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CARBON-SEQUESTERING FERTILIZERS USAGE TO BOOST POTASSIUM EFFICIENCY IN WHEAT GROWTH UNDER SALINE CONDITIONS

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SUMMARY

Potassium (K) is a crucial element required for the healthy growth of plants, as it activates many enzymatic reactions in the plant body. Nowadays, K-deficiency is widespread worldwide. The high cost of potassium fertilization and less awareness about the pros of external nutrition from K fertilizer application are possible reasons for K-deficient soils in Pakistan. Efforts are ongoing to improve the potassium use efficiency (KUE) and bioavailability of K from commercial potassium sources. Therefore, a field experiment commenced to minimize the bioavailable K losses using carbon sequestering fertilizer (CSF) under saline soil conditions (4 dS m^{-1}) using wheat as a test crop in Pind Dadan Khan, Punjab, Pakistan. The experiment ran in a three-replication randomized complete block design (RCBD) statistical scheme using four treatments, i.e., T1 = Control; T2 = Filter cake press mud (FCP) as CSF; T3 = Sulphate of potash (SOP); and T4 = SOP + FCP, using two wheat varieties, namely, Faisalabad 2008 (FSD-08) and Chakwal-50. Results implied that SOP application in combination with FCP (T4) performed best treatments with Faisalabad 2008 as the better variety than Chakwal-50 under saline growth environment. Maximum spike length (8.85 cm), the number of grains/spike (45), shoot dry weight (2.75 g), soil K contents (310 ppm), soil C content (1.03%), chlorophyll content (2.18 μmol m^{-2}), and H-ATPs (99.5) resulted in Faisalabad 2008 when applied with the combination of SOP and FCP (T4). Thus, the combined application of mineral and organic sources of CSF improved the wheat growth parameters and nutritional status of the soil.

Keywords: Carbon sequestering fertilizer, saline soil, potassium fertilizer, wheat

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Key findings: Salinity stress severely affects the growth and quality of wheat. The K fertilizer application improved wheat crop quality, yield attributes, and survival in salinity stress scenarios. Combining K fertilizers with organic amendments helps improve K use efficiency and K bioavailability from commercial K sources. Among commercial K sources, SOP performed best in supporting wheat growth under a saline environment.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is an extensively cultivated crop across the globe and ranks among the top three most produced crops after corn and rice, but in Pakistan, it is the topmost crop grown due to high nutritional contents and grains (Ikhtiar and Zeb, 2007). It is a widely domesticated food crop that remains the chief staple food, used in producing biscuits, bread, feeds, and confectionary products in West Asia, European nations, and North Africa for the past 8000 years. Approximately 20% of the total arable land in the world is under wheat (Shiferaw *et al*., 2013). The crop's history dates back more than ten millennia ago (Smith *et al*., 2015). Bread wheat is the staple food crop and the most notable source of nutrition for the inhabitants of Pakistan. Its planting in Pakistan starts in November, and harvesting by the end of April (Ahmad, 2009). Pakistan has a reported average yield of wheat at about 2.38 MT/ha, which is extremely low compared with other wheat-producing countries in the world like Denmark, the United Kingdom, Ireland, France, Egypt, and Saudi Arabia, which have 7.86, 7.83, 7.78, 6.23, 6.15, and 4.48 MT/ha, respectively (Khan and Tariq, 2014).

Population pressure in Pakistan is multiplying day by day. With wheat considered a staple in Pakistan, this cultivated crop can fulfill 60% of the dietary requirements per capita. However, the per-acre yield is the lowest compared with other countries (Akram *et al*., 2012). Moreover, a yield gap of around 60% exists in wheat productivity due to reduced yields. The foremost reason for low output and instability comprises delayed cropping of Kharif crops, followed by late sowing of wheat, the non availability of inputs (seed and fertilizer application), weeds, insufficient irrigation water, drought, soil degradation, and weak extension services system (Khan *et al*., 2021). Therefore, it is urgent to focus on wheat yield improvement in salt-affected soils to fulfill the food demand for a growing population (Alam *et al*., 2000; Sabah *et al*., 2020).

Pakistani soils are facing severe issues of salinity and sodicity, which increase daily for two main reasons: brackish tube well irrigation and canal water shortage. There are 6.30 M ha of salt-affected lands. The magnitude of the problem can refer to the area of productive land engulfed by salinity at the rate of 60,000 ha/annum. Salts negatively affect growth parameters, such as, leaf count, expansion area, photosynthetic ability, and thus overall wheat yield (El-Hendawy *et al*., 2005; Safaa *et al*., 2013). The saline growth environment reduced the production of many cereal crops, including wheat. Slowed growth in saline-soil conditions resulted from many biochemical and physiological changes (Seleiman *et al.*, 2022). Plants' salt uptake reduced turgidity, photosynthesis, and activity of enzymes (Safaa *et al.*, 2013). A negative influence of salinity on the stomatal opening and photosynthetic activity has ultimately weakened photosynthate assimilation. Salt content increase in growth media lowered the cell turgidity and caused the closure of stomata, leading to low light absorption by leaves and, eventually, low photosynthate production. Furthermore, a decline in the translocation of assimilated products occurs under salinity stress. An inhibited germination and growth, hormonal imbalance, oxidative stress, and yield reductions are the possible outcomes of plant exposure to saline growth media (Majeed, 2018; Saddiq *et al*., 2021; Seleiman *et al*., 2022).

Plants need balanced nutrition; therefore, they uptake nutrients from the soil essential for growth; one of these is K, one of the 19 crucial elements. Potassium is a vital element required for the healthy progress of plants, as it activates many enzymatic reactions in the plant body. Nowadays, a marked deficiency of bioavailable K occurs worldwide, and scientists are working on its continuous availability. Like other living organisms, plants also require nutritional balance. Hence, they absorb nutrients from the soil for plant growth. The importance of potassium can be well-defined by studying its functions, including enzyme activity and balance of charge in plants. Potassium is among the abundantly prevailing soil macronutrients in Pakistan. However, an occurring prodigious amount of K in the soil is undesirable until its availability because clay minerals, present in these soils, fix a vast amount of K, and this potassium is unavailable to plants for their growth-less K fertilization. Tube-well irrigation water is the other major factor for low crop yields and depleting K resources in developing countries. With excessive cropping intensity and an exhaustive decrease in the available potassium contents in the soil, insufficient K fertilizers and their maximum uptake create a harmful scenario for sustainable agriculture for Pakistani farmers (Wakeel *et al*., 2017).

Viable potassium management at various soil positions necessitates a considerate relationship between crop production and enduring K fertilization. The response of wheat grains, K efficiency, and fractional balance at five different idiosyncratic agro-ecological zones in China gained analysis. In comparison to phosphorus (P) and inorganic nitrogen (N) impregnation, the inorganic NPK fertilization considerably increased the yield of wheat, where soils have little exchangeable and non-exchangeable K contents (Zhang *et al*., 2011).

Reducing these nutrient deficiencies created by salinity could succeed by adding fertilizers. Correlating, the K role in plant physiology under stressful environments is well identified (Krauss, 2003; Gupta and Haung, 2014). Augmenting nutrients, particularly NPK, is imperative under salt-stress conditions (Noaman, 2004). The role of K in the physiological functioning of plants like wheat is well known (Saifullah *et al*., 2002). Several biochemical and physiological functions, such as, the activity of specific enzymes involved in photosynthesis, synthesis of proteins, osmoregulation, transfer of energy, stomatal opening and closing, ionic balance, and resistance under stress environment bore control from K availability (Golldack *et al*., 2003; Ashraf *et al*., 2013; Wang *et al*., 2013). The growth and survival of plants under salt stress could be improved through better soil fertility and the proper management in reducing salt content from growth media (Idrees *et al*., 2004). Concerning this, an efficient system that contributes to salt tolerance in plants is a K ion uptake over Na ions (Wenxue *et al*., 2003; Kausar *et al*., 2014). The function of K in maintaining osmotic adjustment under salt stress is also notable (Kausar *et al*., 2014; Ashraf and Sarwar, 2002). A deficiency of K results in the stomata closure, reducing the photosynthetic ability of plants. Similarly, several researchers have reported the role of K in wheat development and yield (Mesbah, 2009).

Organic manure is a valuable and cheap source of fertilizer and source of plant nutrients. Several studies have proven its good effect on soil (Oldare *et al.*, 2007). According to experimental findings, organic compost can enhance soil K uptake, significantly impacting soil K availability (Omondi *et al*., 2016). Salt-affected soils show better crop production with compost and biofertilizer treatment, enhancing soil physicochemical properties (Sabah *et al*., 2020). Therefore, this study’s undertaking had field conditions to evaluate the role of carbon-sequestrating fertilizer in minimizing the bioavailable losses from commercial K nutrition sources and improving K-acquisition by growing wheat under a saline environment.

MATERIALS AND METHODS

The research sought to find positive paybacks of carbon-sequestration fertilizers (CSF) on the development of different wheat varieties by mitigating bioavailable K losses and, thereby, enhancing the bioavailability of K in the growth environment using CSF under saline conditions. The experimental period was from sowing to maturity (120 days).

Climatic conditions of experiment site

The field experiment transpired at the Nadeem Zarai Farm (Latitude 32.56, Longitude 72.55), Lila Road, Pind Dadan Khan, Punjab, Pakistan. Pind Dadan Khan has a climate of extreme heat, with an annual highest temperature averaging 41.7 °C (107.1 °F), and the average yearly lowest temperature is 4.9 °C (40.8 °F), with an annual rainfall mean of 27 mm.

Experimental layout and treatments

Four treatments with three replications ensued using RCBD. The treatments include T1 = Control; T2 = Filter cake press mud (FCP) as CSF; T3 = Sulphate of potash (SOP); and T4 = SOP + FCP using two wheat varieties, namely, Faisalabad 2008 (FSD-08) and Chakwal-50. Table 2 provide information about physio chemical analysis of various organic materials used for study.

Soil and plant analysis

The research used the standard procedure in Handbook 60 for collecting and analyzing soil and plant samples. Pre experiment analysis of soil is provide in Table 1. Data recording occurred for parameters, such as, plant height, spike length, 1000-grain weight, the number of grains per spike, potassium and sodium in wheat straw, soil K content, soil Na content, and ionic content. Employing the Jenway Model PFP-7 equipment, measured the soluble sodium in soil sample extracts while the flame photometer calibration continued using standards made with sodium chloride salt. Then, determining the extract's soluble sodium engaged the method 10a of Handbook 60. Flame photometer (Jenway Model PFP-7) usage also determined the K in soil extracts using ammonium acetate (1*N*) for the extraction of K from soil (Method18, P 100, Handbook 60). Organic matter percentage determination followed the process described by Walkley and Black (1934) in the soil. Wet digestion technique application helped the analysis of plants and organic materials. Plasma membrane stability acquisition by estimation of electrolyte leakage used the method suggested by Sun *et al.* (2006). Wheat leaf washing and segmenting used the rotary shaker (100 rpm) at room temperature to remove solutes generated from the leaf surface due to cell damage. The LF 92 conductivity meter aided in measuring the electrolyte leakage at various washing intervals (0, 15, 30, 45, 60, 75, and 90 min). Acetone solution with a concentration of 85% rinsed chlorophyll based on Mackinney's work and measuring its absorbance employed the Campspec M501 Single Beam UV/vis Spectrophotometer at λ = 663 nm and λ = 645 nm (Arnon, 1949).

Table 1. Analysis of experimental soil.

Soil Parameters	Unit	Value
Saturation percentage	%	29
pHs	-	7.9
ECe	dS m^{-1}	4.9
Bicarbonates (HCO_3^{2-})	mg/kg	
Chlorides (Cl^{1-})	mg/kg	178.9
Sulphates (SO_4^{2-})	mg/kg	590.35
Calcium + Magnesium (Ca^{2+}+ Mg^{2+})	mg/kg	1720.34
Sodium (Na^+)	mg/kg	810.4
Textural class	-	silt loam
Organic matter	%	1.8
Available Phosphorus/ Olsen P	Ppm	190
Total Phosphorus	Ppm	9.6

Table 2. Carbon sequestering fertilizer (press mud) analysis.

Parameters	Unit	Values
pH (1:1)	-	7.59
Organic matter	%	31.1
Organic carbon	%	17.12
Total nitrogen	%	1.54
C/N ratio	%	10.5
Total phosphorus	%	1.22
Potassium	%	0.48

Statistical analysis

All collected data underwent the statistical analysis of variance (ANOVA) from the experiment in RCBD, with three replications. Treatment comparisons between the potassium fertilizers and organic amendments used contrasts, including further necessary semblances. All treatment means, subjected to LSD and statistical analysis, ensued on the R-software (Steel *et al.*, 1997).

RESULTS

Agronomic data

Shoot dry weight (g)

The data regarding the effect of filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on shoot dry weight (SDW) (Figure 1) implied that the wheat variety FSD-08 achieved maximum SDW (2.75 g) in the treatment T4 receiving a combination of SOP and FCP. On the other hand, the minimum shoot dry weight (1.80 g) emerged in the control treatment (T1). Using SOP and FCP separately gave a 2.64 and 2.20 g SDW, respectively. Both genotypes showed statistically non significant results at a probability level of 0.05 under saline soil conditions in the field. In the case of Chakwal-50, the treatment T1 (control) provided a minimum SDW of 1.03 g. Contrastingly, the combined use of SOP and FCP resulted in a maximum SDW of 1.25 g compared with the sole use of FCP (1.13 g SDW) and SOP (1.16 g SDW).

Number of grains per spike

The data on FCP, SOP, and FCP+SOP effects on the number of grains per spike (Figure 2) indicated that wheat variety FSD-08 performed better than Chakwal-50. In the case of FSD-08, the minimum number of grains per spike (34) appeared in the control treatment (T1). Contrarily, the maximum number of grains per spike (45) occurred with the combined application of SOP and FCP. SOP and FCP use alone resulted in 41.17 and 37 grains per spike, respectively. Both genotypes showed statistically non significant results at a probability level of 0.05. In the case of Chakwal-50, the control treatment showed 33.67 grains per spike, reaching a maximum number of grains per spike (42.5) in T4 (SOP+FCP). Application of FCP and SOP alone produced 36.60 and 37.97 grains per spike, respectively.

Spike length (cm)

The data concerning the effects of FCP, SOP, and FCP+SOP on the spike length of two wheat varieties (Figure 3) signified that variety FSD-08 proved better than Chakwal-50 for producing the highest spike length under saline soil conditions. FSD-08 showed a minimum spike length (6 cm) in the control treatment. However, the maximum spike length (8.85 cm) was apparent with the combined application of SOP and FCP (T4). In all other treatments, T2 (SOP) and T3 (FCP) gave relatively lower spike lengths (7.82 and 7.33 cm, respectively) compared with T4. Both genotypes showed statistically non significant results at a probability level of 0.05. In the case of

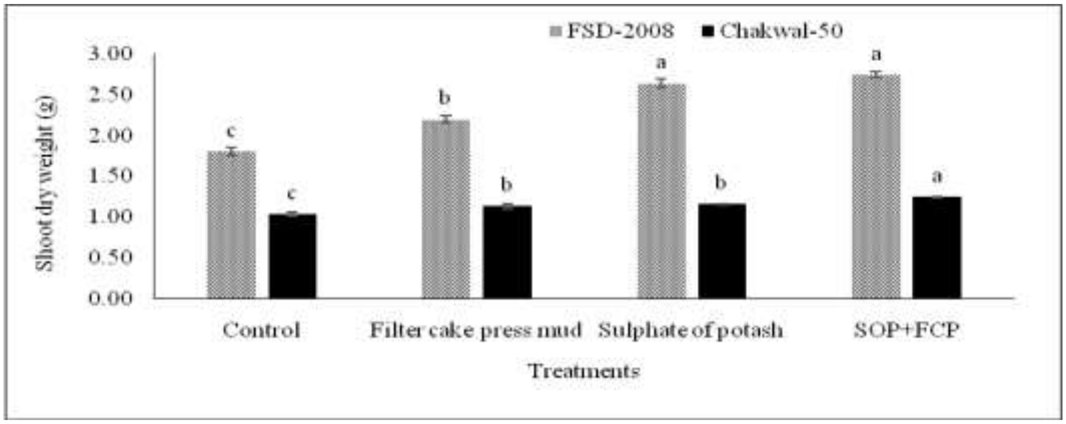

Figure 1. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP) & FCP+SOP on shoot dry matter of wheat.

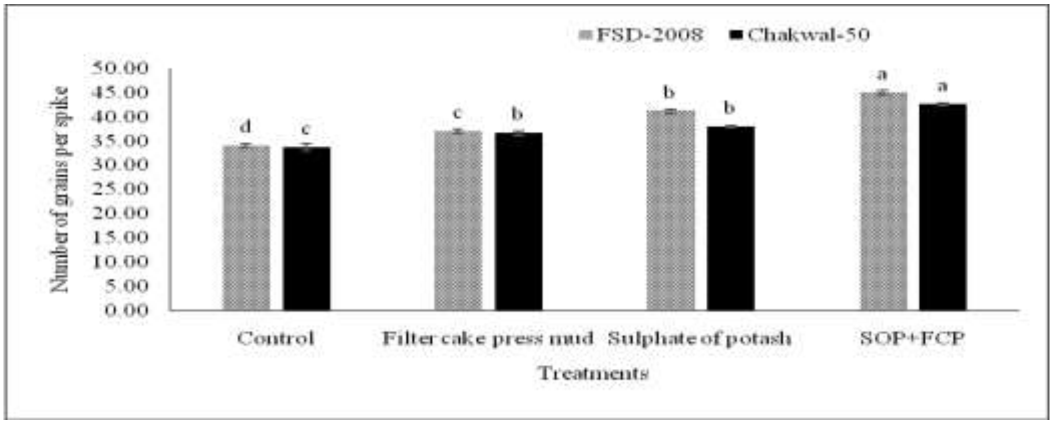

Figure 2. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on number of grains per spike.

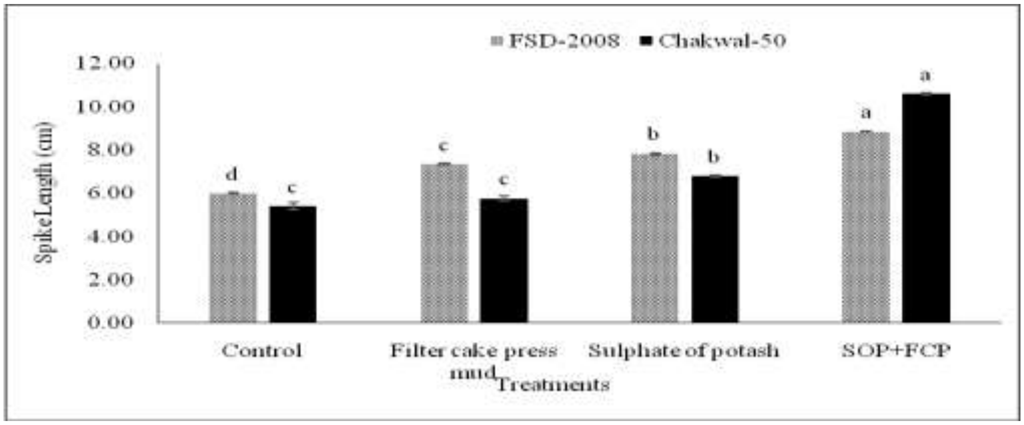

Figure 3. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on spike length (cm).

Chakwal-50, the minimum spike length (5.40 cm) was visible in the control treatment (T1), reaching a maximum of 10.60 cm in T4 receiving SOP+FCP. Filter cake press mud and SOP applied alone, gave 5.77 and 6.80 cm spike lengths, respectively.

Soil data

Soil Na content (ppm)

Figure 4 demonstrates the effects of filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on soil sodium. Data revealed that the FSD-08 performed better than the Chakwal-50 variety of wheat. For the FSD-08, a maximum Na content in the soil (158 ppm) resulted in the control treatment (T1). Meanwhile, the minimum Na content with the SOP (T3) showed a numerical value of 145 ppm. On the other hand, other treatments, FCP and SOP+FCP, gave 152 and 150 ppm, respectively. Both genotypes showed statistically non significant results at a probability level of 0.05. However, in the case of Chakwal-50, treatment T1 (control) manifested a minimum Na content in soil of 149 ppm, and a maximum Na content of 162 ppm resulted in treatment T2 receiving FCP.

Soil K content (ppm)

The data related to the effects of FCP, SOP, and FCP+SOP on soil K content (Figure 5) displayed that the minimum soil K content (200 ppm) was notable in the control treatment (T1), then reaching a maximum of 310 ppm in the T4 combined application (SOP+FCP) in the case of FSD-08. Sulphate of potash and filter cake press mud separately resulted in 239 and 290 ppm soil K content, respectively. Both genotypes showed statistically non significant results at a probability level of 0.05. However, in the case of Chakwal-50, treatment T1 (control) exhibited a minimum Na content in soil of 162 ppm, with a maximum of 205 ppm recorded in treatment 4 receiving SOP+FCP.

Soil carbon fraction (%)

Figure 6 details the effect of FCP, SOP, and FCP+SOP on soil carbon fraction. For the FSD-08 variety, a minimum soil carbon fraction (0.60%) surfaced in T1 (control) that approached the utmost level of 1.03% soil carbon in treatment T4 (combined application of FCP and SOP). Both genotypes showed statistically non significant results at a probability level of 0.05. However, in the case of the Chakwal-50, treatment T1 (control) resulted in the minimum soil carbon fraction (0.59%), and treatment T4 gave the maximum soil carbon fraction of 0.96%.

Physiological data

Electrolyte leakage percentage

The findings related to filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP influences on the electrolyte leakage percentage appear in Figure 7. In the case of FSD-08, the lowest electrolyte leakage percentage (5.70%) was noteworthy in the control treatment (T1), and the maximum electrolyte leakage percentage (6.92%) was with FCP (T2). Similarly, for Chakwal-50, the control treatment showed a minimum electrolyte leakage percentage (5.10%), and FCP (T2) provided the maximum electrolyte leakage percentage (5.83%).

Chlorophyll content in flag leaf

Results in Figure 8 depicted the impacts of FCP, SOP, and FCP+SOP on the chlorophyll content in wheat's flag leaf. For FSD-08, the minimum chlorophyll content in the flag leaf (0.66 µmol m^{-2}) was apparent in the control treatment, whereas the maximum was with the SOP (2.18 µmol m^{-2}). On the other hand, regarding Chakwal-50, the control treatment (T1) produced 0.79 µmol m^{-2} chlorophyll content in flag leaf, which was the lowest among all treatments. Conversely, the combined use of SOP and FCP (T4) gave the maximum chlorophyll content in the flag leaf (1.40 µmol m^{-2}).

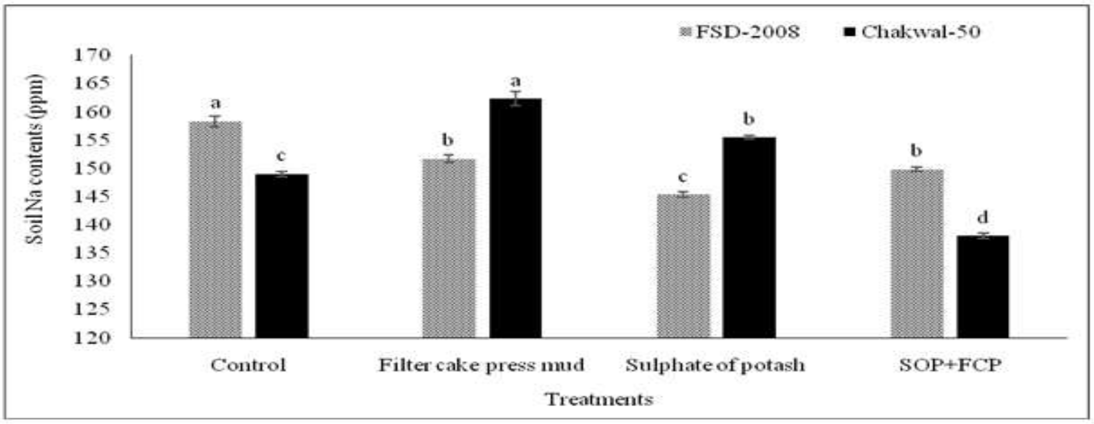

Figure 4. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on soil sodium content

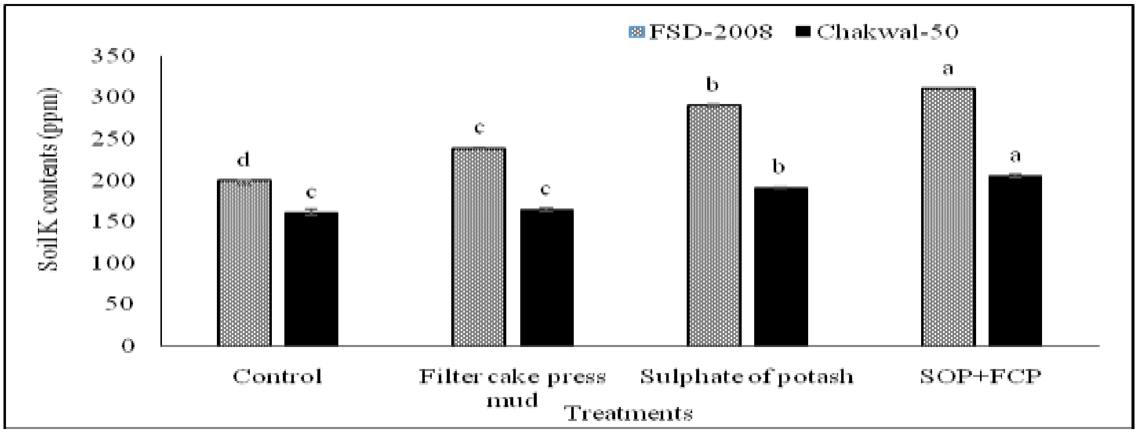

Figure 5. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on soil potassium content

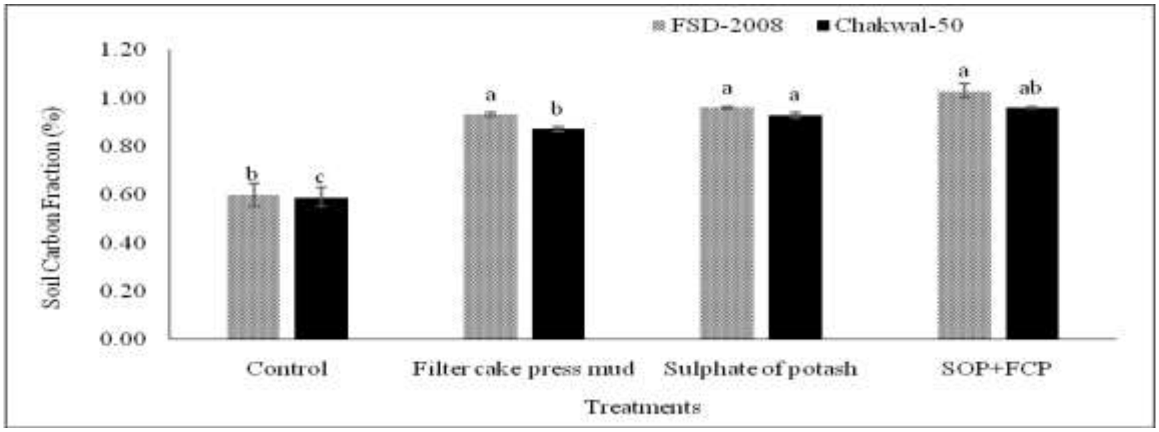

Figure 6. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on soil carbon fraction

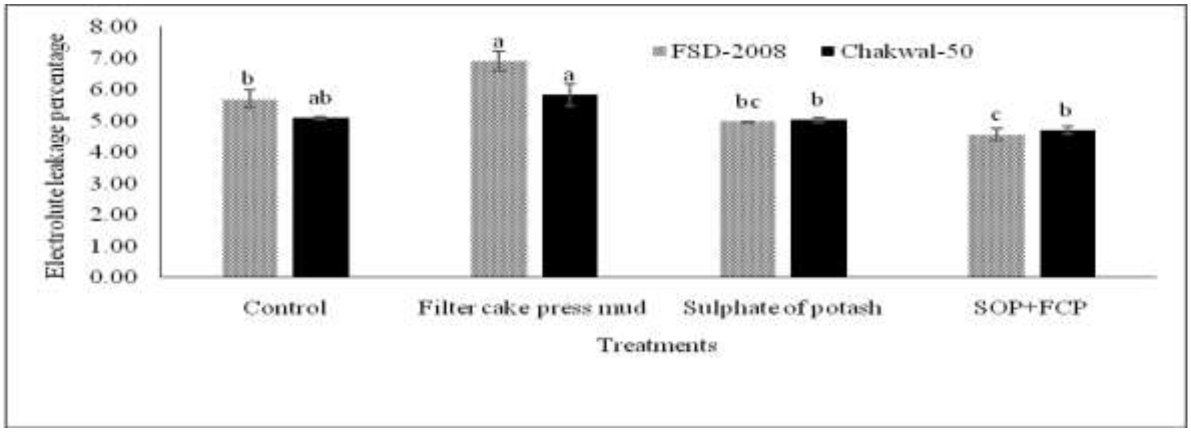

Figure 7. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on electrolyte leakage percentage

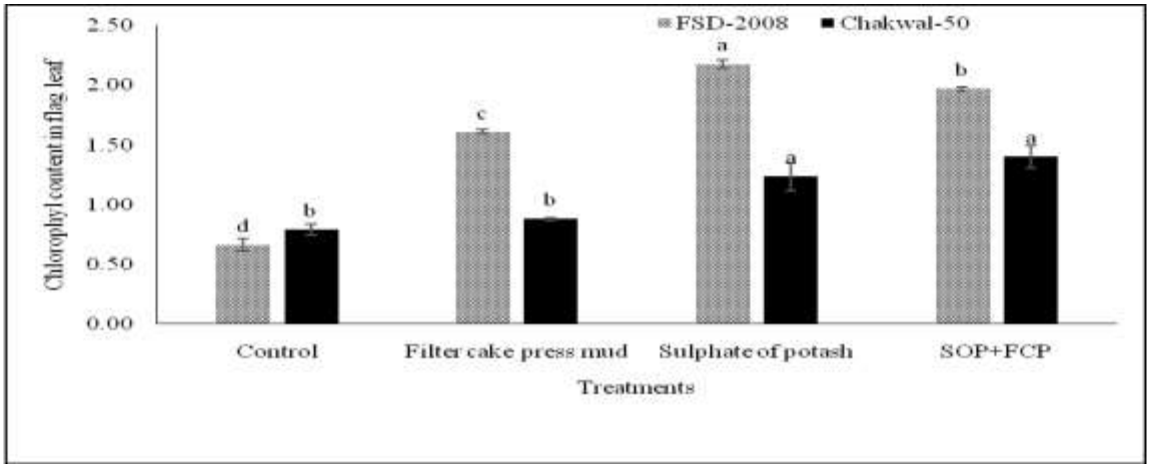

Figure 8. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on chlorophyll content in flag leaf (μmol m^{-2})

H-ATPs

The data pertaining to the effects of FCP, SOP, and FCP+SOP on H-ATPs reflected that for FSD-08, a minimum H-ATPs (49.2) was evident in the control treatment (Figure 9), whereas the maximum H-ATPs (99.5) was prominent in treatment T4 (SOP+FCP). In the case of Chakwal-50, treatment T1 (control) showed 49.3 H-ATPs, and treatment T4 (SOP+FCP) provided the maximum H-ATPs (78.7) under saline soil conditions in the field.

DISCUSSION

The total K content in soil often exceeds 20,000 ppm (parts per million). Although soils contain large amounts of total potassium, only a limited amount of K is available to plants for their growth. The reason is that most of the K in soil minerals is in the structural component and is, therefore, unavailable for plant growth. Potassium is a vital mineral for plant development, although its neglect generally occurs in several agricultural production

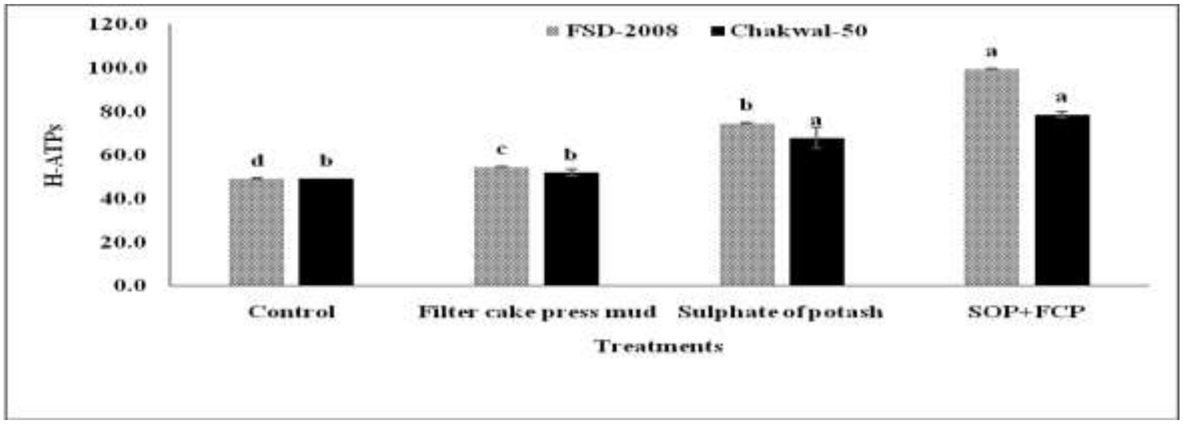

Figure 9. Effect of Filter cake press mud (FCP), Sulphate of potash (SOP), and FCP+SOP on H-ATPs

systems favoring N and P. A sufficient supply of K is necessary for organic and conventional crop cultivation (Ali *et al*., 2023; Ramzan *et al*., 2023;). Potassium's involvement in physiological events in plants includes osmoregulation, protein synthesis, enzyme activation, and photosynthate transfer. On many farms, the K balance is negative, meaning that more K extraction in harvested crops happens than being restored in the soil (Mikkelsen, 2007).

Potassium is beneficial for plant health, osmoregulation, enzyme activation, photosynthesis, translocation, internal cation/anion balance, protein synthesis, and correct water relations, which are some of the specialized roles of K in plants. Proper K nutrition improves tolerance to external stressors like cold, drought, heat, and high light intensity. An appropriate supply of K also reduces the stress caused by illness and insect damage. Although there are no known adverse effects of K on the environment or human health, insufficient K can have severe consequences on crop growth and the effective utilization of other nutrients, such as N and P. Maintaining proper K levels is critical for both organic and conventional crop production. Compost and manure organic materials are highly diverse (due to their primary constituents and treatment), and their K concentrations are also highly variable. Organic matter previously composted usually becomes a nutrient source. Like known inorganic sources, the K in these organic compounds is primarily available for plant absorption. Repeated applications of significant amounts of manure can cause K accumulation in the soil, contributing to the plant's excessive K consumption (Mikkelsen, 2007; Turaev *et al*., 2023).

Results revealed that better shoot dry weight, spike length, and the number of grains per spike were visible in FSD-08 compared with Chakwal-50, showing the better tolerance and adaptability of FSD-08 under salt stress conditions. The findings of Yagmur (2007) also highlighted the positive role of potassium application in alleviating salt stress and mitigating harmful salt stress on wheat's shoot and root dry matter, as well as, chlorophyll a and b contents.

Wheat cultivars responded differently to NaCl supply in soil depending on soil Na and K levels: (1) low to moderate soil Na levels with low availability of K stimulated plant root growth; (2) high sodium levels in soil reduced root and shoot dry weights when compared with K levels. As a result, the effect of Na and K on wheat cultivars' use efficiency varies. Consequently, K-efficient cultivars absorbed more potassium through shoots than K-inefficient cultivars. Similarly, genetic differences influenced Na uptake and salt tolerance, with K-efficient cultivars being salt-tolerant while inefficient cultivars were not (Krishnasamy *et al*., 2014).

Noteworthily, a higher chlorophyll content, reduced electrolyte leakage in the plasma membrane, and higher enzyme activity

(H-ATPase) emerged with the application of potassium Sulphate. It could be due to the role of K in the enzyme activation involved in growth, photosynthesis, and osmoregulation. Salinity stress usually impairs a crop's regular growth and activities due to salt stress. However, applying K minimizes the adverse effects of salinity by improving chlorophyll contents and lowering electrolyte leakage under salt-stressed conditions, thereby supporting plant growth under such stressed scenarios. Several researchers concluded similar outcomes and reported the positive role of K application in supporting plant growth under salt stress conditions (Misra and Gupta, 2005; Misra *et al.*, 2006; and Hernandez *et al.*, 2000). Possible mechanisms responsible for ameliorating damages caused by salt stress in plants comprised the role of K in activating antioxidant enzymes, strengthening the plant defense system, thus lowering the damage caused by reactive oxygen species, regulating K homeostasis, and enhancing nitrogen use efficacy, thereby, improving the plant's survival and growth under salinity stress (Tittal *et al*., 2021).

CONCLUSIONS

Salinity severely affected the growth of wheat crops. The K application is mandatory for better wheat crop growth and survival in salinity stress scenarios. Coupling K fertilizers with organic amendments helps improve K use efficiency and K bioavailability from commercial K sources. Among commercial K sources, SOP proved to be a superior source of K to support development in saline growth environments. However, integrating commercial K nutrition sources with carbon-sequestering fertilizers (organic amendments) proved best for the wheat's growth and survival in salt-stress surroundings.

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