RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
55 (1) 187-201, 2023
http://doi.org/10.54910/sabrao2023.55.1.18
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

POTASSIUM APPLICATION USING THE 4R NUTRIENT STEWARDSHIP APPROACH FOR IMPROVING WHEAT GROWTH AND YIELD TRAITS

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SUMMARY

Potassium (K) plays a key role in numerous plant metabolic processes, and its adequate amount is necessary for proper plant growth and development. Imbalanced fertilizer application has rapidly depleted the soil available K and harmed crops. However, the science-based K application in crops must follow the 4R nutrient stewardship approach to enhance crop yields. Therefore, a planned pot study used the 4R nutrient management technique for wheat potassium management. The evaluation of two wheat cultivars (Punjab-2008 and Barani-2011) employed two commercial K sources (MOP and SOP) with different application methods (basal and foliar) and sowing times (15 October, 15 November, and 15 December). The wheat variety Punjab-2008 performed better in root and shoot length, fresh biomass, and grain yield between 15 October and 15 November. Meanwhile, the Barani-2011, sown on 15 November, produced higher total chlorophyll contents and water use efficiency (WUE). The use of SOP (high dose), MOP (medium to high dose), and foliar spray of SOP at 1.5% and 3% resulted in maximum shoot length and the root-to-shoot ratio for both tested cultivars. Punjab-2008 produced higher grain yield when applied with a high SOP level than a high level of MOP. Similarly, a maximum leaf area index and proline contents observed in Punjab-2008 occurred with a high level of SOP applied. In contrast, a higher net photosynthesis rate and WUE emerged in Barani-2011 under a medium SOP level and a higher level of MOP. Thus, the conclusion is that medium to high rates of SOP proved a better source of K nutrition for improving yield parameters of wheat cultivars.

Keywords: Potassium management, 4R nutrient stewardship approach, nutrient use efficiency, grain yield

Key findings: The K fertilizer application using the 4R stewardship approach improved wheat crop quality and yield attributes. As observed, the medium to high rates of SOP proved a better source of K nutrition in helping improve yield parameters of wheat cultivars. Punjab-2008 performed better in wheat growth and yield attributes, while Barani-2011 found it efficient for physiological and biochemical traits. However, both cultivars gave the best results when sown on 15th November.

Communicating Editor: Prof. Naqib Ullah Khan

Manuscript received: December 24, 2022; Accepted: February 9, 2023.

Citation: Ramzan H, Tahir MA, Sarwar G, Sabah NU, Gul S, Manzoor MZ (2023). Potassium application using the 4R nutrient stewardship approach for improving wheat growth and yield traits. *SABRAO J. Breed. Genet.* 55(1): 187-201. http://doi.org/10.54910/sabrao2023.55.1.18.

INTRODUCTION

Potassium (K) is essential for completing the plant life cycle and a crucial part of various metabolic processes. Inadequate application of K leads to K mining from soil, ultimately leading to deficiency symptoms in crops, reducing crop yield and quality (Singh *et al*., 2021). Latest studies showed the farmers' optimal to suboptimal P use, unbalanced nitrogen application, and non-application of K under intensively cultivated areas (Syers, 2003; Singh *et al*., 2014, Singh *et al*., 2015a) resulted in soil fertility depletion (particularly K) in exhaustive production systems of Asia (Timsina *et al*., 2013).

Imbalanced nutrient application in crop production has negative environmental and agricultural implications (Liu *et al*., 2015; Swailam *et al*., 2021). Improving crop nutrient use efficiency is now a top focus for agriculture experts (Salim and Raza, 2020). Plants need potassium (K) for protein synthesis, enzyme activity, and photosynthesis, the third most required nutrient among the essential nutrients (Pettigrew, 2008). For cereal plants, the worldwide potassium use efficiency projects to be 19%, which is less than nitrogen (33%) and higher than phosphorus (16%) (Dhillon *et al*., 2019). The effectiveness of applied K utilization differs with diverse cropping systems, soil native supplying capability, rate, source, time, and technique of K application. These dynamics, with the variable soil K available, need attention when devising K-managing approaches in cropping systems (Singh *et al*., 2014, Singh *et al*., 2015b). For most crops, K fertilizer applied at once may result in lower KUE, as the K needs of plants differ with the crop growth pattern and nutritional requirements at different soil productivity levels and physiological stages of plants (Singh *et al*., 2021).

Globally, Pakistan is the eighth-largest wheat (*Triticum aestivum* L.) crop producer. Wheat cultivation is on 8.8 million ha, averaging a yield of 2,827 kg/ha (Economic Survey of Pakistan, 2020–2021). However, a large quantity of K requirement of wheat and a constant amount is essential until the tillering or reproductive phase of a crop ends. Applying K before or at the sowing time diminished it from the soil due to modifications to other K pools, which lowers its provision to complete the crop growth cycle. On the other hand, foliar spray of K provides an opportunity to avoid K deficiency, particularly at later growth phases when the basal application is ineffective (Singh *et al*., 2021).

Wheat requires high K demand for optimum crop productivity. Therefore, an appropriate K application needs to adopt the 4R (Right time, Right rate, Right method, Right source) nutrient stewardship approach in crops to guarantee high yield, optimal nutrient use efficiency, and enhanced farm income (Singh *et al*., 2021). Fertilizer application through the 4R nutrient stewardship framework came from scientific ideas to ensure proper absorption of nutrients at the right time and to limit their losses (Ramzan *et al*., 2020). The 4R nutrition framework for nutrient management has the potential to improve crop yields and quality while lowering production costs and labor requirements. This method can also reduce soil deterioration and nutrient losses, which is good for the environment. Expect better financial results as these benefits (Bryla, 2011).

The presented study evaluated the farmers' status, practice, and perceptions to integrate traditional knowledge in future project planning to develop a sustainable and cost-effective wheat cultivation system. The 4R nutrient management approach to nutrient stewardship is equally imperative in addressing the nutrient supply challenges, as the right source to choose at the right rate and applied at the right time and right place. Considering the above discussion, the presented research adjusted K nutrients in wheat cropping systems using the 4R nutrient control method. The recently designed study checked the growth and yield response of two wheat cultivars under basal and foliar application of K under the 4R nutrient management approach, assessing the right potassium source to apply at the right time under local climatic conditions.

MATERIALS AND METHODS

Details of experimental location

A pot experiment conducted during 2017–2018 at the College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan (32.07° N, 72.68° E), checked the efficacy of K fertilizer application using the 4R approach for the growth of wheat.

Experimental material

Two wheat cultivars (Punjab-2008 and Barani-2011) tested in this research consisted of their seeds obtained from Punjab Seed Corporation Faisalabad, Pakistan, with 80% moisture content.

Experimental design and treatments

The research employed a completely randomized design (CRD) with four repeats (10 treatments × 3 Sowing times × 2 Cultivars × 4 replications = a total of 240 pots). Two wheat cultivars, Punjab-2008 (Irrigated zone) and Barani-2011 (Arid zone) sown on three different sowing dates, including D_1: 15 November, D_2: 15 October, and D_3:15 December. Two sources of potassium application were MOP and SOP, applied at three rates (control, medium, and high) as basal and foliar application. The treatments comprised of control = recommended (N:P:K=0), SOP(L_1) = sulfate of potash + 0.975 g (low level), SOP(L_2) = sulfate of potash + 1.95 g (medium level), SOP(L_3) = sulfate of potash + 3.9 g (high level), MOP(L_1) = muriate of potash + 0.875 g (low level), MOP(L_2) = muriate of potash + 1.75g (medium level), MOP(L_3) = muriate of potash + 3.5 g (high level), F(1.5% SOP) = sulfate of potash + 1.5 % (foliar solution), F(1.5% MOP) = muriate of potash + 1.5% (foliar solution), F(3% SOP) = sulfate of potash + 3% (foliar solution), F(3% MOP) = muriate of potash + 3% (foliar solution).

Experimental protocol

The pots used size 30 cm × 24 cm in this experiment, with one hole at the bottom of each pot for proper water drainage. Each pot filled with 10 kg of air-dried, nutrient-rich sandy clay loam soil has five sown seeds of each wheat variety. The pots, kept in a growth chamber, received a set temperature (15 °C to 25 °C throughout the day) and relative humidity (5%). Thinning ensued to maintain one plant per pot for one week after germination. The uprooting of weeds (if they emerged) occurred manually from each pot. The physio-chemical properties of the soil appear in Table 1.

Data collection and measurements

Growth attributes

The root and shoot length (cm) was measured manually using a meter rod. The root/shoot ratio calculation followed the equation (root/shoot ratio = dry weight for roots/dry weight for the top of the plant). The measurement of root fresh and dry weight (g/plant), fresh and dry biomass (g/pot), 1000-grain weight (g/pot), and grain yield (g/pot) adopted standard procedures.

Physiological and biochemical traits

Determining total leaf chlorophyll contents (m µg/g F.W) employed the technique determined by Arnon (1949). The net photosynthesis rate (µ mol CO_2 m^{-2} s^{-1}) recording used a portable infrared gas analyzer (CI-340 Portable Photosynthesis System, CID Biosciences, USA) with the following modifications: atmospheric pressure - 98.9 kPa, mass flow rate - 0.29 mol m^{-2} s^{-1}, photosynthetically active radiation at leaf surface maximum up to 1389 µmol m^{-2} s^{-1}, and the temperature of the ambient air in the leaf chamber ranged from 23 °C to 34 °C.

Table 1. Analysis of the soil before the experiment

Soil properties	Units	Values
Sand	%	50
Silt	%	25.40
Clay	%	24.6
Soil texture	-	Sandy loam
EC	dSm^{-1}	2.01
Available K	ppm	130
CO_3^{-2}	meL^{-1}	0.51
CEC	$cmol_cL^{-1}$	13.0
HCO_3	meL^{-1}	2.44
Saturation percentage	%	33.0
Ca^{2+} + Mg^{2+}	meL^{-1}	10.1
Ph	-	7.88
SO_4	meL^{-1}	9.69
Cl^-	meL^{-1}	12.8
Organic matter	%	0.46
Soluble Na	meL^{-1}	16.9
Available P	mg kg^{-1}	5.2

EC: Electrical conductivity; K: Potassium; CO_3^{-2}: carbonate; CEC: cation exchange capacity; $HCO_3^{:}$ bicarbonate; Ca^{2+} + Mg^{2+}: Calcium + Magnesium; SO_4: Sulfate; Cl^-: Chloride; Na: Sodium; P: Phosphorus.

Working out the average, the water vapor pressure at the outlet of the leaf chamber ranged from 1.7 to 2.4 kPa. The obtained readings took place between 9:45 to 11:30 a.m., with completely stretched leaves designated for measurements. Water use efficiency (%) measurement utilized the following equation:

$$WUE = Y / ET$$

Where *WUE* (kg ha^{-1} mm^{-1}) is the water use efficiency for grain yield; *Y* (g $plant^{-1}$) is the grain yield at maturity; *ET* (mm) is the total crop evapotranspiration over the growing season of winter wheat. The leaf area index was restrained with a leaf area meter system (Leaf area meter AM 200), as determined by Beadle (1987). However, the proline contents of wheat calculation conferred to the procedures determined by Bates *et al*. (1973).

Statistical analysis

The analysis of variance (ANOVA) technique determined the statistical differences between the treatments under study, analyzing the statistical impact of generated data using the "Statistical Package for the Social Sciences" (SPSS) software package.. The comparison of treatment means also used the Least Significance Difference (LSD) test at a 0.05 probability level (Steel *et al*., 1997).

RESULTS

Growth parameters

The data regarding the impact of the 4R nutrition stewardship model on shoot length of wheat under different levels (low, medium, high), sources of potassium (SOP and MOP), sowing time, and mode of application portrayal is in Figure 1. The Punjab-2008 produced a longer shoot length than Barani-2011. The effect of sowing dates and treatments revealed significance. Sown wheat on 15 October (D_2) and 15 December (D_3) produced longer shoots (80.37 and 80.33 cm, respectively) than those on 15 November (D_1) (79.44 cm). Among treatments, SOP(L_3) had a higher shoot length than other treatments (Figure 1). Meanwhile, the noted minimum shoot length resulted from the control treatment (73.25 cm). Dates and wheat cultivars interaction showed that Punjab-2008 at D_1 and Barani sowed at D_3 indicated statistically equal shoot lengths (80.86 and 80.65 cm, respectively). Both wheat cultivars with no application of MOP or SOP and sown at D_1 and D_2 showed minimum shoot length (Figure 1).

Both tested wheat cultivars differed significantly in root length (Figure 2). The Punjab-2008 exhibited a higher root length (5.54 cm) than Barani-2011 (5.14 cm). Sowing of wheat at D_1 resulted in higher root length, while D_3 showed minimum root length. All the treatments of MOP and SOP resulted in an improvement in root length over control. However, the maximum root length measured in wheat plants occurred when fertilized with medium to high doses of MOP(L_2) and MOP(L_3) (Figure 2). The noted minimum root length was from the control treatment (3.74 cm).

Data regarding root-to-shoot ratio indicated that the wheat variety Punjab-2008 showed more root-to-shoot ratio than Barani-2011 (Figure 3). Among sowing dates, D_1 had more root-to-shoot ratio than D_2 and D_3. Similarly, the effect of treatments was significant, and all the treatments of MOP and SOP improved the root shoot ratio over the control treatment. The maximum root-to-shoot ratio measured emerged for low to high doses of MOP, whereas the minimum came from the control treatment. Both wheat cultivars had a higher root-to-shoot ratio when sown at D_1. The interactive effect of treatments with sowing dates showed that applying a low to a high level of MOP resulted in a greater root-to-shoot ratio, followed by F (1.5% SOP) (Figure 3).

The effect of sowing dates on the root fresh weight of wheat cultivars was non-significant (Figure 4). Similarly, wheat cultivars had a non-significant difference in root fresh weight. However, the interaction effect of treatments with sowing dates was noteworthy. Application of MOP(L_2) sowing at D_2 produced higher root fresh weight, which was equal to F (1.5% SOP), followed by F (3% SOP). But, the recorded minimum root fresh weight appeared for the control treatment (Figure 4).

Data about root dry weight indicated in Figure 5 showed that wheat sown at D_2 and D_3 resulted in higher root dry weight (3.05 g) over D_1 (2.56 g). Wheat variety Punjab-2008 produced more root dry weight (3.35 g) than Barani-2011 (2.44 g). Among the treatments, maximum root dry weight (6.12 g) surfaced for a high level of MOP, followed by a low to medium level of MOP, whereas the minimum observed showed for the control treatment (1.40 g). The interactive effect of D × V and V × T was non-significant, while D × T was significant. Wheat sowing at D_1, D_2, and D_3 using a high level of MOP resulted in maximum

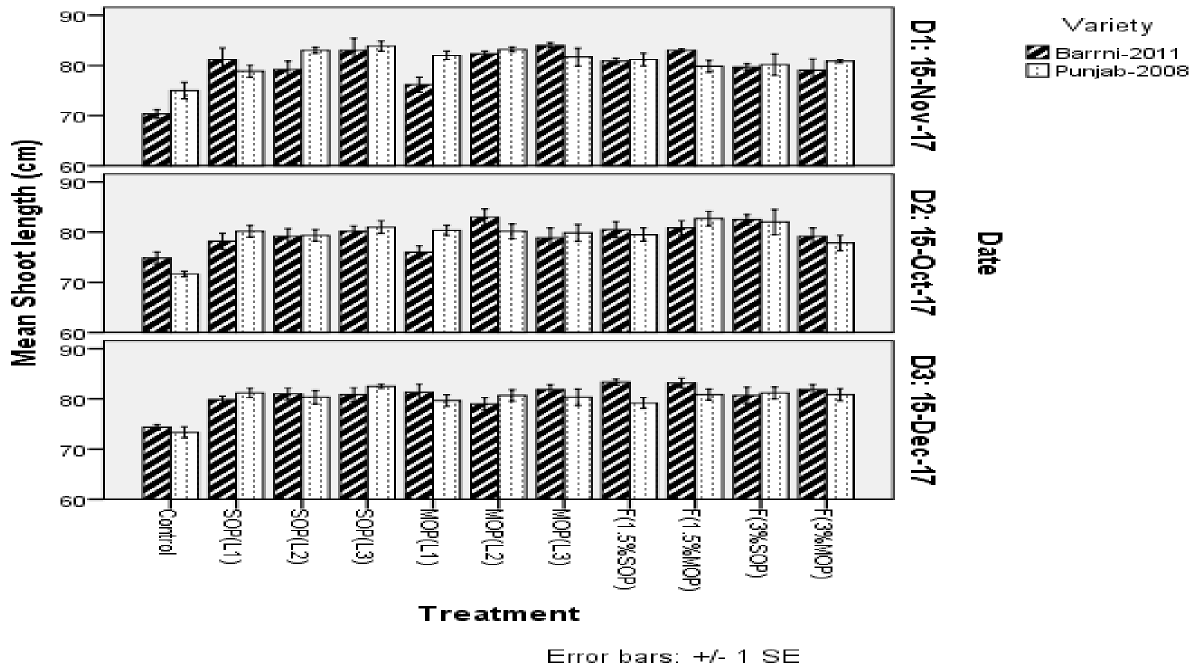

Figure 1. Effect of potassium nutrient management on shoot length of wheat by using 4R model under potted condition.

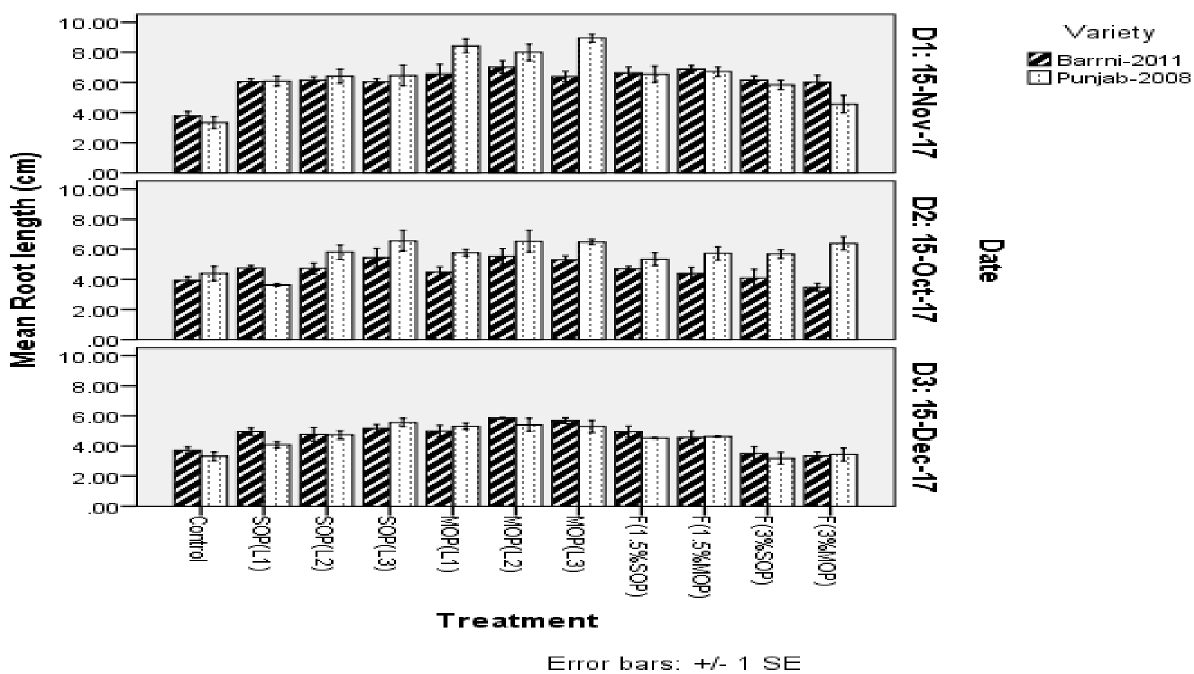

Figure 2. Effect of potassium nutrient management on root length of wheat by using 4R model under potted condition.

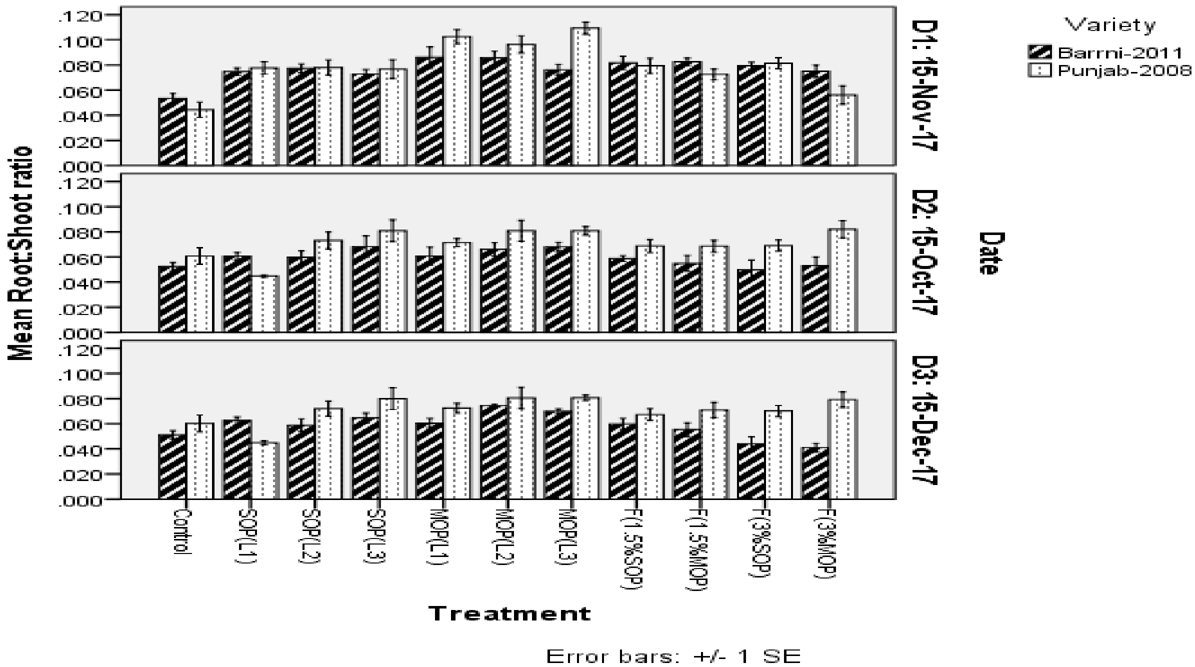

Figure 3. Effect of potassium nutrient management on root-to-shoot ratio of wheat by using the 4R model under potted condition.

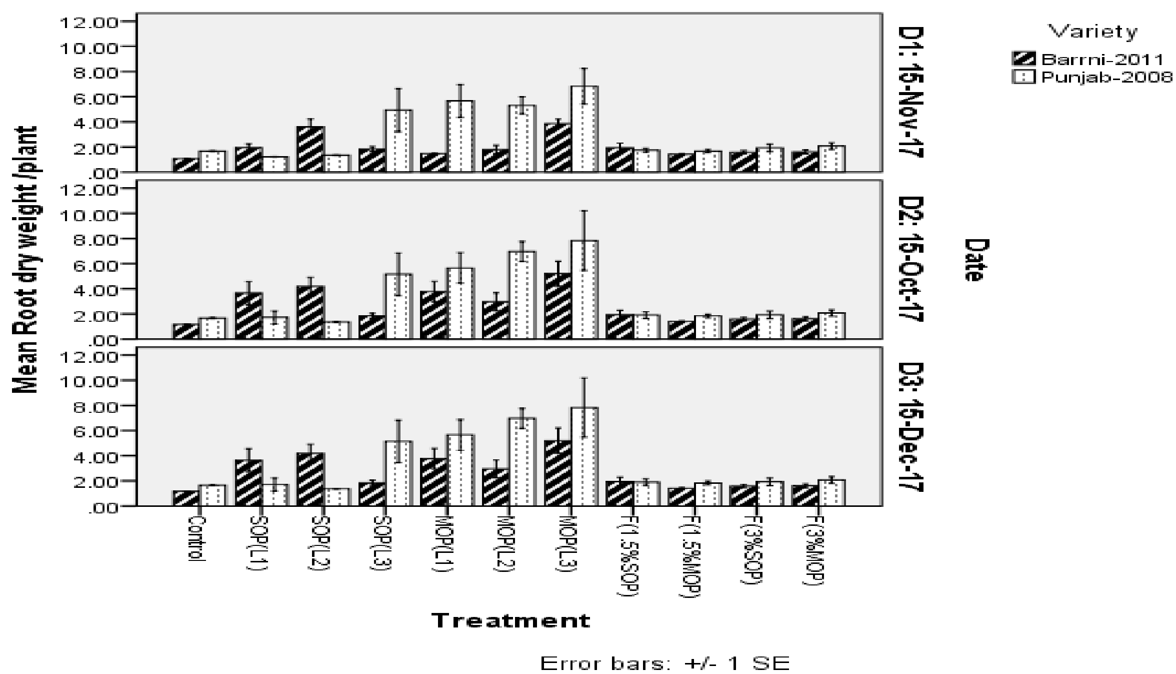

Figure 4. Effect of potassium nutrient management on root dry weight of wheat by using 4R model under potted condition.

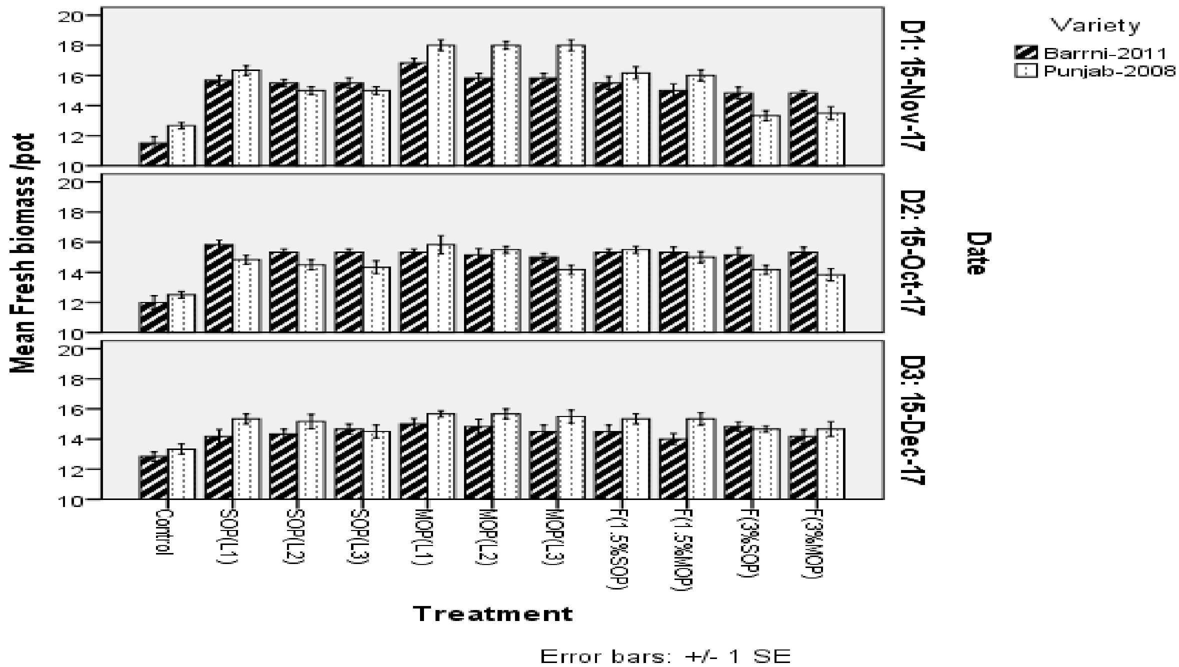

Figure 5. Effect of potassium nutrient management on fresh biomass of wheat by using the 4R model under potted condition.

root dry weight in both tested cultivars. Minimum root dry weight resulted from the control treatment under all sowing dates (Figure 5).

A significant difference between both wheat cultivars for fresh biomass came out (Figure 6). Lower fresh biomass (14.84 g pot^{-1}) materialized in Punjab-2008 than in Barani-2011 (15.07 g pot^{-1}). In the case of sowing times, the maximum fresh biomass (15.40 g pot^{-1}) of wheat turned up when sown at D_1, while D_2 and D_3 resulted in less fresh biomass (Figure 6). Among all the treatments of potassium, the application of MOP(L_1) and MOP(L_2) significantly enhanced the fresh biomass of wheat (16.11 and 15.83 g pot^{-1}, respectively). However, the wheat cultivars sown under control treatment (without SOP and MOP) showed minimum fresh biomass, followed by F (3% MOP).

Data related to the dry biomass of wheat exhibited that both Punjab-2008 and Barani-2011 cultivars showed similar dry biomass (Figure 7), whereas sowing of wheat at D_1 and D_3 produced higher dry biomass (4.55 g) than D_2. Significant differences arose among the treatments, and all the treatments influenced an improvement in the dry biomass of wheat over the control. The highest dry biomass of wheat recording came under the application of low to high levels of MOP(L_1), MOP(L_2), and MOP(L_3), and foliar spray of SOP at 1.5% and MOP at 3%, but the control treatment resulted in minimum dry biomass (2.41 g pot^{-1}), followed by SOP(L_1).

The impact of sowing dates on the 1000-grain weight of wheat was significant (Figure 8). The wheat crop planted at D_3 produced a higher 1000-grain weight statistically at par with D_2, while wheat cultivars sown during D_1 had a minimum 1000-grain weight. Among the tested wheat cultivars, Punjab-2008 produced a higher 1000-grain weight than Barani-2011. In the comparison of treatments, the application of SOP (L_1, L_2, and L_3) and MOP (L1, L2, and L3) had similar 1000-grain weight but higher from the wheat plants applied with F (1.5% SOP), F (1.5% MOP), F (3% SOP), and F (3% MOP). A minimum 1000-grain weight was an outcome for the control treatment.

The varietal and sowing date's impact on grain yield was also significant (Figure 9). Both wheat cultivars produced a higher grain yield when sown during D_1 and D_2, while recording minimum grain yield under D_3. The effect of treatment was significant; however, their interaction with sowing dates was non-significant. The use of MOP(L_3) produced a maximum grain yield equal to MOP(L_2),

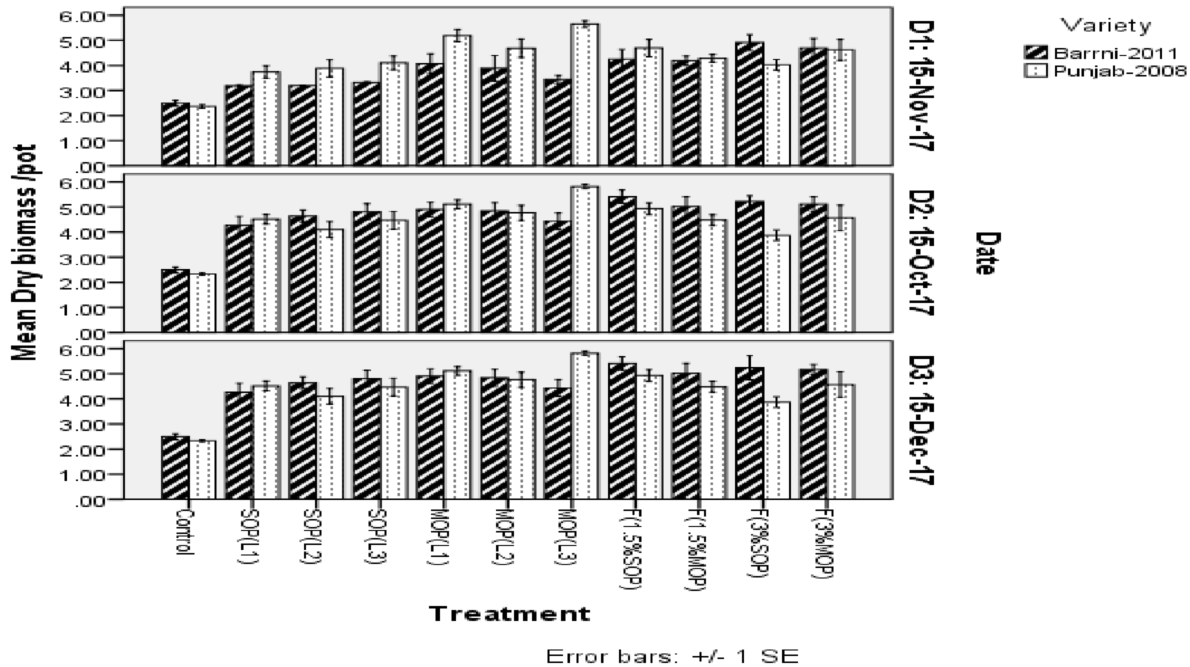

Figure 6. Effect of potassium nutrient management on dry biomass of wheat by using the 4R model under potted condition.

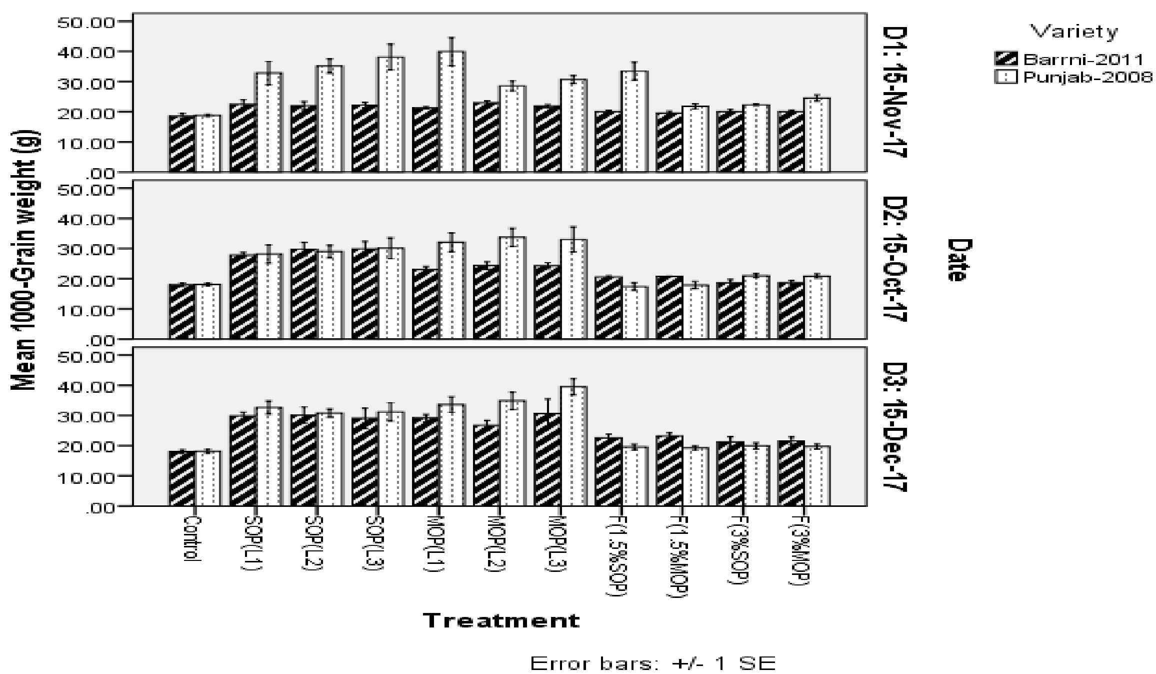

Figure 7: Effect of potassium nutrient management on 1000-grain weight of wheat by using the 4R model under potted condition.

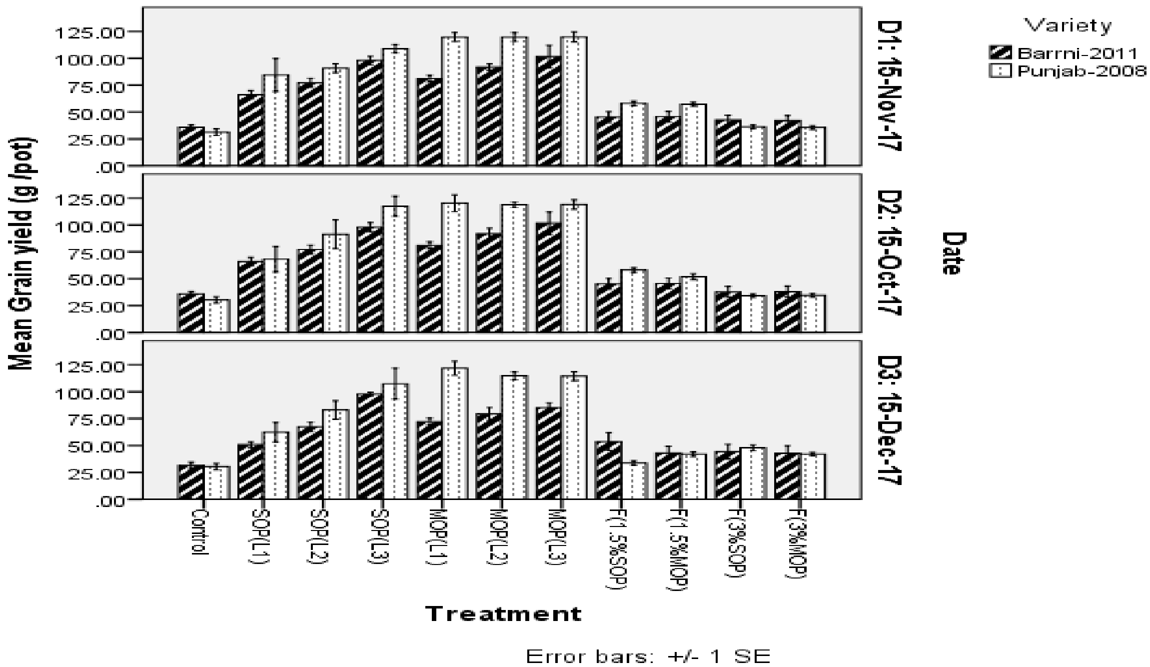

Figure 8. Effect of potassium nutrient management on grain yield of wheat by using the 4R model under potted condition.

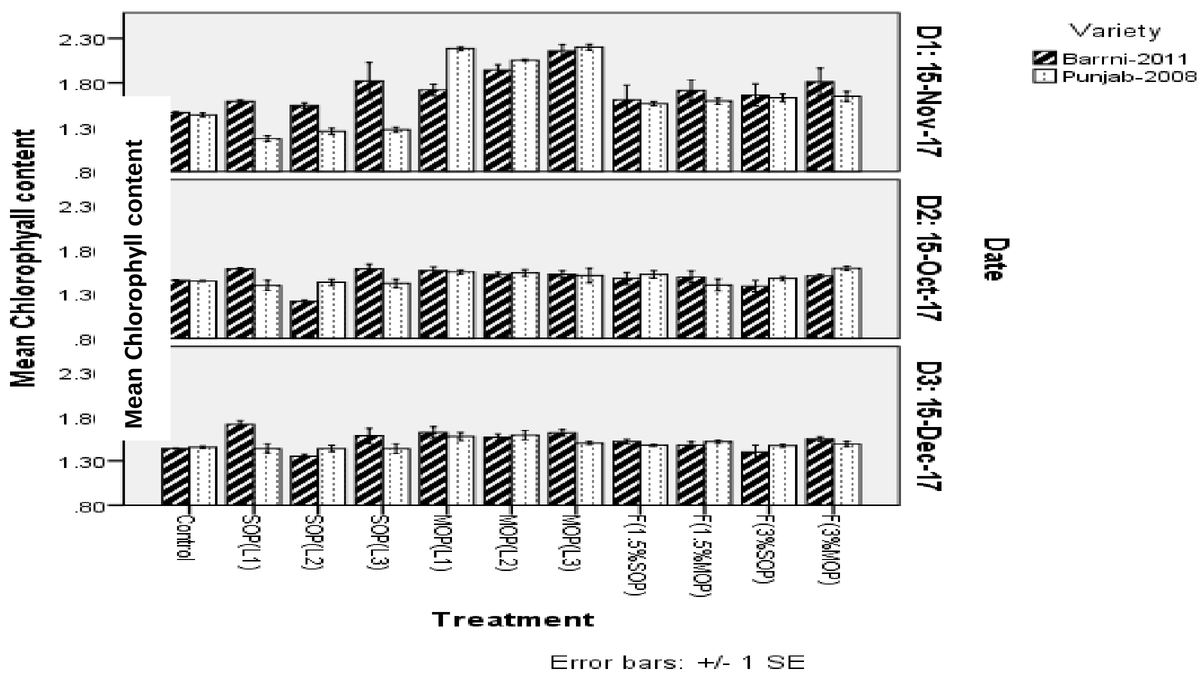

Figure 9. Effect of potassium nutrient management on total chlorophyll of wheat by using the 4R model under potted condition.

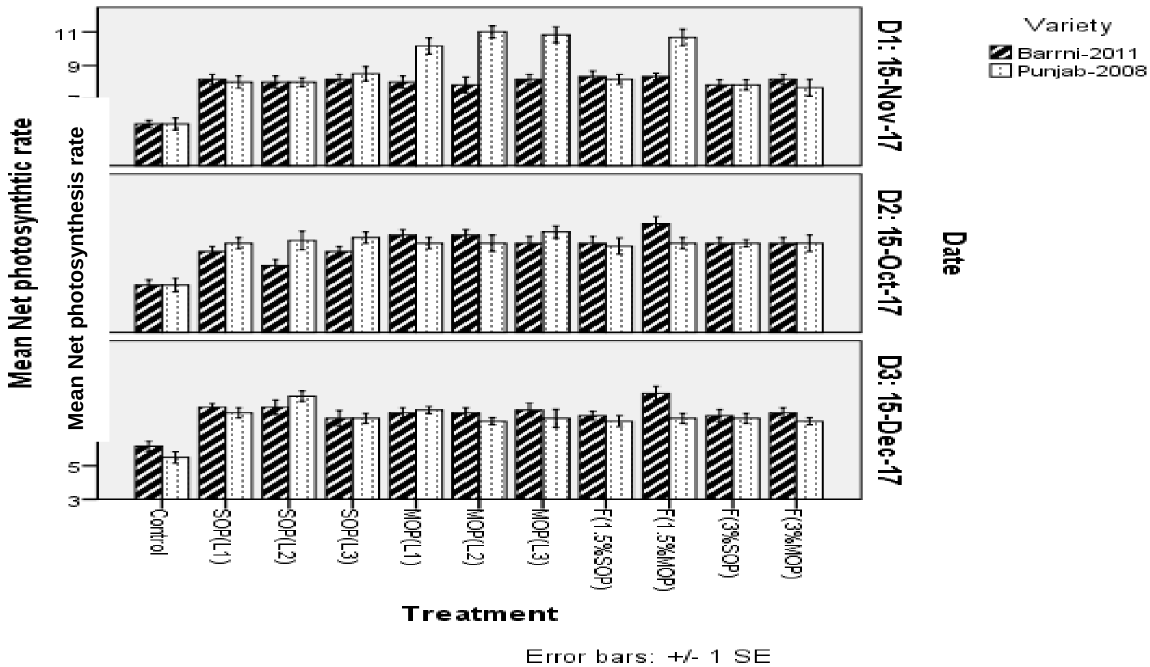

Figure 10. Effect of potassium nutrient management on net photosynthesis rate of wheat by using the 4R model under potted condition.

followed by MOP (L_1). Overall, minimum grain yield occurred in the control treatment with no SOP and MOP applied. Interactive effect of cultivars, treatments, and sowing dates (V × T × D) showed that Punjab-2008 with SOP (L_3), MOP (L_1), MOP (L_2), and MOP(L_3) gave similar and higher grain yield than any other treatment combinations (Figure 9).

Physiological and biochemical traits

Data regarding the total chlorophyll contents showed that Punjab-2008 had maximum total chlorophyll contents (1.580 μg/g of FW ± 0.017) compared with Barani-2011 (1.535 μg/g of FW ± 0.017). The effect of sowing dates was significant and maximum total chlorophyll content (1.684 μg/g of FW ± 0.030) recordings happened at the D_1 sowing of the crop, but D_2 and D_3 sown wheat had similar total chlorophyll contents (Figure 10). The potassium fertilizers (SOP and MOP) imparted significant impact, and maximum total chlorophyll contents (1.702 μg/g of FW ± 0.042 to 1.751 μg/g of FW ± 0.055) arose when applied with MOP at low to high levels. Noting minimum total chlorophyll contents took place under no application of MOP and SOP fertilizers (Figure 10). Interaction effect showed that application of MOP at high-level MOP (L_3) during D_2 resulted in maximum total chlorophyll contents (2.181 μg/g of FW ± 0.037).

The wheat variety Punjab-2008 recorded a maximum net photosynthesis rate (8.24 μ mol CO_2 m^{-2} s^{-1} ± 0.11) than Barani-2011 (8.02 μ mol CO_2 m^{-2} s^{-1} ± 0.08) (Figure 11). Among the sowing dates, wheat sown at D_2 and D_1 produced a higher net photosynthesis rate. In the comparison of treatments, the application of MOP from low to high levels and foliar application of MOP at 1.5% resulted in the maximum net photosynthesis rate of wheat (8.64 μ mol CO_2m^{-2} s^{-1} ± 0.18 to 9.00 μ mol CO_2m^{-2} s^{-1} ± 0.21 respectively), with all other treatments except control were non-significant with each other. Similarly, the interaction of sowing time and treatment showed that wheat sown at D_2 with low to high levels of MOP and foliar application of MOP at 1.5% gave the maximum net photosynthesis rate. However, the control treatment resulted in a minimum net photosynthesis rate at D_2.

Different doses of MOP and SOP influenced the wheat's water use efficiency (WUE) (Figure 11). Data designated that both wheat cultivars had a statistically non-significant difference for WUE. However, the wheat sown at D_1 and D_2 showed higher WUE

(47.94% to 48.90%) than at D_3 (47.51%). Similarly, among the treatments, the maximum WUE recorded for wheat plants resulted in low to medium levels of SOP fertilization, with the least WUE noted for the control treatment (39.11%). Interaction of D × T was significant, and wheat plants fertilized with low to high levels of SOP produced maximum WUE sown at D_1 and D_2. The least WUE recording appeared for wheat grown under control treatments (Figure 11).

Punjab-2008 (0.599 m/mol ± 0.006) produced more leaf area index (LAI) than Barani-2011 (0.588 m/mol ± 0.008) (Figure 12). Between the sowing dates, wheat sown on D_1 and D_3 had more LAI (0.599 m/mol ± 0.007) than on D_2 (0.584 m/mol ± 0.010). Medium application of MOP resulted in higher LAI compared with other treatments. However, among SOP treatments, medium to high levels of SOP application increased the LAI of wheat. The interactive effect of sowing dates, wheat cultivars, and treatments showed that Baran-2011 sown at D_1 with SOP(L_3) produced the maximum LAI (Figure 12).

Concerning proline contents, Barani-2011 produced more proline contents than Punjab-2008 (Figure 13). Between the sowing dates, D_2 and D_3 showed a higher proline (1.51 mg/g FW) than D_1 (1.44 mg/g FW). The proline content of wheat showed that MOP and SOP significantly improved the concentration of proline content (Figure 13). The effect of treatments on the proline content of wheat was significant, as well as the interaction of treatments. All the treatments increased the proline content in wheat over the control treatment. However, among the MOP and SOP treatments, the lowest proline content observed resulted in control (1.07 mg/g FW). Maximum proline content ensued for the application of SOP(L_3) and MOP(L_3), followed by all other treatments except F (3% MOP). The interaction effect of D × V shown in Barani-2011, sown at D_2 and D_3, and Punjab-2008, sown at D_1, has higher proline content (Figure 13).

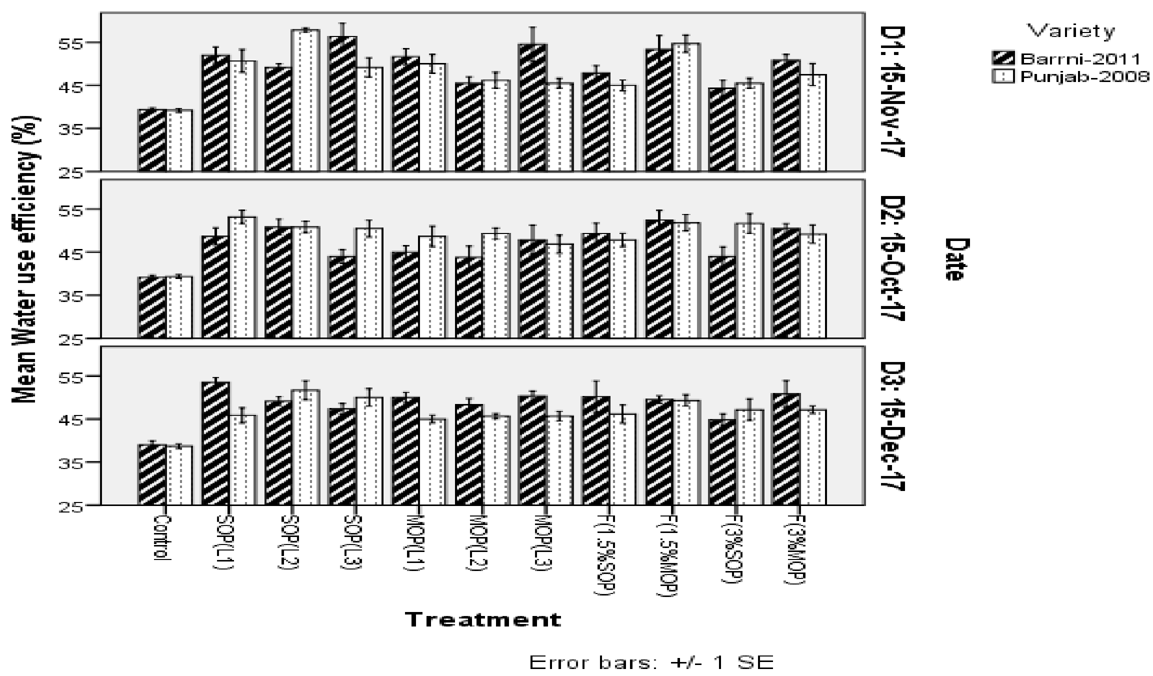

Figure 11. Effect of potassium nutrient management on water use efficiency rate of wheat by using the 4R model under potted condition.

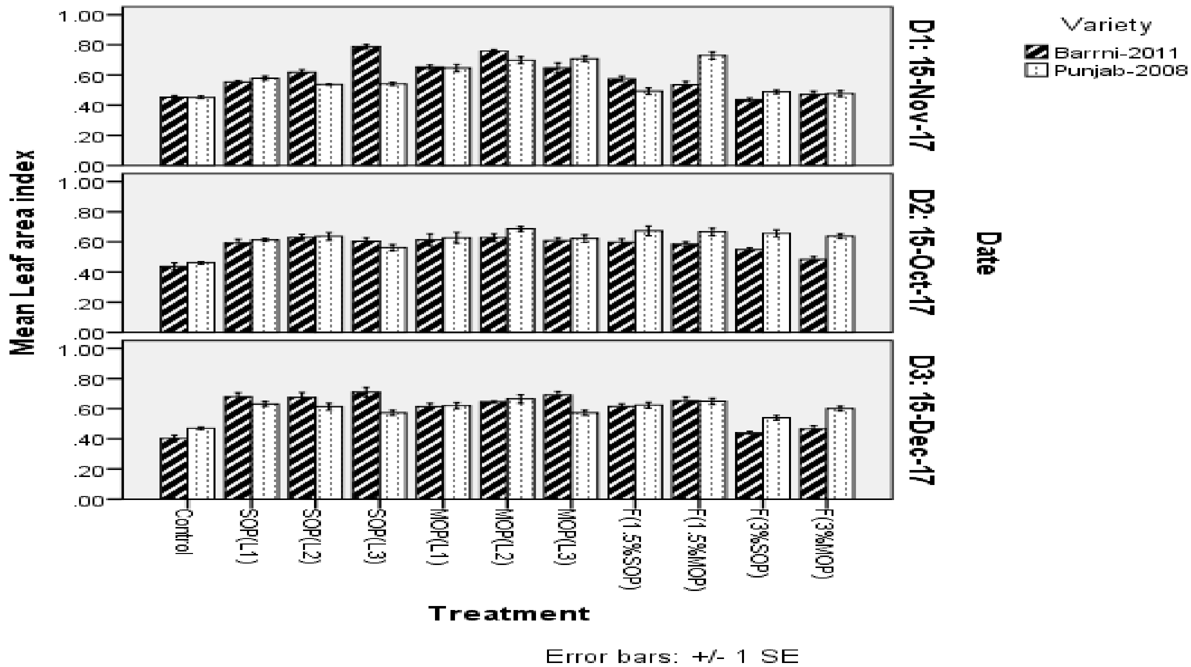

Figure 12. Effect of potassium nutrient management on leaf area index rate of wheat by using the 4R model under potted condition.

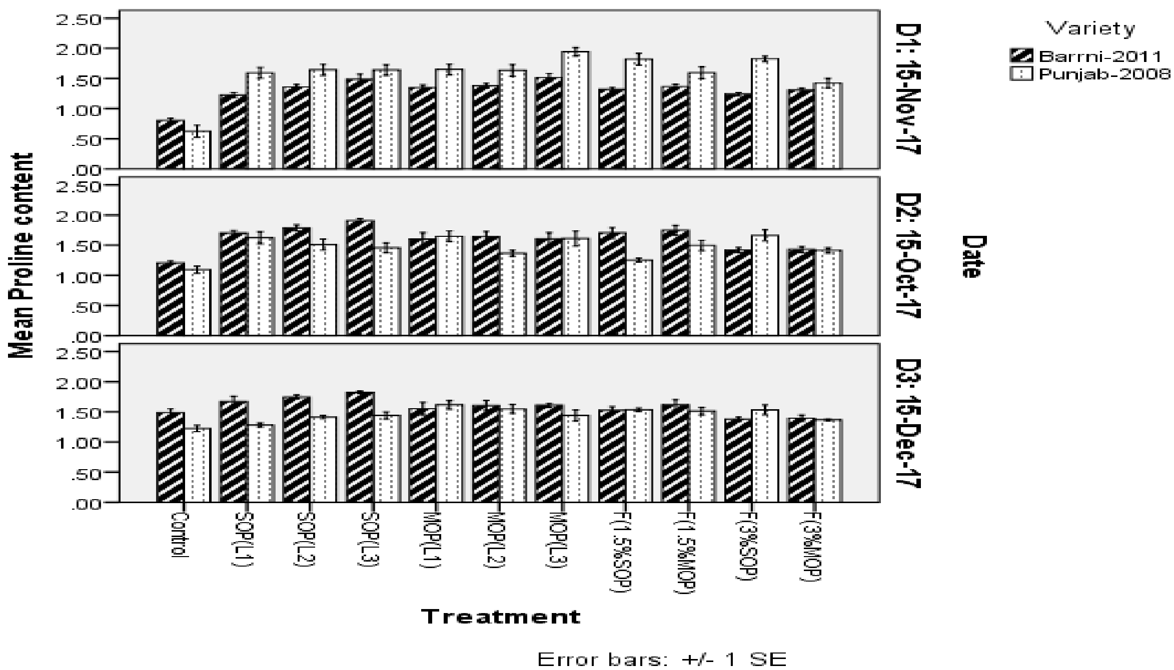

Figure 13. Effect of potassium nutrient management on proline contents of wheat by using the 4R model under potted condition.

DISCUSSION

The availability of K in agricultural soils is a multifaceted relation among properties of soil and management (Jones, 2019). It is very essential to consider both when determining the K nutrition approach. The crop yield response to potassium fertilization mainly depends on the potassium-delivering ability of soil (Schneider *et al*., 2003; Huang *et al*., 2009). The available K to plant only symbolizes a minor portion of the entire soil K. Efforts are underway to enhance the crop response to K fertilization (Jones, 2019). In this regard, the 4R nutrient stewardship approaches of the right source of K applied at the right rate at the right time and right place interacts with inherent soil properties to optimize K availability. The 4R Nutrient Stewardship is a new, innovative nutrient management approach for fertilizer best management practices adopted by the world's fertilizer industry.

In this experiment, applying two sources of K (SOP and MOP) imparts a constructive impact on both wheat cultivars. The increase in root and shoot length of Punjab-2008 occurred when planted on 15 October (D_2) and 15 November (D_1), with a high dose of SOP and MOP. It might be due to the optimum availability of K from soil to crop plant that improves the growth of both tested cultivars. Ali *et al*. (2019) indicated that an enhancement in the root and shoot length came out after a high dose of SOP. These results match the findings of Arif *et al*. (2017), who depicted that high-level MOP considerably enhanced the wheat shoot length. The findings further showed that applying a higher level of MOP effectively improved the root fresh and dry weight of both tested wheat cultivars when planted on D_2. These outcomes gained support from Baque *et al*. (2006), who mentioned an improvement in root fresh and dry weight after K application in wheat.

The study indicated that higher fresh and dry biomass of wheat could result from the basal application of medium to high levels of MOP due to the vigorous and timely obtainability of K fertilizer that the wheat plant quickly uptakes. Similar results came from Baque et al. (2006), who found that the dry weight of wheat enhanced considerably with K application. Other researchers, Arif *et al.* (2017) and Ali *et al*. (2019), also recorded an increase in the dry biomass of wheat when using higher rates of SOP and MOP. Alam *et al*. (2009) suggested that the fresh weight of wheat increased when applied with a high dose of K.

The higher levels of SOP and MOP caused a significant improvement in 1000-grain weight and grain yield of Punjab-2008 when sown on D_2. The boost in wheat yield was due to K fertilization at the right time, rate, and source. Various studies showed that a balanced supply of N, P, and K could increase crop yield (Wang *et al*., 2007, 2010). Arif *et al*. (2017) and Khan *et al*. (2007) reported obtaining a higher 1000-grain weight of wheat after MOP application. Similarly, the outcomes of Ali *et al*. (2019) exhibited that the grain yield of wheat recorded maximum with a higher dose of K.

The potassium fertilizers (SOP and MOP) exhibited an impact on the total chlorophyll contents of both wheat cultivars when sown on D_1. The increase in the total chlorophyll contents of wheat due to K application plays a critical role in the activation of enzymes and phloem loading, as well as, in the photosynthesis of plants (Pettigrew, 2008). Said findings received support from Ali *et al.* (2019), who already noted that acquiring higher total chlorophyll contents of wheat emerges when applied with SOP at a medium rate. In the study, a significant positive response of K fertilization turned out in terms of net photosynthesis rate and water use efficiency (WUE) in Barani-2011 cultivars. It may be due to the genetic characteristics of the Barani-2011 variety, applied with the right sources (SOP and MOP) of K at the right time and rate. The K is one of the critical nutrient essentials for wheat plants, possessing primary roles in the processes of cell extension and osmoregulation, stomatal movement, protein synthesis, activation of enzymes, phloem loading, photosynthesis, transport, and uptake (Marschner, 1995; Pettigrew, 2008). Meena *et al*. (2020) reported that the WUE of wheat increased significantly with foliar application of K. Alike, Wang *et al*. (2020) documented that a higher net photosynthesis rate appears when applied with a high dose of K.

Study results indicated that the wheat variety Barani-2011 sown on D_1 with a high basal dose of SOP produced maximum LAI, and proline content was higher when applied with SOP(L_3) and MOP(L_3). It might be due to the optimum availability of K with basal and foliar application of SOP and MOP. Singh *et al*. (2021) reported that plants require K in large quantities, imparting a positive impact on different metabolic processes. Analogous results from Ali *et al*. (2019) observed that the maximum LAI of wheat occurred when applied with a high dose of SOP. Seleiman *et al*. (2020) mentioned that the K application showed better for the proline content enhancement of the wheat crop. Selecting the right K source requires reflection on crop demands, cost, sensitivities, and accessibility. However, knowing when to apply the K guarantees one to measure the soil supply and encounters the crop demands at the right time. Similarly, enhancing the capability of crop roots to consume the K more efficiently when applying it at the right place is economically and agronomically more effective for crop growth and yield.

CONCLUSIONS

The Punjab-2008 performed better in wheat growth and yield attributes, while Barani-2011 found it efficient for physiological and biochemical traits. However, both cultivars gave the best results when sown on 15 November. The medium to higher doses of SOP and MOP (basal or foliar) application improved the growth and yield of both wheat cultivars. The Punjab-2008 produced maximum leaf area index and proline, while Barani-2011 gave higher net photosynthesis rate and water use efficiency under medium and higher levels of SOP, respectively.

REFERENCES

Alam MR, Ali MA, Molla MSH, Momin MA, Mannan MA (2009). Evaluation of different levels of potassium on the yield and protein content of wheat in the high Ganges river floodplain soil. *Bangladesh J. Agric. Res.* 34(1): 97-104.

Ali I, Khan AA, Munsif F, He L, Khan A, Ullah S, Ligeng J (2019). Optimizing rates and application time of potassium fertilizer for improving growth, grain nutrients content, and yield of wheat crop. *Open Agric.* 4(1): 500-508.

Arif A, Wang Z, Wang J, Mather B, Bashualdo H, Zhao D (2017). Load modeling-A review. *IEEE Trans. Smart Grid.* 9(6): 5986-5999.

Arnon DI (1949). Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.* 24(1): 1-15.

Baque MA, Karim MA, Hamid A, Tetsushi H (2006). Effects of fertilizer potassium on growth, yield, and nutrient uptake of wheat (*Triticum aestivum*) under water stress conditions. *S. Pac. Stud*. 27(1): 25-35.

Bates LS, Waldren RP, Teare ID (1973). Rapid determination of free proline for water-stress studies. *J. Plant & Soil*. 39(1): 205-207.

Beadle CL (1987). Plant Growth Analysis. In: JDO Coomlos, SP Long, JMO Scurlock (eds.), Techniques in Bio-productivity and Photosynthesis, 2nd Ed. Pergamon Press, Oxford, New York. pp: 21-23.

Bryla DR (2011). Application of the "4R" nutrient stewardship concept to horticultural crops: Getting nutrients in the "right" place. *J. Hortic. Techn.* 21(6): 674-682.

Dhillon JS, Eickhoff EM, Mullen RW, Raun WR (2019). World potassium use efficiency in cereal crops. *J. Agron.* 111(2): 889-896.

Economic Survey of Pakistan (2020–2021). Pakistan Bureau of Statistics.

Huang SW, Jin JY, Tan DS (2009). Crop response to long-term potassium application as affected by potassium-supplying power of the selected soils in Northern China. *Commun. Soil Sci. Plant Anal*. 40(17-18): 2833-2854.

Jones BJD (2019). Potassium availability: Synchronizing nutrient supply and plant demand through 4R nutrient stewardship. *J. Soils Crop.* 52(6): 26-29.

Khan R, Gurmani AR, Gurmani AH, Zia MS (2007). Effect of potassium application on crop yields under wheat rice system. *Sarhad J. Agric*. 23(2): 277-285.

Marschner H (1995). Mineral Plant Nutrition of Higher Plants, 2nd Ed. Academic Press, London.

Meena RP, Venkatesh K, Khobra R, Tripathi SC, Prajapat K, Sharma RK, Singh GP (2020). Effect of rice residue retention and foliar application of K on water productivity and profitability of wheat in North West India. *J. Agron.* 10(3): 434.

Pettigrew WT (2008). Potassium influences yield and quality production for maize, wheat, soybean, and cotton. *Physiol. Plant.* 133(4): 670-681.

Ramzan H, Tahir MA, Abbas G, Mehmood T (2020). Potassium nutrient management in wheat through 4R nutrient stewardship. *J. Agric. Environ. Sci.* 22: 10-16.

Salim N, Raza A (2020). Nutrient use efficiency (NUE) for sustainable wheat production: A review. *J. Plant Nutr*. 43(2): 297-315.

Schneider A, Castillon P, Pellerin S (2003). Relationships between soil potassium supply characteristics based on soil solution concentration and buffer power and field responses of winter wheat and maize. *Plant and Soil*. 254(2): 269-278.

Singh VK, Dwivedi BS, Rathore SS, Mishra RP, Satyanarayana T, Majumdar K (2021). Timing potassium applications to synchronize with plant demand. *Improving Potassium Recommendations for Agricultural Crops*. 363-384.

Singh VK, Dwivedi BS, Tiwari KN, Majumdar K, Rani M, Singh SK, Timsina J (2014). Optimizing nutrient management strategies for the rice-wheat system in the Indo-Gangetic Plains of India and adjacent regions for higher productivity, nutrient use efficiency, and profits. *Field Crops Res.* 164: 30-44.

Singh VK, Shukla AK, Dwivedi BS, Singh MP, Majumdar K, Kumar V, Singh SK (2015a). Site-specific nutrient management under rice-based cropping systems in Indo-Gangetic Plains: Yield, profit and apparent nutrient balance. *Agric. Res.* 4(4): 365-377.

Singh VK, Shukla AK, Singh MP, Majumdar K, Mishra RP, Rani M, Singh SK (2015b). Effect of site-specific nutrient management on yield, profit and apparent nutrient balance under pre-dominant cropping systems of Upper Gangetic Plains. *Indian J. Agric. Sci*. 85: 335-343.

Steel RGD, Torrie JH, Dicky D (1997). Principles and Procedures of Statistics. Multiple comparisons. 3rd Ed. McGraw Hill Book Co., New York, USA. pp. 178-198.

Swailam MA, Mowafy SAE, El-Naggar NZA, Mansour E (2021). Agronomic responses of diverse bread wheat genotypes to phosphorus levels and nitrogen forms in a semiarid environment. *SABRAO J. Breed. Genet.* 53: 592-608. https://doi.org/10.54910/sabrao2021.53.4.4.

Syers JK (2003). Potassium in soils: Current concepts. In: AE Johnston (ed.) Feed the soil to feed the people: The role of potash in sustainable agriculture. Proceedings of IPI Golden Jubilee Congress 1952–2002, Basel, Switzerland, 8–10 Oct 2002. International Potash Institute, Basel, Switzerland, pp 301-310.

Timsina J, Kumar Singh V, Majumdar K (2013). Potassium management in rice-maize systems in South Asia. *J. Soil Sci. Plant Nutr*. 176(3): 317-330.

Wang X, Cai D, Hoogmoed WB, Perdok UD, Oenema O (2007). Crop residue, manure and fertilizer in dryland maize under reduced tillage in northern China: I grain yields and nutrient use efficiencies. *Nutr. Cycl. Agroecosystems*. 79(1): 1-16.

Wang Y, Wang E, Wang D, Huang S, Ma Y, Smith CJ, Wang L (2010). Crop productivity and nutrient use efficiency as affected by long-term fertilization in North China Plain. *Nutr. Cycl. Agroecosystems*. 86(1): 105-119.

Wang Y, Zhang Z, Liang Y, Han Y, Han Y, Tan J (2020). High potassium application rate increased the grain yield of shading-stressed winter wheat by improving photosynthesis and photosynthate translocation. *Front. Plant Sci.* 11: 134-144.