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Interactive Effects of Potassium Sulfate and Soil Salinity on Mineral Nutrition (K, Ca, Mg) and Chlorophyll Content of Triticum Durum L. At The H'madna Station (Relizane, Algeria)

Lallahoum Benaouda[1*], Belkacem Boumaraf [2], and Zohra Rahim[3]

[1*] Laboratory of Ecosystem Diversity and Dynamics of Agricultural Production Systems in Arid Zones (DDAPSAZ), Department of Agronomic Sciences, University of Mohamed Khider Biskra., BP 145 RP, 07000 Biskra, Algeria. Email: l.benaouda@univ-dbkm.dz
[2] Laboratory for the Promotion of Innovation in Agriculture in Arid Regions (PIAAR), Department of Agronomic Sciences, University of Mohamed Khider Biskra, BP 145 RP, 07000 Biskra Algeria. Email: belkacem.boumaraf@univ-biskra.dz
[3]Biotechnology and Valoraisation of Biological Ressources (BVRB) Laboratory, Departement of Agronomics Sciences, Dr. Yahia, University of Medea, Urban center, 26000, Algeria. Email: rahim.zohra@univ-medea.dz

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Abstract. *Soil salinity is a major limiting factor in agricultural production, particularly affecting wheat. In this context, this study aims to evaluate the interactive effects of salinity and potassium fertilization (K_2SO_4) on mineral nutrition (K, Ca, Mg) and chlorophyll content in wheat. The experiment was conducted at three salinity levels (S1: unsalted; S2: slightly salted; and S3: salted) and four potassium rates (0, 150, 300, and 450 kg ha^{-1}). Les résultats montrent que la salinité entraîne une augmentation significative des teneurs en calcium (8,99 meq 100 g^{-1} de sol ± 1,29) et en magnésium (2,02 meq 100 g^{-1} de sol ± 0,53) dans le sol, tandis que la fertilisation potassique influence principalement la teneur en potassium assimilable (0,33 meq 100 g^{-1} sol ± 0,20), avec des valeurs maximales observées à partir de la dose de 300 kg ha^{-1}. Au niveau foliaire, l'augmentation des apports en K_2SO_4 améliore significativement la teneur en potassium, atteignant des valeurs proches de l'optimum à partir de 300 kg ha^{-1}. In contrast, a gradual decrease in calcium (1,31% DM ± 0,32) and magnesium (0,56% DM ± 0,07) content is observed as potassium rates increase, reflecting ionic antagonism. Furthermore, salinity reduces potassium uptake and promotes the accumulation of magnesium in plant tissues. The results regarding physiological parameters indicate that salinity significantly reduces the chlorophyll a (40,27 µg/mg ± 4,42) and b (13,18 µg/mg ± 2,40) content, reflecting a decrease in photosynthetic activity. However, the application of K_2SO_4 improves these parameters, with optimal values observed at a rate of 300 kg ha^{-1}. Principal component analysis confirms that salinity is the dominant factor influencing the variables studied, while potassium fertilization partially mitigates its negative effects. An intermediate dose of 300 kg ha^{-1} appears to be optimal for improving the nutritional balance and wheat's tolerance to salt stress.*

Keywords: *Salinity; potassium sulfate; Durum wheat; mineral nutrition; chlorophyll; H'madna; Relizane.*

1. INTRODUCTION

Soil salinity is currently one of the main obstacles to agricultural production worldwide, particularly in arid and semi-arid regions. It affects an increasingly large proportion of cultivated land and thus constitutes a serious threat to food security (1); (2). Saline stress has a significant impact on plant physiological processes, particularly photosynthesis. It reduces chlorophyll content and disrupts chloroplast function, leading to a decrease in photosynthetic efficiency and biomass production. Recent studies show, however, that adequate potassium nutrition can mitigate these effects by improving stomatal regulation and the enzymatic activity involved in photosynthesis (3); (4)).

Durum wheat (Triticum durum L.) is an important cereal crop but is sensitive to salinity, particularly during the initial stages of development. Saline stress causes an ionic imbalance characterized by an accumulation of sodium (Na^+) and a decrease in potassium (K^+), which disrupts physiological functions and reduces growth and yield. It also induces osmotic and oxidative stress, affecting the plant's metabolism ((5); (6); (7)). In this context, potassium plays a key role in plants' ability to cope with salt stress. It is involved in several vital functions, including osmotic regulation, enzyme activation, maintenance of membrane potential, and the proper functioning of photosynthesis. An adequate potassium supply thus improves the selectivity of ion absorption and limits the toxic effects of sodium, contributing to better plant tolerance to saline conditions ((8); (9)). Its concentration in soils is relatively low and variable ((10); (9)). The use of potassium sulfate (K_2SO_4) appears to be a promising agronomic option, particularly in saline soils. Due to its low salinity index, it allows for the application of potassium without exacerbating soil salinity stress. However, its application can lead to interactions with other essential cations such as calcium ($Ca2^+$) and magnesium ($Mg2^+$), sometimes causing nutritional imbalances linked to competition and ionic antagonism at the root level ((11); (12); (13)).

Despite the progress made in this area, the interactions between salinity and potassium fertilization remain poorly understood, particularly under specific local conditions. A better understanding of these mechanisms is, however, essential for adapting agricultural practices and enhancing crop tolerance to salt stress.

The main objective is to evaluate the combined effects of salinity and potassium fertilization on the dynamics of nutrients (K, Ca, Mg), both in the soil and in the plant, as well as on chlorophyll content. More specifically, the goal is to identify the optimal potassium rates that improve wheat's tolerance to salt stress while maintaining an adequate nutritional balance. This work is part of an effort to improve agricultural practices in saline environments and to contribute to the development of sustainable agriculture in the face of growing environmental constraints.

2. MATERIALS AND METHODS

2.1. EXPERIMENTAL SITE

The study originates from the INRAA research station at H'madna, Relizane. We selected three parcels with different levels of salinity. According to the electrical conductivity scale in (dS/m), mentioned by (14), soils in the region are generally saline.

This study was conducted over two growing seasons (2022/2023 and 2023/2024) using a split-plot design with three blocks and four potassium treatments under different soil salinity levels. Three salinity classes were considered based on electrical conductivity: S1 (non-saline), S2 (slightly saline), and S3 (saline). Potassium sulfate (K_2SO_4), suitable for saline soils, was applied at four rates: K_0 (0 kg ha^{-1}), K_1 (150 kg ha^{-1}), K_2 (300 kg ha^{-1} recommended dose based on crop requirements), and K_3 (450 kg ha^{-1}). The experiment was carried out under controlled pot conditions. A drainage and leachate recycling system was implemented to maintain stable soil salinity throughout the growing period. Wheat seeds were pre-germinated before transplanting, and fertilizer was applied prior to planting. Leaf samples were collected at the early heading stage, corresponding to peak nutrient uptake. Analyses focused on nitrogen, phosphorus, dry matter, and protein contents in the grains.

The soil and leaf samples collected were analyzed in the APSVNR laboratory (Agricultural Production and Sustainable Valorization of Natural Resources, University of Khemis Miliana).

2.2. PLANT MATERIAL

In our study we choose the variety of Targui durum wheat (Ammar 06) as the cereal of interest. Research has been carried out on this variety at the ITGC (Institut Technique of field Crops, Algiers), focusing mainly on the plant's morphological parameters. However, no specific research on salinity tolerance has been carried out.

2.3. SOIL CHARACTERISTICS

The soil type used for experimentation in this study originates from the INRAA research station at H'madna, Relizane. These soils are part of the lower Chelif perimeter, and are characterized by a clay-loam texture. (15) showed that the soils at the H'madna site are solonetz solontchaks with a sodic, magnesic and calcic nature. On the surface, most of these soils have a very fine texture, while the underlying horizons are dominated by a more or less silty texture.

The results of granulometric analysis clearly show that the soils at this station are fine-textured. They are considered moderately calcareous ($CaCO_3$, 21,07 % ± 4,32). The average organic matter content ranges from 0,46% ± 0,30. The soil pH is 7,64 ± 0,50, indicating that the soils at the station have a relatively alkaline soil reaction (Table 01).

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Table 01: Physical and chemical characteristics of the soil.

Granulometry				**Physico-chemical parameter**			
Horizon	**%Clay**	**%Silt**	**%Sand**	**pH**	**$\%CaCO_3$**	**%OM**	**EC (dS/m)**
0-30	47,45 ± 2.91	21,26 ± 3.15	30,11 ± 3	7,64 ± 0.30	21,07 ± 4.32	0,46 ± 0,30	1,5 ± 0,84
	Analysis of soil solution (meq/100 g soil)						
	Ca^{++}	**Mg^{++}**	**K^{+}**	**Na^{+}**	**Cl^{-}**	**HCO_3^{-}**	**SO_4^{--}**
	15,8 ± 4,71	3,33 ± 0,30	0,19 ± 0,60	16,21 ±2,61	10,29 ± 3,44	1,3 ± 0,50	8,22 ± 3

2.4. STATISTICAL ANALYSIS

The assumptions of normality and homogeneity of variances were verified using the Shapiro-Wilk test and Levene's test, respectively. Next, a two-factor analysis of variance (ANOVA) was performed with fertilization and salinity as fixed factors.

All statistical analyses were performed using R software (version 4.x) with the agricolae and Facto Mine R and factoextra packages. Statistical significance was set at $p < 0.05$.

3. RESULTS

3.1. EFFECT OF SALINITY AND K_2SO_4 ON SOIL POTASSIUM, CALCIUM, AND MAGNESIUM CONTENT

A/ON THE POTASSIUM (K) CONTENT OF THE SOIL

The mean assimilable potassium content ranges from 0.33 meq 100 g^{-1} soil ± 0.20, indicating that, in our case, the soils have low to moderate levels of assimilable potassium. An exchangeable potassium content between 0.25 and 0.40 meq 100 g^{-1} is generally considered optimal for demanding crops such as wheat, as it ensures adequate plant nutrition, stabilizes yields, and maintains soil fertility (16).

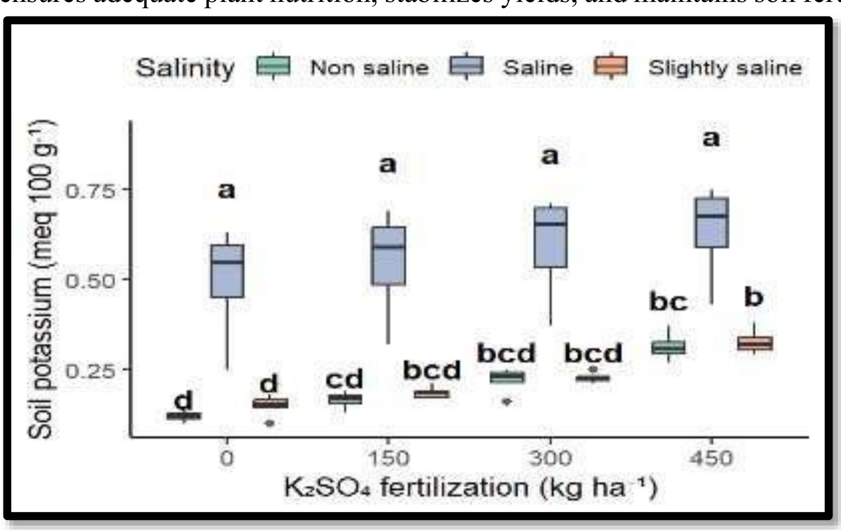

Figure 01. Variations in the content of assimilable potassium in the soil**.**

Soil potassium content generally increases with higher application rates of K_2SO_4. The highest values are observed in saline soils, while non-saline soils have the lowest levels. In non-saline and slightly saline soils, increased potassium fertilization leads to a significant rise in soil potassium, whereas in saline soils, no significant difference is observed between the applied rates (fig. 01).

B/ ON THE CALCIUM (Ca) CONTENT OF THE SOIL

The results show that salinity strongly influences soil calcium content, with an average value of 8.99 meq 100 g^{-1} soil ± 1.29. Saline soils exhibit the highest calcium values. Variations in available calcium content indicate significant differences between salinity levels (Fig. 02).

In addition, the increasing application of K_2SO_4 did not result in a significant variation in soil calcium within each salinity level.

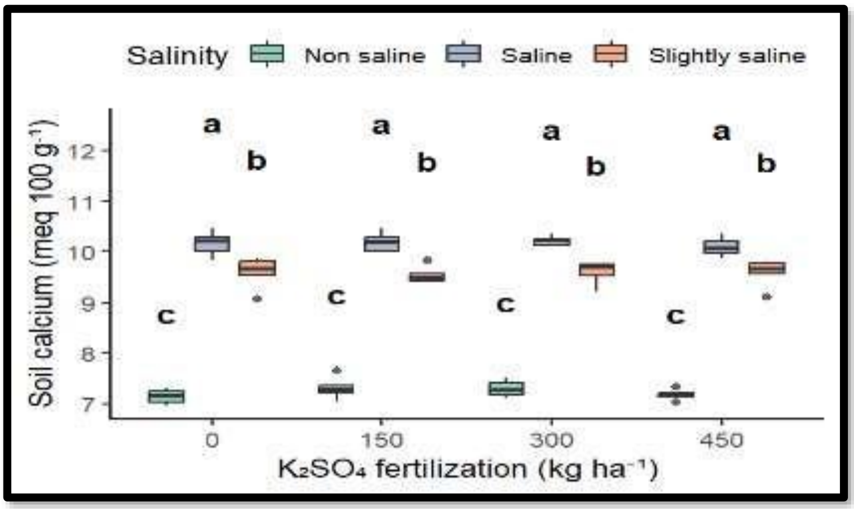

Figure 02. Variations in the content of assimilable calcium in the soil**.**

C/ ON THE MAGNESIUM (Mg) CONTENT OF THE SOIL

The results shown in Figure 3 indicate that the average obtained value is 2.02 meq/100 g of soil ± 0.53.

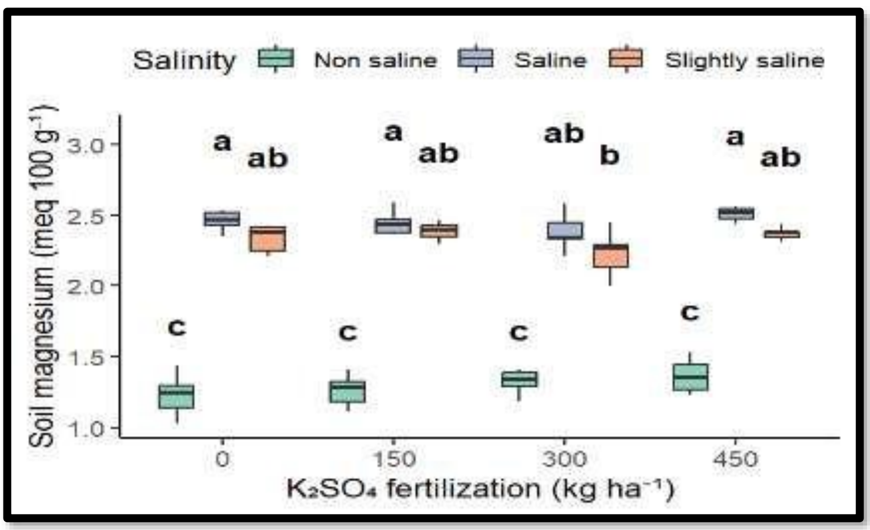

Figure 03. Variations in the content of assimilable magnesium in the soil.

Soil magnesium content varies significantly depending on salinity levels, with saline soils exhibiting the highest magnesium concentrations. Increasing the application rate of K_2SO_4 does not result in a change in soil magnesium levels. Statistical analysis reveals significant differences primarily related to salinity. According to the FAO fertility scales (17) and the harmonization procedures of the Global Soil Partnership (18), the average levels of available calcium and magnesium indicate a moderate to high level of sufficiency.

3.2. EFFECT OF SALINITY AND K_2SO_4 ON FOLIAR POTASSIUM, CALCIUM, AND MAGNESIUM CONTENT

A/ ON POTASSIUM (K) CONTENT IN LEAVES

We observe that, in the absence of fertilization (0 kg ha⁻¹), K concentrations are the lowest. Increasing the application rates of K_2SO_4 (300 and 450 kg ha⁻¹) leads to a significant increase in potassium in plant tissues. The average content obtained is 1,11% DM ± 0,5 (Fig. 04). According to (17) standards, the optimal potassium content in wheat leaves at the early heading stage ranges between 1.5 and 2.5% DM.

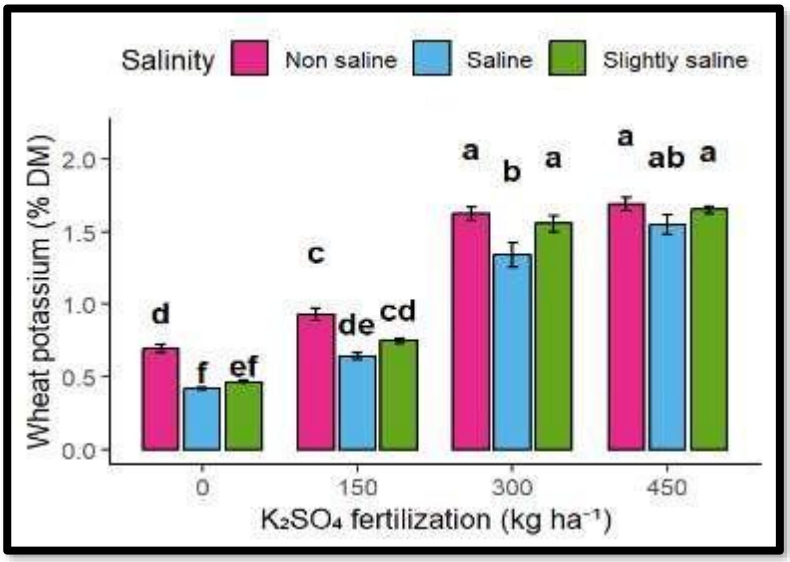

Figure 04. Variations in foliar potassium content (% dry weight).

Nos résultats indiquent que les teneurs des feuilles en potassium atteignent le niveau optimum à partir de l'apport de K_2SO_4 de la dose 300 kg ha^{-1}, la dose qui couvre les besoins des plantes, dans ce type de sol (sol à texture fine et faibles teneurs en potassium assimilable). La salinité a un effet inhibiteur sur l'absorption du potassium par le blé.

B/ ON THE CALCIUM (Ca) CONTENT OF LEAVES

The results obtained for foliar calcium concentrations are shown in Figure 5.

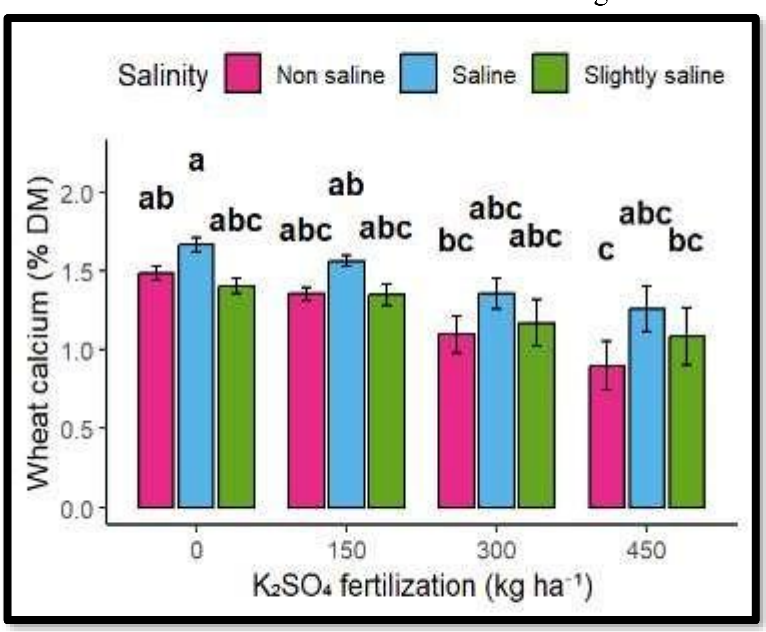

Figure 05. Variations in leaf calcium content (% dry weight).

In contrast to potassium, there was a gradual decrease in foliar calcium content as K_2SO_4 application rates increased, across all salinity levels. The average Ca content in wheat leaves at the heading stage was 1,31% DM ± 0,32.

C/ ON THE FOLIAR MAGNESIUM (Mg) CONTENT

The highest magnesium accumulation in wheat leaves is consistently observed in the saline soil, regardless of the K_2SO_4 application rate. With an average content of 0.56% DM ± 0.07, the highest value is observed at the dose of 0 kg ha^{-1}, while the lowest value is observed at the dose of 450 kg ha^{-1} (Fig. 06).

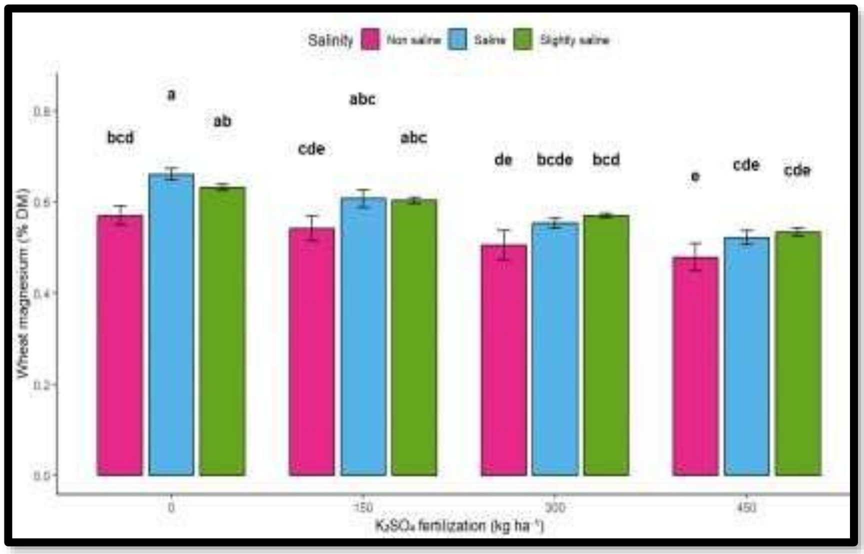

Figure 06. Variations in foliar magnesium content (% dry weight).

3.3. EFFET DE LA SALINITE ET DU K_2SO_4 SUR LA TENEUR EN CHLOROPHYLLE

A/ ON CHLOROPHYLL (a) CONTENT

The results relating to variations in chlorophyll (a) content are presented in Figure 7. This figure indicates that the average chlorophyll (a) content is 40.27 µg/mg ± 4.42. The lowest values were recorded in the saline soil treated with 0 kg ha^{-1} of K_2SO_4, while the highest average values were obtained from the 300 kg ha^{-1} application rate.

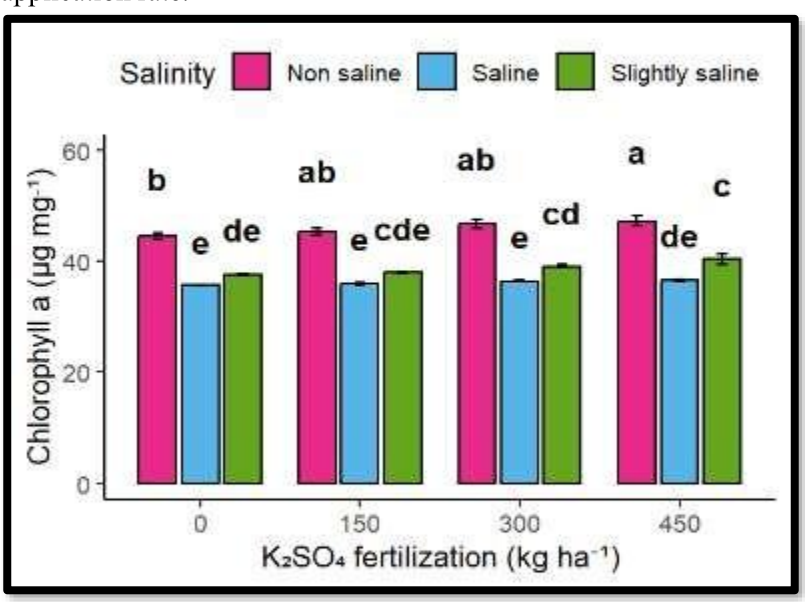

Figure 07. Variations in chlorophyll (a) content in wheat leaves.

B/ ON CHLOROPHYLL (B) CONTENT

Salinity affects chlorophyll (b) content; the lowest value was observed in the saline soil without any potassium fertilizer application, at 9.21 µg/mg. The average value was 13.18 µg/mg ± 2.40. The Salinity has a negative impact on chlorophyll (b) content; however, the addition of K_2SO_4 has a positive effect on it.

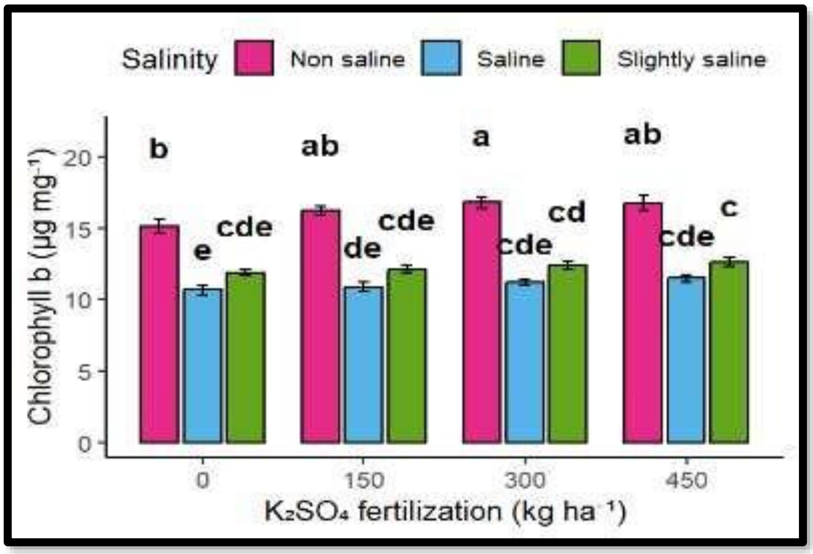

Figure 08. Variations in chlorophyll (b) content in wheat leaves.

3.4. PRINCIPAL COMPONENT ANALYSIS (PCA)

Principal component analysis (PCA-Biplot) was performed to explore the clustering of individuals based on salinity levels and K_2SO_4 doses. The first two axes explain 82% of the total variance, with 62.3% for axis 1 (Dim1) and 19.7% for axis 2 (Dim2), indicating a good representation of the data in the factorial plot. The results are presented in Figures 09 and 10.

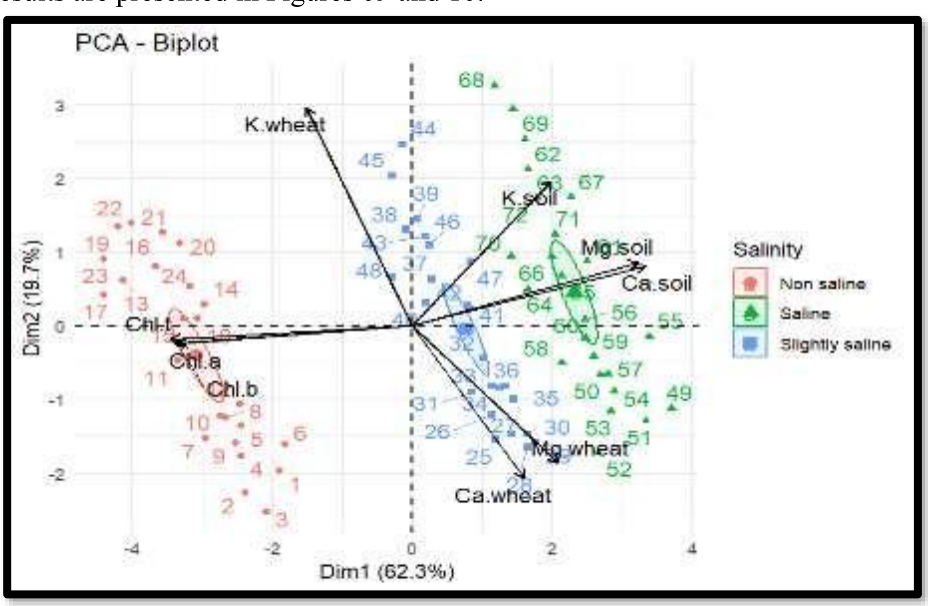

Figure 09. Multivariate analysis of soil salinity effects by PCA-Biplot.

The ACP-Biplot shows a gradual differentiation of individuals based on salinity levels, confirming its major role in the variables studied. Increased salinity is associated with an accumulation of Ca and Mg and a decrease in chlorophyll, indicating significant physiological stress in wheat.

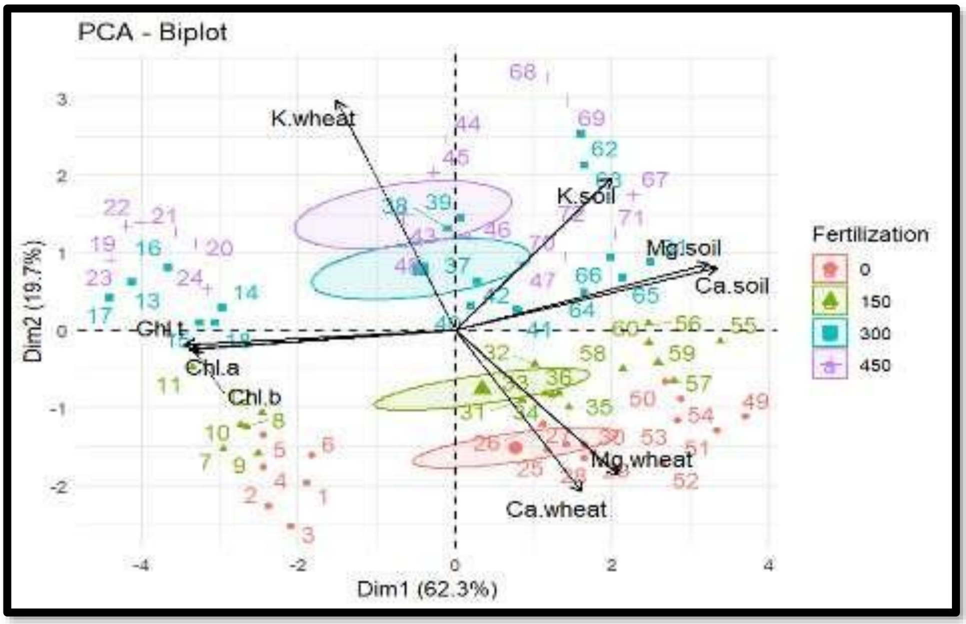

Figure 10. Multivariate analysis of the effects of K_2SO_4 fertilization using PCA-Biplot.

The ACP-Biplot shows a clear pattern of variation among individuals based on K_2SO_4 application rates, with Dim1 as the primary factor of variation. The plants' response appears to be gradual, with a more pronounced differentiation at application rates of 300 and 450 kg ha^{-1}, suggesting a threshold effect where the response becomes more pronounced at higher fertilization rates.

4. DISCUSSION

The results clearly indicate that salinity and potassium fertilization (K_2SO_4) play a major role in the dynamics of soil nutrients, as well as in the mineral nutrition and physiological functioning of wheat. In this study, increased salinity led to a significant accumulation of calcium and magnesium in the soil. These observations confirm that saline soils are generally rich in basic cations such as Ca^{2+} and Mg^{2+}, due to ion exchange and the concentration of soluble salts. Comparable results have been reported in recent research showing that salinity alters soil ion homeostasis and limits the balanced uptake of essential nutrients in wheat (20).

The lack of a significant effect of K_2SO_4 on calcium and magnesium, regardless of salinity levels, indicates a certain stability of these elements in the soil. This confirms that potassium fertilization primarily affects potassium, with little influence on divalent cations (21).

Furthermore, increasing potassium supply significantly improves foliar K content, confirming its key role in osmotic regulation and ionic balance. It thus helps enhance wheat's tolerance to salt stress by promoting more selective ion uptake (22).

However, high potassium applications can lead to an imbalance with magnesium. In this study, Mg content decreased as K doses increased, reaching a minimum at 450 kg ha^{-1}, likely due to competition between K^+ and Mg^{2+} during uptake. This type of interaction between these cations is frequently observed in studies on wheat mineral nutrition under stress conditions ((23); (12); (13)).

Under saline conditions, a higher accumulation of magnesium in the leaves was also observed. This finding is consistent with certain observations reported in the literature, suggesting that salt stress can disrupt ion transport and cause an excessive accumulation of certain nutrients in plant tissues due to physiological and membrane alterations (24).

Assessing the nutritional ratios between potassium, calcium, and magnesium provides a deeper understanding of ionic balances within the plant. In this study, the interpretation of the K/Ca and K/Mg ratios was based on the principles of the DRIS (Diagnosis and Recommendation Integrated System) method, which relies on the analysis of nutrient ratios to identify nutritional imbalances and limiting elements in crops ((25); (26)).

The results show that the K/Ca (1.03 ± 0.8) and K/Mg (2,06 ± 1,07) ratios remain low at application rates of 0 and 150 kg ha^{-1}, indicating an imbalance in favor of calcium and magnesium. Starting at 300 kg ha^{-1}, these ratios fall within the optimal ranges (0,7–1,3 for K/Ca and 2–4 for K/Mg), reflecting an improvement in nutritional balance. According to (27), the balance of essential nutrients in plants plays a crucial role in their growth, productivity, and overall health.
In our study, increased salinity leads to a gradual decrease in chlorophylls a and b, likely due to osmotic stress, which disrupts pigment formation and the proper functioning of chloroplasts. (28) demonstrated that potassium deficiency significantly reduces photosynthesis.
Saline stress causes stomatal closure, which limits the entry of CO_2 into the leaves, thereby reducing the rate of photosynthesis and carbon fixation (29). Furthermore, the enzymes involved in photosynthetic reactions are particularly sensitive to sodium-induced ionic disturbances, leading to a decrease in photosynthetic efficiency and biomass production ((3); (30); (31)). Salinity reduces chlorophyll pigments by disrupting chloroplasts and increasing oxidative stress, leading to a decrease in photosynthetic activity in plants ((32); (33)).
Potassium fertilization, particularly with potassium sulfate, helps mitigate the effects of salt stress by increasing the chlorophyll content in wheat leaves, a finding consistent with recent observations by (34); (24) and (4).
The results show that the effect of K_2SO_4 is dose-dependent, with optimal efficacy observed at around 300 kg ha^{-1}. Moderate doses improve wheat growth, while higher doses produce more variable results (35).

5. CONCLUSION

The results of this study show that salinity significantly affects the growth of durum wheat (Triticum durum L.) by disrupting its mineral nutrition and reducing its photosynthetic capacity. Increased levels of calcium and magnesium in the soil, along with decreased chlorophyll, indicate significant stress on the plant. The application of potassium sulfate (K_2SO_4) proved beneficial, improving potassium uptake and helping the wheat better withstand these adverse conditions. However, high doses can lead to an imbalance with other elements such as calcium and magnesium. Overall, the dose of 300 kg ha^{-1} appears to offer the best compromise between nutrition and salt stress tolerance. Further studies under field conditions would be useful to confirm these observations. Overall, these results underscore the importance of sound potassium fertilization management in saline soils to maintain an optimal balance among major cations and improve wheat's tolerance to salt stress.

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CONFLICT OF INTEREST: The authors have no conflicts of interest.

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