-2}$ was noted with 1 % (282). FIF (315) produced higher spike $m^{-2}$ as compared with LIF (275). The C vs. T, higher spike $m^{-2}$ (296) was noted with treated plots while lower was observed with control plots (245). The interaction (IR x SK) showed that applying the higher K levels increased the spike $m^{-2}$ and the increase was more under FIF

**Grains $spike^{-1}$**

Table 2 demonstrated the data concerning of grains $spike^{-1}$ of wheat. ANOVA revealed that SK, FK and IR had significant effects on grains $spike^{-1}$, while all the interactive impacts were found non-significant. The C vs. T had a significant effect on grains $spike^{-1}$. Among SK levels, more grains $spike^{-1}$ (60) was observed with 125 kg K $ha^{-1}$ which was statistically at par with 100 kg K $ha^{-1}$ (58), while less grains $spike^{-1}$ was noted with 75 kg K $ha^{-1}$ (53). Among FK levels, more grains $spike^{-1}$ (59) was noted with 3 % which was similar with 2 % (58), while fewer grains $spike^{-1}$ was observed with 75 kg K $ha^{-1}$ (54). The FIF plots (60) had higher grains $spike^{-1}$ while fewer were noted with LIF (54). In case of C vs. T, higher grains $spike^{-1}$ (57) was noted with treated plots compared with control plots (54).

**Thousand grains weight (g)**

Data on thousand grains weight of wheat are presented in Table 2. The analysis of variance showed that SK, FK and IR affect was found prominent on thousand grains weight. All the interactions were found non-significant except IR x SK interaction. The C vs. T was also found significant. The maximum thousand grains weight (41.14 g) was observed with 125 kg K $ha^{-1}$ which was statistically at par with 100 kg K $ha^{-1}$ (40.50 g), while lower thousand grain weight was observed with 75 kg K $ha^{-1}$ (37.60 g). Among FK levels, 3 % (41.64) recorded higher thousand grain weight while lower was noted with 1 % (37.51 g). The FIF plots (41.09 g) had higher thousand grains weight as compared with LIF (38.40 g). In case of C vs. T, the treated plots (39.75 g) had higher thousand grain weight while lower was noted for control plots (36.05 g). The IR x SK interaction exhibited that increasing the SK levels under FIF produced more thousand grain weight than LIF.

**Table 2. Spikes $m^{-2}$, grains $spike^{-1}$ and thousand grain weight (g) as impacted by soil and foliar potassium application under full (FIF) and limited irrigation (LIF).**

| Source of Variation | Parameters | | |
|---|---|---|---|
| **Irrigation Regimes (IR)** | Spikes ($m^{-2}$) | Grains $spike^{-1}$ | Thousand grain weight (g) |
| **Full Irrigation (FIF)** | 315 a | 60 a | 41.09 a |
| **Limited Irrigation (LIF)** | 275 b | 54 b | 38.40 b |
| **LSD (0.05)** | 5.69 | 1.23 | 0.70 |
| **Soil K (SK) (kg $ha^{-1}$)** | | | |
| **75** | 284 b | 53 b | 37.60 b |
| **100** | 295 a | 58 a | 40.50 a |
| **125** | 306 a | 60 a | 41.14 a |
| **LSD (0.05)** | 11.21 | 2.26 | 1.21 |
| **Foliar K (FK) (%)** | | | |
| **1** | 282 b | 54 b | 37.51 c |
| **2** | 296 a | 58 a | 40.09 b |
| **3** | 307 a | 59 a | 41.64 a |
| **LSD (0.05)** | 11.21 | 2.26 | 1.21 |
| **Planned Mean** | | | |
| **Control** | 245 b | 53 b | 36.05 b |
| **Treated** | 296 a | 57 a | 39.75 a |
| **Significant Interactions** | | | |
| **IR x SK** | *** | NS | * |
| **SK x FK** | NS | NS | NS |
| **IR x FK** | NS | NS | NS |
| **IR x SK x FK** | NS | NS | NS |

**Notes:**

Within each source of variation and column, means followed by different letters are significantly different according to the Least Significant Difference (LSD) test at $P < 0.05$.

NS, non-significant; *, **, *** significant at the 5%, 1%, and 0.1% levels of probability, respectively.

**Biological Yield (kg $ha^{-1}$)**

The SK, FK and IR had significantly affected biological yield of wheat (Table 3). All the interactions were found non-significant while C vs. T had a significant effect on biological yield. Among SK levels, higher biological yield (11322 kg $ha^{-1}$) was obtained with 125 kg K $ha^{-1}$ which was statistically at par with 100 kg K $ha^{-1}$ (10686 kg $ha^{-1}$), while lower yield was recorded with 75 kg K $ha^{-1}$ (10000 kg $ha^{-1}$). Among FK levels, highest biological yield (11047 kg $ha^{-1}$) was obtained with 3 % which was statistically similar with 2 % (10933 kg $ha^{-1}$), while the lowest biological yield was recorded with 1 % (10028 kg $ha^{-1}$). The FIF plots (11600 kg $ha^{-1}$) had produced higher biological yield as compared with

LIF plots (9739 kg ha$^{-1}$). In case of C vs. T, treated plots (10669 kg ha$^{-1}$) produced more biological than control plots (9275 kg ha$^{-1}$).

**Grain Yield (kg ha$^{-1}$)**

Grain yield of wheat was significantly affected by SK, FK and IR as shown in Table 3. The interactions were found non-significantly, however C vs. T was found significant for grain yield. In case of SK levels, the highest grain yield (3377 kg ha$^{-1}$) was obtained with 125 kg K ha$^{-1}$ which was statistically at par with 100 kg K ha$^{-1}$ (3165 kg ha$^{-1}$), while the lowest grain yield was noted with 75 kg K ha$^{-1}$ (2881 kg ha$^{-1}$). Among FK levels, maximum grain yield (3347 kg ha$^{-1}$) was obtained with 3 % which was statistically at par with 2 % (3173 kg ha$^{-1}$), while minimum grain yield was calculated for 1 % (2902 kg ha$^{-1}$). The FIF plots (11322 kg ha$^{-1}$) had produced higher grain yield than LIF plots (2644 kg ha$^{-1}$). In C vs. T, the higher grain yield (3114 kg ha$^{-1}$) was obtained from treated plots while lower yield was obtained from the control plots (2321 kg ha$^{-1}$).

**Harvest Index (%)**

Harvest index of wheat was non-significantly affected by the SK and FK levels, while the effect of irrigation was found significant (Table 3). All the interactive effects were noted to be non-significant while C vs. T was found significant. In irrigation regimes, higher harvest index (31 %) was calculated for FIF while minimum harvest index (27 %) was calculated for LIF. In case of C vs. T, the treated plots (29 %) had higher harvest index than control plots (25 %).

**Table 3. Biological yield (kg ha$^{-1}$), grain yield (kg ha$^{-1}$) and harvest index (%) as impacted by soil and foliar potassium application under full (FIF) and limited irrigation (LIF).**

| Source of Variation | Parameters | | |
|---|---|---|---|
| **Irrigation Regimes (IR)** | **Biological yield (kg ha$^{-1}$)** | **Grain yield (kg ha$^{-1}$)** | **Harvest index (%)** |
| **Full Irrigation (FIF)** | 11600 a | 3637 a | 31 a |
| **Limited Irrigation (LIF)** | 9739 b | 2644 b | 27 b |
| **LSD $_{(0.05)}$** | 605.64 | 243.30 | 2.45 |
| **Soil K (SK) (kg ha$^{-1}$)** | | | |
| **75** | 10000 b | 2881 b | 29 |
| **100** | 10686 a | 3165 a | 30 |
| **125** | 11322 a | 3377 a | 30 |
| **LSD (0.05)** | 649.91 | 262.39 | NS |
| **Foliar K (FK) (%)** | | | |
| **1** | 10028 b | 2902 b | 29 |
| **2** | 10933 a | 3173 a | 29 |
| **3** | 11047 a | 3347 a | 30 |
| **LSD $_{(0.05)}$** | 649.91 | 262.39 | NS |
| **Planned Mean** | | | |
| **Control** | 9275 b | 2321 b | 25 b |
| **Treated** | 10669 a | 3141 a | 29 a |

| | | | |
|---|---|---|---|
| **Significant Interactions** | | | |
| **IR x SK** | NS | NS | NS |
| **SK x FK** | NS | NS | NS |
| **IR x FK** | NS | NS | NS |
| **IR x SK x FK** | NS | NS | NS |

**Notes:**

Within each source of variation and column, means followed by different letters are significantly different according to the Least Significant Difference (LSD) test at $P < 0.05$. NS, non-significant.

**Principal Component Analysis (PCA)**

The principal component analysis (PCA) biplot (Figure 1) illustrates the distribution of wheat treatments under different soil and foliar potassium levels combined with full and limited irrigation. The first two principal components (PC1 and PC2) explained 61.50% and 10.74% of the total variance, respectively, accounting for a cumulative 72.24% of the variation in agronomic traits.

Yield-associated parameters such as grain yield (GY), biological yield (BY), harvest index (HI), spikes $m^{-2}$ (SM2), thousand grain weight (TGW) and grains spike$^{-1}$ (GPS) were positively correlated with PC1, demonstrating their major contribution to treatment differentiation. Among these, HI, GY and LA exhibited longer vector lengths, suggesting stronger associations with PC1.

Treatment grouping revealed that combinations of full irrigation with higher soil and foliar potassium doses such as treatments 5–10 were positioned on the positive side of PC1, closely aligned with yield-contributing traits (GY, BY and HI). In contrast, treatments under limited irrigation with lower potassium application like treatments 11–15 were located on the negative side of PC1 and PC2, showing weak associations with yield attributes. Intermediate treatments with moderate potassium supply such as treatments 16–20 occupied central positions, indicating partial contribution to performance.

Overall, the PCA separated treatments clearly by irrigation regime and potassium application, highlighting that full irrigation combined with higher soil and foliar potassium levels was strongly linked with improved yield traits, while limited irrigation and low potassium were associated with reduced crop performance.

**Correlation Analysis**

The correlation matrix (Figure 2) revealed significant associations among different wheat traits under the influence of soil and foliar potassium with full and limited irrigation. Most of the traits exhibited strong positive correlations with one another, indicating that improvements in one attribute were generally accompanied by improvements in others.

Grain yield (GY) showed a strong and positive correlation with biological yield (BY), harvest index (HI), thousand grain weight (TGW) and grains spike$^{-1}$ (GPS), suggesting that these traits are major contributors to yield performance. Similarly, BY exhibited significant positive associations with yield-related parameters, confirming its central role in determining productivity.

A notable negative correlation was observed between HI and BY, indicating that genotypes or treatments with very high biomass did not always convert proportionately into grain yield efficiency. This trade-off reflects the balance between sources (biomass production) and sinks (grain filling) under varying potassium and irrigation regimes.

Other traits such as leaf area (LA), plant height (PH) and spikes $m^{-2}$ (SM2) were positively correlated with GY and BY, highlighting their indirect contribution toward yield formation. Early maturity traits (EM2 and DTM) showed moderate associations with yield attributes, suggesting that timing of development also influences final productivity.

Overall, the correlation analysis highlights that yield in wheat is a function of multiple integrated traits, with BY, HI and TGW emerging as the most critical determinants under potassium and irrigation management strategies.

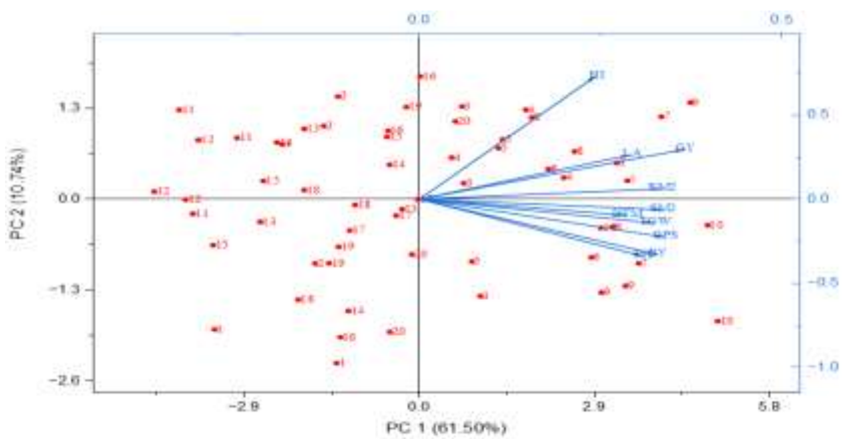


**Figure 1. Principal component analysis (PCA) for wheat as affected by soil and foliar potassium under full and limited irrigation.**

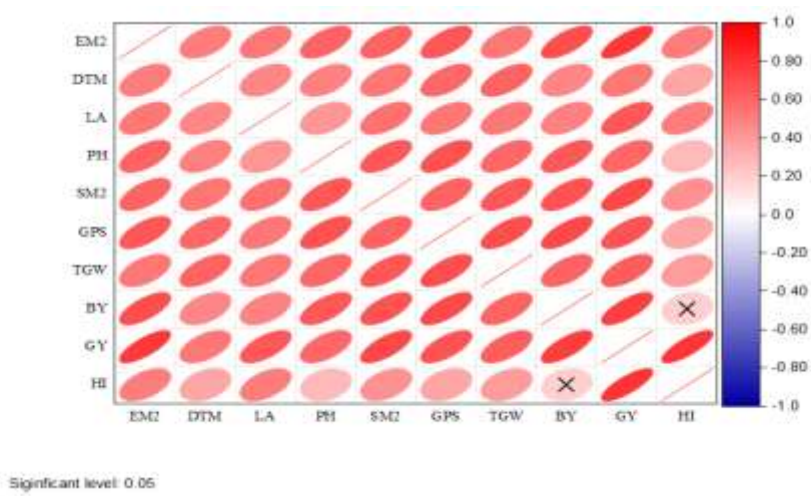

**Figure 2. Correlation analysis for wheat as affected by soil and foliar potassium under full and limited irrigation.**

EM2= emergence $m^{-2}$, DTM= days to maturity, LA= leaf area, PH= Plant height, sm2= Spikes $m^{-2}$, GPS= Grains $spike^{-1}$, TGW= Thousand grain weight, BY= Biological yield, GY= Grain yield, HI= Harvest index
1 = (Full irrigation + 0 kg $ha^{-1}$ Soil K + 0% Foliar K), 2 = (Full irrigation + 75 kg $ha^{-1}$ Soil K + 1% Foliar K), 3 = (Full irrigation + 75 kg $ha^{-1}$ Soil K + 2% Foliar K), 4 = (Full irrigation + 75 kg $ha^{-1}$ Soil K + 3% Foliar K), 5 = (Full irrigation + 100 kg $ha^{-1}$ Soil K + 1% Foliar K), 6 = (Full irrigation + 100 kg $ha^{-1}$ Soil K + 2% Foliar K), 7 = (Full irrigation + 100 kg $ha^{-1}$ Soil K + 3% Foliar K), 8 = (Full irrigation + 125 kg $ha^{-1}$ Soil K + 1% Foliar K), 9 = (Full irrigation + 125 kg $ha^{-1}$ Soil K + 2% Foliar K), 10 = (Full irrigation + 125 kg $ha^{-1}$ Soil K + 3% Foliar K), 11 = (Limited irrigation + 0 kg $ha^{-1}$ Soil K + 0% Foliar K), 12 = (Limited irrigation + 75 kg $ha^{-1}$ Soil K + 1% Foliar K), 13 = (Limited irrigation + 75 kg $ha^{-1}$ Soil K + 2% Foliar K), 14 = (Limited irrigation + 75 kg $ha^{-1}$ Soil K + 3% Foliar K), 15 = (Limited irrigation + 100 kg $ha^{-1}$ Soil K + 1% Foliar K), 16 = (Limited irrigation + 100 kg $ha^{-1}$ Soil K + 2% Foliar K), 17 = (Limited irrigation + 100 kg $ha^{-1}$ Soil K + 3% Foliar K), 18 = (Limited irrigation + 125 kg $ha^{-1}$ Soil K + 1% Foliar K), 19 = (Limited irrigation + 125 kg $ha^{-1}$ Soil K + 2% Foliar K), 20 = (Limited irrigation + 125 kg $ha^{-1}$ Soil K + 3% Foliar K)

**Discussion**

The application of soil potassium (SK), and irrigation (IR) affected wheat emergence $m^{-2}$, and the response was not significant for foliar potassium (FK). According to Jatoi et al. (2024), split application of potassium increased wheat yield parameters including improved early growth stages; such as emergence. Our findings are in line with the results reported by Kakar et al. (2021) who found that the irrigation level affects all yield components of the spring wheat under semiarid conditions.

Soil potassium (SK), foliar potassium (FK) and irrigation (IR) had a positive impact on maturity timing of wheat. This agrees with the observed effects of higher potassium to promote vegetative growth which could prolong the maturity period as found by Kubar et al. (2019). Finds by Godebo et al. (2021) of extended wheat maturity by up to two weeks when fertilized with combined nitrogen and potassium are also supported by our findings. Although there is a complex relationship between water availability and crop development, Soulé et al. (2024) showed that reduced irrigation intervals increased maturity.

Based on the present study, both soil applied potassium (SK) and foliar potassium (FK) applications increased leaf area in wheat. Jain et al. (2024) found that integrating potassium with organic amendments, like paddy crop residues, increased the leaf area index (LAI) in wheat and emphasized the adequacy of a combined nutrient management strategy. They observed that foliar potassium application, particularly as $K_2SiO_3$, improved water use efficiency and led to increased leaf area in wheat under drought stress situation (El Shafei et al., 2023). Hu et al. (2020) found that potassium deficiency principally influenced leaf anatomy and photosynthetic capacity more than areas in oilseed rape and that species specific response to potassium nutrition.

Factors that significantly affect wheat plant height were soil potassium (SK), foliar potassium (FK) and irrigation frequency (IR). A similar finding was reported by A own et al. (2012), who found that foliar potassium application to the water deficient treatment of wheat had positive effects on wheat growth and yield. This is in agreement with the finding of Akhter et al. (2017) that application of potassium and nitrogen split, together with irrigation scheduling, increased wheat growth metrics, including plant height.

It was observed that all three components of irrigation (IR), foliar potassium (FK), and soil potassium (SK) had statistically ($P<0.05$) significant impacts on the wheat spiked density. According to Messaoudi et al. (2023), spike number per $m^2$ and grain yield was increased by 100 kg K $ha^{-1}$. It was found in a study of Ishaq et al. (2023) that foliar applied potassium increased the uptake of soil potassium through increased growth and enhancement of photosynthesis in wheat. As our results is not consistent with Brhane et al. (2017) that increasing potassium rate from 30 kg/ha did not result in greater yield improvements, since other environmental condition may have overshadowed effects of potassium. This merely underscores the need for site specific nutrient management strategies.

It is shown that the fertilizer of soil and foliar (potassium (K) and the irrigation (IR) significantly influenced the grains per spike in wheat. Using the result that foliar potassium application at the flowering stage significantly improved grain protein content and quality, indirectly suggesting enhanced grain development, Gu et al. (2021) demonstrated that foliar potassium application at flowering stage is effective at improving grain protein content and quality. As has been reported by Elhag (2017), increased irrigation frequency positively impacts yield components, including grains per spike, in wheat cultivars.

All the treatments consisting of irrigation (IR), foliar potassium (FK) and soil potassium (SK) significantly boosted the thousand-grain weight of the wheat ($P < 0.05$).This is supported by the results obtained by Adnan et al. (2016), who indicated that the application of higher K (90 kg K $ha^{-1}$) greatly increased TGW but further K application did not show significant effect. The optimal K rate might be varied depending on regional soil and environmental conditions according to Ojha et al. (2021) who mentioned that K application above 60 kg K $ha^{-1}$ did not significantly increase TGW in wheat. Houmani et al. (2022) also support this observation as they reported that adequate K application under ideal irrigation conditions enhanced physiological parameters and grain yield of wheat.

Results of the present study show that SK and FK considerably affect the biological yield of wheat, having the highest yield for 125 kg K $ha^{-1}$ SK and 3 % concentration of FK. Based on Kubar et al. (2019), 100% potassium application resulted in increased growth and yield component values of 20-50% above control treatments, indicating that further wheat growth depends on sufficient potassium availability. El Shafei et al. (2023) stated regarding foliar applications that foliar potassium treatments increased wheat water use efficiency and grain production per unit of water use under drought stress which demonstrated the effectiveness of foliar potassium application for stress conditions.

The significant influence of soil potassium (SK), foliar potassium (FK), and irrigation (IR) on wheat grain yield, while the interaction effects were non-significant. This corresponds with findings by Adnan et al. (2016) in which wheat yield components were substantially increased by 90 kg K $ha^{-1}$ but not at higher rates. Jain et al. (2024) mentioned that potassium at 125% of the recommended dose gave optimum growth and yield. Similarly, Kumar et al. (2020) also found that foliar potassium fertigation had alleviated salinity stress and thereby increased wheat yield. Katohar et al. (2023) corroborate the findings with the observation of enhanced grain yield and water productivity in wheat from optimized irrigation regimes.

The irrigation regimes significantly influenced harvest index (HI) of wheat while soil potassium (SK) and foliar potassium (FK) applications were non significantly different. Eissa, (2014) did not find any significant difference among the irrigation systems on HI meaning the irrigation method and environmental conditions might not modulate the response of HI to water availability. According to Asad et al. (2014) that besides irrigation levels affecting the grain yield and the water use efficiency, irrigation levels do not affect the HI significantly in some of the temperature regimes indicating that temperature stress can counteract the benefits of irrigation on HI.

The results of the PCA of this study indicate that PC1 (with an explanation of approximately 61.50% variance) is largely related to yield-related characteristics (grain yield, biological yield, harvest index, spike number, etc.) and this finding is consistent with Abbas et al. (2019), who studied that in Karor, Pakistan, grain yield and yield components of wheat were greatly enhanced with increasing potassium application with the highest yield recorded at 45 kg K ha-1 compared to control plots. The PCA separations of the treatments of full irrigation + high K and limited irrigation + low/zero K treatments are similar to the results of deficit irrigation studies. In the article "Impact of deficit irrigation strategies on winter wheat," Memon et al. (2021) noted that the yield and yield components decreased significantly in water stress conditions and that partial or near complete irrigation and adequate K ameliorated some of the decreases.

Most agronomic characteristics of the study have strong positive correlations, especially grain yield (GY), biological yield (BY) and harvest index (HI). Shahryari and Mollasadeghi (2011) supported this trend when they found that under normal irrigation, biological yield was among the highest correlated with grain yield in wheat genotypes and under stress of drought many traits were correlated weakly. The yield traits were also strongly correlated with the harvest index (HI) in your analysis. This is in line with the results obtained by Chen et al. (2025), who indicated that wheat under better irrigation regimes exhibited a high HI as well as higher yield and above-ground biomass.

**Conclusion**

To conclude, the investigation showed that the application of high doses of potassium in soil (125 kg ha$^{-1}$) was optimal regarding all responses of yield components (plant height, spike density, grains spike$^{-1}$, thousand grain weight and yields), would have similar results to 100 kg ha$^{-1}$ of potassium. The application of potassium foliar 3 percent was the best with all yield parameters growth and productivity (leaf area, plant height, spike density, grains per spike and yields) would have comparable results with 2. These results indicate that there were not statistically significant differences in most of the parameters between higher potassium rates (125 kg ha$^{-1}$ soil or 3% foliar) and slightly lower applications (100 kg ha$^{-1}$ soil or 1% foliar), providing potential suggestions to make savings. Irrigation was found important in maximizing wheat productivity at any growth stages. It is recommended that application of soil potassium at the rate of 100 kg $ha^{-1}$ while application of 2 % foliar potassium with full irrigation in the field will produced higher yield and yield components of wheat in Peshawar region.

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