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Evalutaion Of The Interactive Effect Of Different Salinity Levels And Amendments On Wheat Productivity

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ABSTRACT

A pot experiment was conducted at Gomal University, the effects of soil salinity and sulphuric acid levels on the growth and yield of the wheat. Our results show that soil salinity and sulphuric acid levels significantly influenced different aspects of growth of wheat, including germination rate, chlorophyll content, plant height, leaf area index, spike weight, number of spikelets per spike, number of tillers per plant, spike length, number of grains per spike, grain yield, 1000 grains weight, straw yield, and harvest index. The wheat showed the best performance in terms of germination rate, plant height, leaf area index, spike weight, number of spikelet's, no. of tillers, spike length, grain count, grain yield, 1000 grains weight, and straw yield under the lowest salinity level (0.33 dsm-1). Higher concentrations of sulphuric acid, mostly at 400 Kg hac-1, significantly improved various growth parameters across different salinity levels, suggesting its effectiveness in reduce salinity stress. The maximum observed values for most parameters, such as chlorophyll content, leaf area index, spike weight, and harvest index, at this sulphuric acid level. Results showed that the lower concentrations of sulphuric acid showed small benefits, higher concentrations were more effective in increasing growth of wheat and yield, mostly under medium to high salinity stress. At the highest salinity level (7.75 dsm-1), some parameters like plant height and no. of tillers showed a decline at higher sulphuric acid concentrations. The study underscored the contribution of interactions between salinity levels and sulphuric acid concentrations, affecting different aspects of wheat growth.

INTRODUCTION

Wheat (Triticum aestivum L.) is a major staple food crop. Wheat is cultivated over 22 million acres with total production of 26.394 million tons recorded during 2021-2022, wheat contributes 7.8 % value addition in agriculture and 1.8 percent of Pakistan GDP (Anonymous, 2022). Wheat is one of the oldest cultivated crops in the world, it is believed that wheat was either being cultivated or was growing wild when humankind began to live on earth. According to Muslim historians, the plant that was forbidden to Adam and Eve (AS) in the heaven was wheat plant. However, Christian believes that the forbidden fruit was the apple. Wheat has a significant role in Islamic history and culture. In the Quran, the holy book of Islam, wheat is mentioned several times and it is considered to be a blessed crop that provides sustenance to people. The Prophet Muhammad also spoke about the importance of wheat and its role in feeding people.

It was grown in many parts of the Muslim world, including North Africa, the Middle East, and Central Asia. Wheat is grown in many Muslim-majority countries, including Egypt, Turkey, Iran, and Pakistan etc. Among other major field crops in Pakistan, wheat occupies central position. Wheat growth and yield is not up to the mark due to various biotic and abiotic factors. However, soil salinity is one of the most harm full factor for decline of agriculture productivity. The total 20% of the world Cultivated land (9.3×108 ha) is saline sodic (Shahid et al, 2018). Soil salinity affect the soil texture and structure which inhibit the germination and growth of cultivated crop. Wheat crop is sensitive to salt stress which affects the germination and growth stages that resulting in great loss to yield and poor crop establishment (Page et al, 2021). The major factors which build up the salt salinization in soil are polluted irrigation source, inadequate drainage and excessive use of chemical fertilizers, improper cultivation practices, higher evapotranspiration and low rainfall (Munns and Gilliham, 2015). Higher level of salinity (soluble and exchange able sodium) negatively affects the plant growth & development which resulted in lower yield because of specific ion toxicity, ionic stress, poor physical properties, osmotic stress, nutrient imbalance and higher soil pH (Soni et al, 2021). Over the years, various researchers including Ding et al. (2021) and Luo et al. (2018), have explored methods for reclaiming salt-affected soils using both physical and biological approaches. These methods include the use of chemicals like gypsum, sulfuric acid ($H2SO4$), sulfur as well as biological agents such as green manures and composts. Gypsum has been found to be effective in improving soil structure and reducing soil alkalinity by facilitating the exchange of sodium ions with calcium ions. Similarly, sulfur contributes to lowering soil pH and reducing alkalinity through its conversion into sulfuric acid. Gypsum has also played a crucial role in improving the phosphorus, nitrogen & potash content in plants. On the other hand, H_2SO_4 application has been significantly reduced soil pH by improving nutrient availability and uptake in wheat. It is suggested that H_2SO_4 and gypsum could serve as effective source for saline-sodic and calcareous soils reclamation. The use of H_2SO_4 on salt-affected soils enhances the release of calcium ions (Ca^{2+}) and optimizes soil pH by dissolving indigenous calcium carbonate ($CaCO_3$). This reclamation process not lonely improves the physical status of the soil but also promotes the growth & development of crops. Thus, the use of chemical agents like H_2SO_4 and sulfur proves to be an efficient approach for reclaiming saline-sodic soils and enhancing wheat productivity. These agents help to create a more favorable environment for wheat and other crops by improving soil structure and reducing soil alkalinity. The primary aim of current studies is to observe the interactive effects of different salinity levels & amendments on wheat productivity & soil properties. Farmers usually have little knowledge about reclamation of saline soils. Illiteracy is the main cause of acquiring this knowledge and farmers should be trained how to reclaim the salinity issues to get maximum yield. Adaptation of non-recommended techniques and inputs to reclaim the salinity problem is the common practice of our farming community which increases the total cost of production. Hence, appropriate knowledge, suitable techniques and proper selection of inputs to reclaim the saline soil are the main limitations.

OBJECTIVES

1. To observe the effect of salt concentration on germination, growth and yield of spring wheat.
2. To evaluate the reclaiming effect of sulphuric acid on different levels of salinity and yield of wheat crop.

MATERIALS AND METHODS

The various levels of soil salinity and their reclamation approaches on wheat growth and yield, the pot trial was performing at the Agronomic Research Area of Faculty of Agriculture, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan, during 2022-2023. The trial was performed in CRD (completely randomized design) with three replications while layout of the experiment was factorial. Three salinity levels were kept in Factor-A, whereas, four levels of sulfuric acid were maintained in Factor-B. Pots (measuring 0.063 m^2) were filled with fine textured loamy soil. Seed of wheat variety Wadan was sown through dibbling @ 2 seeds $hill^{-1}$ and there were 7 hills per pot. Fertilizers were applied @ 120:90:60 kg ha^{-1} in the form of Urea, SSP and SOP. The treatment and the experimental procedure is described below:

FACTOR-A: SALINITY LEVELS

S1 = 0.33 dsm^{-1}

S2 = 5.5 dsm^{-1}

S3 = 7.75 dsm^{-1}

The salinity levels were developed by adding measured quantity of salts (NaCl) into each pot of soil.

FACTOR-B: SULFURIC ACID LEVELS

A0 = Control

A1 = @ 100 kg ha^{-1}

A2 = @ 200 kg ha^{-1}

A3 = @ 300 kg ha^{-1}

A3 = @ 400 kg ha^{-1}

Detail of data collection is given as under:

Seed germination (%)

Germination of seeds in each pot was carefully recorded and calculated germination percentage.

LEAF AREA INDEX

The leaf area index was calculated at 56thand112thday of sowing.

CHLOROPHYLL CONTENT (SPAD VALUE)

In each pot, the chlorophyll content of five randomly selected plants was noted using a SPAD meter before heading stage.

PLANT HEIGHT AT MATURITY (CM)

It was recorded by measuring five plants from ground to top of the spikes at physiological maturity.

NUMBER OF TILLERS (POT-1)

Total fertile tillers were counted in each pot and noted.

SPIKE LENGTH (CM)

Length of five randomly selected spikes from each pot was measured, averaged and recorded.

SPIKE WEIGHT (G)

Five spikes were selected randomly from each pot, weighted and noted.

NUMBER OF GRAINS (SPIKE-1)

Five spikes were randomly taken from each experimental unit to count the grains number per spike. Total grains per spike were counted and their mean was determined.

NUMBER OF SPIKELET (SPIKE-1)

The number of spikelet per spike was counted from already five randomly selected spikes from each pot for number of grains count, averaged and noted.

1000 GRAIN WEIGHT (G)

One thousand grains were counted from each pot and their weight was taken & expressed in grams.

GRAIN YIELD (G POT-1)

Grain yield in each pot was noted after harvesting and threshing in grams using standard procedure.

STRAW YIELD (G POT-1)

Straw yield was computed by using the following method:

Straw yield = Total biomass – Economic yield

HARVEST INDEX (%)

It was calculated by dividing grain yield to biological yield and then multiplied with 100, given as under.

H I = grain yield / biological yield × 100

BENEFIT COST RATIO

Economy of different experimental treatments was calculated as under.

BCR = total income/total expenses

STATISTICAL ANALYSIS

The data was analyzed by ANOVA technique (Steel et al., 1997) and means were compared through LSD0.05 by using "Statistics ver. 8.1"

RESULTS AND DISCUSSION

SEED GERMINATION (%)

The use of 100 kg ha-1 sulphuric acid showed decrease in germination percentage as compared to @ 300 and 400 kg ha-1 across all salinity levels. The maximum germination percentage rate (95, 91 and 85%) was observed @ 400 kg ha-1 sulphuric acid dose at all the salinity levels (S1, S2 & S3) respectively. Similarly, it was also noted that germination percentage rate ranged between 93 to 82% @ 200 and 300 kg ha-1 sulphuric acid dose at all the salinity levels with the same pattern that higher the sulphuric acid dose showed high germination rates across different salinity levels. Similarly, lower germination percentage rate (90, 84 and 79%) was observed at lesser sulphuric acid dose 100 kg ha-1 at all the salinity levels (S1, S2 & S3) respectively. Sulphuric acid dose @ 400 kg ha-1 showed maximum germination percentages in all conditions, especially notable in the highest salinity level (S3), which might indicate a specific benefit of this concentration under extreme salinity conditions. In S1 @ 0.33 dsm-1 (lower salinity level), higher germination rates across all sulphuric acid treatments was noted, indicating optimal conditions for wheat germination. S2 @ 5.5 dsm-1 (moderate salinity level) indicated adverse impact on germination, however, with some sulphuric acid treatments (particularly @ 300 and @ 400 kg ha-1) showed beneficial effects. S3 @ 7.75 dsm-1 (higher salinity level) exhibited the lower germination rates, but significant improvement observed with 300 and 400 kg ha-1 sulphuric acid treatments. The interaction between sulphuric acid levels and salinity levels showed direct proportional relationship. Lesser the salinity level requires lower sulphuric acid dose to optimize the germination percentage while higher the salinity level require higher sulphuric acid dose to get maximum germination percentage. This suggests that sulphuric acid, at certain concentrations, can moderate the negative effects of salinity on wheat germination. The effectiveness of sulphuric acid in enhancing germination under salinity stress is highly dependent on its concentration.

TABLE 4.1 SEED GERMINATION (%) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			Mean
	S1 = 0.33 dsm-1	S2 = 5.5 dsm-1	S3 = 7.75 dsm-1	
No sulphuric acid	90.00de	84.00gh	79.66j	84.55 d
@ 100 kg ha-1	91.00cd	87.33f	82.00i	86.77c
@ 200 kg ha-1	92.00bc	88.66ef	82.33hi	87.66c
@ 300 kg ha-1	93.33ab	90.00de	83.33ghi	90.33a
@ 400 kg ha-1	95.00a	91.00cd	85.00g	90.33a
Means	92.26a	88.20b	82.46c	

TABLE .2 CHLOROPHYLL CONTENT OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			
	S1 = 0.33 dsm-1	**S2 = 5.5 dsm-1**	**S3=7.75 dsm-1**	**Mean**
No sulphuric acid	56.00d	45.0ij	40.00k	47.00e
@ 100 kg ha-1	57.43cd	47.46gh	42.73j	49.21d
@ 200 kg ha-1	58.20bc	48.93fg	44.50ij	50.54c
@ 300 kg ha-1	59.33ab	50.26ef	46.00hi	51.86b
@ 400 kg ha-1	60.13a	51.73e	47.67g	53.17a
Means	58.22a	48.68b	44.18c	

TABLE.3 PLANT HEIGHT AT MATURITY (CM) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			
	S1 = 0.33 dsm-1	**S2 = 5.5 dsm-1**	**S3 = 7.75 dsm-1**	**Mean**
No sulphuric acid	83.00 ab	70.06abc	63.16abc	72.07 NS
@ 100 kg ha-1	84.70 ab	72.93abc	65.40abc	74.34
@ 200 kg ha-1	86.06 ab	75.13abc	67.80abc	76.33
@ 300 kg ha-1	87.73a	77.16ab	70.43abc	78.44
@ 400 kg ha-1	89.22a	79.33ab	72.53abc	80.36
Means	86.14a	74.92ab	67.86b	

TABLE.4 LEAF AREA INDEX OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			
	S1 = 0.33 dsm-1	**S2 = 5.5 dsm-1**	**S3 = 7.75 dsm-1**	**Mean**
No sulphuric acid	13.73 a-d	12.03a-e	9.83de	11.86b
@ 100 kg ha-1	14.56abc	12.80a-e	11.00b-e	12.78b
@ 200 kg ha-1	15.06abc	13.80a-d	12.08a-e	13.64ab
@ 300 kg ha-1	15.83a	14.50abc	13.13a-d	14.48ab

@ 400 kg ha-1	16.36a	15.46ab	14.10abc	15.31a
Means	15.11a	13.71ab	12.02b	

CHLOROPHYLL CONTENT (SPAD VALUE)

The control treatment displayed lower chlorophyll content across different sulphuric acid (SA) levels, with an average of 47.00 units, setting a baseline for comparison. SA @ 100 kg ha-1 slight increase in chlorophyll content as observed across all salinity levels compared to the control, suggesting a positive effect of this sulphuric acid concentration on chlorophyll synthesis in wheat. SA @ 200 kg ha-1 revealed increase in chlorophyll content, especially visible in higher salinity conditions, indicating that this level of sulphuric acid might help in countering the adverse effects of salinity on chlorophyll production. SA @ 300 kg ha-1 revealed upward trend in chlorophyll content in lower salinity conditions, but a less distinct increase at the highest salinity level (S3), suggesting a diminishing benefit at higher sulphuric acid concentrations. SA @ 400 kg ha-1 improved chlorophyll content in lower salinity conditions, but the effect is less clear in higher salinity levels.

Lower salinity level (S1 = 0.33 dsm-1) revealed higher chlorophyll content across all sulphuric acid treatments, suggesting that wheat chlorophyll production is most efficient under low-salinity conditions. Moderate salinity level (S2 = 5.5 dsm-1) showed moderate chlorophyll content, with improvements seen with increasing sulphuric acid applications, indicating some mitigation of salinity stress. Higher salinity level (S3 = 7.75 dsm-1) exhibited the lowest chlorophyll content, although improvement noted with certain levels of sulphuric acid, implying that sulphuric acid can partially alleviate the negative impact of high salinity on chlorophyll production. The interaction between sulphuric acid levels and salinity levels reveals a nuanced influence on chlorophyll content in wheat. At lower sulphuric acid concentrations, there appears to be a beneficial effect, possibly due to improved nutrient availability or modification of soil properties in a way that favours chlorophyll synthesis. Sulphuric acid can be beneficial for enhancing chlorophyll content in wheat under certain salinity stresses. Our results are in agreement with the findings of Mansour et al. (2020) who stated that chlorophyll content in plant substantially decreased as salinity levels increased, but the reduction in Chlorophyll SPAD was observed only at high salinity levels. height at maturity (cm) Analysed data on plant height is presented in Table 4.3 and ANOVA is mentioned in Appendix-III. The control group showed average plant height across different salinity levels, with an average of 72.07 cm with SA @100 kg ha-1 a slight increase in plant height was observed across all salinity levels compared to the control, suggesting a beneficial effect of this low sulphuric acid concentration on wheat growth. SA @ 200 kg ha-1 revealed further increase in plant height particularly in higher salinity conditions, indicating that this level of sulphuric acid might help reduce the adverse effects of salinity stress on wheat. SA @ 300 kg ha-1 showed trend of an increase in plant height in lower salinity conditions; however, a significant decrease was noted in the highest salinity level (S3), SA @ 400 kg ha-1 resulted in decreased plant height in the lowest salinity condition. Salinity level (S1 = 0.33 dsm-1) revealed the highest plant heights across all sulphuric acid treatments, indicating that wheat grows best in low-salinity conditions. Salinity level (S2 = 5.5 dsm-1) had moderate impact on plant height, with some sulphuric acid treatments showing beneficial effects. Salinity level (S3 = 7.75 dsm-1) showed the most detrimental to wheat growth, although some improvement was observed with certain levels of sulphuric acid. The interaction between sulphuric acid levels and salinity levels is complex. At lower concentrations, sulphuric acid appears to moderate the negative effects of salinity stress on wheat, possibly by enhancing nutrient availability or altering soil pH to a more favourable level. However, at higher concentrations of sulphuric acid, especially in high salinity conditions, the trend reverses, and plant growth is adversely affected. This could be due to the phytotoxic effects of excess sulphuric acid, leading to soil acidification beyond the optimal pH range for wheat growth. Sulphuric acid can be used to enhance wheat growth under moderate salinity stress, its application must be carefully managed to avoid harmful effects, particularly in soils with already high salinity levels. Plant height reduced significantly with the application of various salinity levels as already cited by Ghogdi et al. (2012).

TABLE.5 SPIKE WEIGHT (G) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels S1 = 0.33 dsm-1	S2 = 5.5 dsm-1	S3 = 7.75 dsm-1	Mean
No sulphuric acid	13.73cde	9.53kl	8.53l	10.60e
@ 100 kg ha-1	14.36c	10.63ij	9.70jk	11.56d
@ 200 kg ha-1	15.06b	11.60gh	10.73hi	12.46c
@ 300 kg ha-1	15.56ab	12.83ef	11.90fg	13.43b
@ 400 kg ha-1	16.13a	13.80cd	13.06de	14.33a

Means	14.97a	11.68b	10.78c	

TABLE.6 NUMBER OF SPIKELET'S (SPIKE-1) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			Mean
	S1 = 0.33 dsm-1	S2 = 5.5 dsm-1	S3 = 7.75 dsm-1	
No sulphuric acid	14.50e	13.46h	12.50j	13.48e
@ 100 kg ha-1	14.70d	13.70g	12.56j	13.65d
@ 200 kg ha-1	15.00c	14.00f	13.00I	14.00c
@ 300 kg ha-1	15.46b	14.63de	13.53h	14.54b
@ 400 kg ha-1	16.00a	15.000C	14.00f	15.00a
Means	15.13a	14.16b	13.12c	

LEAF AREA INDEX

The highest mean LAI was observed at 400 kg ha-1 (16.36), indicating a positive effect of sulphuric acid on wheat leaf development. The results show statistically significant differences between the control and the highest sulphuric acid level, suggesting that sulphuric acid positively influences wheat growth. The LAI varied across different salinity levels revealed that the lowest salinity level (S1 = 0.33 dsm-1) generally showed higher LAI compared to S2 (5.5 dsm-1) and S3 (7.75 dsm-1). This indicates that lower salinity is more favourable for wheat leaf development. The decrease in LAI at higher salinity levels (S2 and S3) suggests that salinity stress negatively impacts wheat growth. The interaction between sulphuric acid and salinity levels was evident. For example, at 400 kg ha-1 sulphuric acid level, the LAI was highest across all salinity levels, suggesting that sulphuric acid application might reduce some of the negative effects of salinity. The variability in LAI under different combinations of sulphuric acid and salinity levels indicates a complex interaction affecting wheat growth. The increase in LAI with higher sulphuric acid levels might be due to improved nutrient availability or soil properties that favour wheat growth. The mechanisms through which sulphuric acid enhances growth could include soil pH modification, enhanced nutrient solubility, or improved root growth and function. The decline in LAI with increased salinity levels is consistent with the known effects of salinity stress on plants, including reduced water uptake, nutrient imbalances, and ionic toxicity. The finding of Saqib et al. (2008) supported our results who reported that leaf area index was reduced significantly with the application of salinity.

SPIKE WEIGHT (G)

The Increasing the amount of sulphuric acid improved the spike weight. Maximum spike weight (14.33 g) was recorded @ 400 kg ha-1 and spike weight decreased with the decreasing level of sulphuric acid. Minimum spike weight was noted in control i.e. (10.60 g). Salinity level (S1 = 0.33 dsm-1) showed the highest spike weights across all sulphuric acid treatments, confirming that wheat performs best under low salinity. At S2 (5.5 dsm-1) spike weights were moderately affected by this level of salinity, with sulphuric acid applications showing beneficial effects. S3 (7.75 dsm-1 high salinity) produced the lowest spike weights were observed under this condition. The data illustrates a clear interaction between sulphuric acid application and salinity levels in soil. Sulphuric acid, when applied at increasing concentrations, consistently improves spike weight in wheat, even under higher salinity stress. This could be due to sulphuric acid's role in nutrient solubilisation and improved nutrient uptake by plants. Notably, the highest sulphuric acid level (@ 400 kg ha-1) resulted in the greatest spike weights across all salinity levels, suggesting that wheat's response to sulphuric acid is positively correlated with its concentration, up to the levels tested. It was reported by Ibrahim, 2003 that higher concentrations of salts negatively affect spike weight.

NUMBER OF SPIKELET'S (SPIKE^{-1})

The Control (no sulphuric acid) exhibited a moderate number of spikelets per spike across different salinity levels, with an overall mean of 13.48, setting a baseline for wheat development without sulphuric acid. SA @100 kg ha-1 showed slight increase in the number of spikelets per spike compared to the control across all salinity levels, suggesting a potential positive impact of this low sulphuric acid concentration on spikelet development. SA @ 200 kg ha-1 revealed further improvement in the number of spikelets per spike especially noticeable in higher salinity conditions indicating that this level of sulphuric acid might positively influence wheat development under salinity stress. However, SA @ 300 kg ha-1 indicated further increase in the number of spikelets per spike in lower salinity conditions, but a less pronounced increase at the highest salinity level (S3), hinting at a diminishing return or lesser benefit at higher sulphuric acid concentrations. SA @ 400 kg ha-1 resulted in highest number of spikelets per spike in all conditions, especially notable in the highest salinity level (S3), suggesting a specific benefit of this concentration under extreme salinity conditions. Looking into the results of salinity levels it was observed that S1 (0.33 dsm-1) produced higher number of spikelets per spike across all sulphuric acid treatments, indicating that wheat spikelet development is most efficient under low-salinity conditions. S2 (5.5 dsm-1) put moderate impact on the number of spikelets per spike, with some improvements observed with increasing sulphuric acid applications, indicating mitigation of salinity stress. S3 (7.75 dsm-1 high salinity) lowered the numbers of spikelets per spike, although some improvements were noted with certain levels of sulphuric acid, suggesting that sulphuric acid can partially alleviate the negative impact of high salinity on spikelet development. The interaction between sulphuric acid levels and salinity levels influence on the number of spikelets per spike in wheat revealed that lower sulphuric acid concentrations provide a benefit, while higher concentrations continuously improve spikelet development, especially under moderate to high salinity stress. This suggested that sulphuric acid, at specific concentrations, can reduce the negative effects of salinity on wheat development. Our results are supported by Maas and Grieve (2019) who stated that drought or high salinity stress decrease the spike and no. of spikelet spike-1 development in wheat.

TABLE 4.7 NUMBER OF TILLERS (POT-1) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			Mean
	$S_1 = 0.33$ dsm^{-1}	$S_2 = 5.5$ dsm^{-1}	$S_3 = 7.75$ dsm^{-1}	
No sulphuric acid	25.00de	20.00j	18.00k	21.00e
@ 100 kg ha^{-1}	26.00c	22.00hi	20.00j	22.66d
@ 200 kg ha^{-1}	26.00c	23.00fg	21.33i	23.44c
@ 300 kg ha^{-1}	27.00b	24.66e	22.66gh	24.77b
@ 400 kg ha^{-1}	28.00a	25.66 cd	24.00ef	25.88a
Means	26.40a	23.06b	21.20c	

TABLE 4.8 SPIKE LENGTH (CM) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			
	S1 = 0.33 dsm-1	S2 = 5.5 dsm-1	S3 = 7.75 dsm-1	Mean
No sulphuric acid	9.50c	8.43f	7.43i	8.45e
@ 100 kg ha-1	9.50c	8.76e	7.76h	8.67d
@ 200 kg ha-1	9.63c	9.13d	8.13g	8.96c
@ 300 kg ha-1	10.00b	9.53c	8.46f	9.33b
@ 400 kg ha-1	10.43a	9.93b	9.00de	9.78a
Means	9.81a	9.16b	8.16c	

NUMBER OF TILLERS (POT^{-1})

With an average of 21.00. SA @100 kg ha-1 exhibited a slight increase in the number of tillers per plant across all salinity levels compared to the control, suggesting a potential benefit of this low sulphuric acid concentration on tiller formation. SA @ 200 kg ha-1 further improved the number of tillers per plant. This indicates that this level of sulphuric acid might be beneficial for tiller development under salinity stress. SA @ 300 kg ha-1 continues the trend of increasing number of tillers per plant, particularly in lower salinity conditions. However, the increase is less evident at the highest salinity level (S3), suggesting a potential threshold for sulphuric acid effectiveness. SA @ 400 kg ha-1 shows the highest number of tillers per plant in all conditions, particularly notable in the highest salinity level (S3), indicating a specific advantage of this concentration under extreme salinity conditions. Low salinity level (S1 = 0.33 dsm-1) generally resulted in the highest number of tillers per plant across all sulphuric acid treatments, showing that wheat tiller development is most efficient under low-salinity conditions. S2 (5.5 dsm-1) showed moderate impact on tiller numbers, with gradual improvements seen with increasing sulphuric acid applications, indicating some improvement of salinity stress. S3 (7.75 dsm-1) typically showed the lowest number of tillers per plant, although improvements were noted with higher sulphuric acid levels, suggesting that sulphuric acid can partially counteract the negative impact of high salinity on tiller development. The interaction between sulphuric acid levels and salinity levels shows a complex influence on tiller development in wheat. Lower concentrations of sulphuric acid provide modest benefits, while higher concentrations increasingly improve tiller formation, especially under moderate to high salinity stress. Our finding is in agreement with Asha and Dhingra (2007) who stated that higher salinity level reduced number of tillers per plant in wheat crop.

SPIKE LENGTH (CM)

Control treatment had an average spike length across different salinity levels, with an overall mean of 8.45 cm, establishing a baseline for the impact of sulphuric acid on wheat. SA @ 100 kg ha-1 displays a slight increase in spike length across all salinity levels compared to the control. SA @ 200 kg ha-1 improved spike length, particularly in higher salinity conditions. This indicates that this level of sulphuric acid might positively affect spike growth under salinity stress. SA @ 300 kg ha-1 shows continued upward trend in spike length, with particularly notable in lower salinity conditions. However, the increase at the highest salinity level (S3), indicated a possible threshold for sulphuric acid effectiveness. SA @ 400 kg ha-1 exhibited the highest spike lengths in all conditions, especially in the highest salinity level (S3), suggesting a specific advantage of this concentration under extreme salinity conditions. Salinity level S1 (0.33 dsm-1) resulted in the longest spike lengths across all sulphuric acid treatments, indicating that wheat spike growth is most efficient under low-salinity conditions. S2 (5.5 dsm-1) Showed a moderate impact on spike length, with gradual improvements seen with increasing sulphuric acid applications, suggesting some improvement of salinity stress. S3 (7.75 dsm-1) showed the shortest spike lengths, although improvements were noted with higher sulphuric acid levels, indicating that sulphuric acid can partially counteract the negative impact of high salinity on spike growth.The interaction between sulphuric acid levels and salinity levels reveals a complex influence on spike length in wheat. Lower concentrations of sulphuric acid provide modest benefits, while higher concentrations increasingly improve spike growth, particularly under moderate to high salinity stress. Sulphuric acid, at specific concentrations showed the potential of sulphuric acid as a treatment to improve wheat spike growth in saline conditions. Our results are similar to the finding of Asha and Dhingra (2007) who reported that high level of salts in the soil reduced spike length.

NUMBER OF GRAINS (SPIKE^{-1})

The untreated (Control) had minimum number of grains per spike across different salinity levels, with an average of 37.00. SA @100 kg ha-1 showed a slight increase in the number of grains per spike across all salinity levels compared to the control, suggesting a potential benefit of this low sulphuric acid concentration on grain development. SA @ 200 kg ha-1 revealed further improvement in the number of grains per spike, especially noticeable in higher salinity conditions. This indicates that this level of sulphuric acid might positively affect grain production under salinity stress. SA @ 300 kg ha-1 indicated continued upward trend in the number of grains per spike, particularly in lower salinity conditions. The increase at the highest salinity level (S3), suggesting a possible threshold for sulphuric acid effectiveness. SA @ 400 kg ha-1 exhibited the highest number of grains per spike in all conditions, especially in the highest salinity level (S3), indicating a specific advantage of this concentration under excessive salinity conditions. Salinity level S1 (0.33 dsm-1) generally resulted in the highest number of grains per spike across all sulphuric acid treatments, indicating that wheat grain development is most efficient under low-salinity conditions. S2 (5.5 dsm-1) Showed a moderate impact on the number of grains per spike, with gradual improvements seen with increasing sulphuric acid applications, suggesting some mitigation of salinity stress. S3 (7.75 dsm-1) exhibited the lowest number of grains per spike, although improvements were noted with higher sulphuric acid levels, indicating that sulphuric acid can partially counteract the negative impact of high salinity on grain development. The interaction between sulphuric acid levels and salinity levels reveals a complex influence on the number of grains per spike in wheat. Lower concentrations of sulphuric acid provide modest benefits, while higher concentrations increasingly improve grain production, especially under moderate to high salinity stress. Sulphuric acid, at specific concentrations can reverse the adverse effect of salinity in wheat grain development. Our findings are supported by Ghogdi et al. (2012) who stated that number of grains per spike was reduced significantly with the application of salinity.

TABLE 4.9 NUMBER OF GRAINS (SPIKE-1) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			
	S1 = 0.33 dsm-1	**S2 = 5.5 dsm-1**	**S3 = 7.75 dsm-1**	**Mean**
No sulphuric acid	43.00e	36.00jk	32.00m	37.00e
@ 100 kg ha-1	44.83d	38.00hi	34.00l	38.94d
@ 200 kg ha-1	46.00c	39.66g	35.00k	40.22c
@ 300 kg ha-1	47.33b	41.66f	37.00ij	42.00b
@ 400 kg ha-1	49.00a	43.66de	39.00gh	43.88a
Means	46.03a	39.80b	35.40c	

TABLE 4.10 GRAIN YIELD (G POT-1) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			
	S1 = 0.33 dsm-1	**S2 = 5.5 dsm-1**	**S3 = 7.75 dsm-1**	**Mean**
No sulphuric acid	34.00c	28.00fg	24.000i	28.66c
@ 100 kg ha-1	34.96bc	29.233ef	26.167h	30.12b
@ 200 kg ha-1	35.66abc	30.000de	27.300gh	30.98ab
@ 300 kg ha-1	36.33ab	30.933d	28.233fg	31.83a
@ 400 kg ha-1	36.90a	31.467d	29.25ef	32.53a
Means	35.57a	29.927b	26.99c	

GRAIN YIELD (G POT^{-1})

Data collected for grain yield are presented in Table 4.10. The ANOVA for this parameter is presented in Appendix-X. The control treatment exhibited grain yield per pot across different salinity levels, with an overall mean of 28.66. SA @ 100 kg ha-1 exhibited a slight increase in grain yield per pot across all salinity levels compared to the control, suggesting a potential benefit of this low sulphuric acid concentration on grain yield. SA @ 200 kg ha-1 further improved grain yield per pot especially noticeable in higher salinity conditions. This suggests that this level of sulphuric acid might positively influence wheat yield under salinity stress. SA @ 300 kg ha-1 continued the upward trend in grain yield per pot, with particularly notable increases in lower salinity conditions. However, the increase at the highest salinity level (S3, indicated a potential threshold for sulphuric acid effectiveness. SA @ 400 kg ha-1 showed the highest grain yield per pot in all conditions, especially in the highest salinity level (S3). Salinity level S1 (0.33 dsm-1) resulted in the highest grain yield per pot across all sulphuric acid treatments, indicating that wheat yield is most efficient under low-salinity conditions. S2 (5.5 dsm-1) Showed a medium impact on grain yield, with gradual improvements observed with increasing sulphuric acid applications. S3 (7.75 dsm-1 high salinity) typically exhibited the lowest grain yield per pot, although improvements were noted with the application of higher sulphuric acid levels, suggesting that sulphuric acid can partially cancel out the negative impact of high salinity on grain yield. The interaction between sulphuric acid levels and salinity levels revealed a complex influence on grain yield in wheat. Lower concentrations of sulphuric acid provide modest benefits, while higher concentrations increasingly improve grain yield, particularly under moderate to high salinity stress. This pattern suggests that sulphuric acid, at specific concentrations, can reduce the adverse effects of salinity on wheat yield. Saline water and inefficient drainage facilities have resulted in rising groundwater levels, which trigger salt accumulation in the topsoil, resulting in negative effects on crop production of crop especially in wheat (Gelaye et al., 2019). This outcome was also advocated by Syed et al. 2021. High level of salts (soluble or exchangeable sodium ions (Na^+)) in the soil adversely affects germination, which results in reduction in grain yield of wheat as well as other crops. Primary reasons for low production in salt-stressed soil include osmotic and specific ion effects, nutritional imbalances, and abnormal pH (Rizk et al., 2020; Soothar et al., 2021). Annual yield of wheat crop is severely affected by the rising salt levels in the soil (Qadir et al., 2014). These findings also confirm our results.

1000 GRAIN WEIGHT (G)

The Control (no sulphuric acid) exhibited an average weight of grain weight across different salinity levels, with an overall mean of 42.00 (g). SA @ 100 kg ha-1 showed a slight increase in the grain weight across all salinity levels compared to the control, suggesting a potential benefit of this low sulphuric acid concentration on grain weight. SA @ 200 kg ha-1 revealed further improved in the grain weight, especially noticeable in higher salinity conditions. This indicates that this level of sulphuric acid might positively influence grain weight under salinity stress. SA @ 300 kg ha-1 revealed trend of increasing the weight of grains, particularly in lower salinity conditions. SA @ 400 kg ha-1 showed the highest weight of grains in all conditions, especially in the highest salinity level (S3), indicating a specific advantage of this sulphuric acid concentration under extreme salinity conditions. Salinity level S1 (0.33 dsm-1) generally resulted in the heaviest 1000 grains across all sulphuric acid treatments, indicating that grain weight is most positively affected under low-salinity conditions. S2 (5.5 dsm-1) showed a moderate impact on the weight of 1000 grains, with gradual improvements seen with increasing sulphuric acid applications, suggesting some mitigation of salinity stress. S3 (7.75 dsm-1) exhibited the lightest weight for grains, although improvements are noted with higher sulphuric acid levels. The interaction between sulphuric acid levels and salinity levels revealed a complex influence on the weight of grains in wheat. Lower concentrations of sulphuric acid provided diffident benefits, while higher concentrations increasingly improved grain weight, particularly under moderate to high salinity stress. Sulphuric acid, at specific concentrations, can reduce the adverse effects of salinity on wheat grain weight. Our finding is supported by Asha and Dhingra (2007) who stated that the soil salinity may cause several deleterious effects like low osmotic potential of soil solution, specific ion effects, and nutritional imbalances or combined effect of all these factors deleterious effects on growth and development which results in reduction in grains. Wheat crop more tolerant at germination stage but highly sensitive to salinity at later stage such as grain formation stage in wheat crop.

TABLE 4.11 1000 GRAIN WEIGHT (G) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS

Sulphuric Acid Levels	**Salinity Levels**			
	S1 = 0.33 dsm-1	**S2 = 5.5 dsm-1**	**S3 = 7.75 dsm-1**	Mean
No sulphuric acid	45.00NS	42.00	39.00	42.00e
@ 100 kg ha-1	46.73	44.00	40.83	43.85d
@ 200 kg ha-1	48.40	46.03	42.76	45.73c

@ 300 kg ha-1	50.23	47.30	44.30	47.27b
@ 400 kg ha-1	51.53	48.96	45.73	48.74a
Means	48.38a	45.66b	42.52c	

TABLE. 12 STRAW YIELD (G POT-1) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS.

Sulphuric Acid Levels	Salinity Levels			
	S1 = 0.33 dsm-1	S2 = 5.5 dsm-1	S3 = 7.75 dsm-1	Mean
No sulphuric acid	55.00f	50.00i	47.00j	50.66e
@ 100 kg ha-1	57.16de	52.26h	49.13i	52.85d
@ 200 kg ha-1	58.86c	54.23fg	51.33h	54.87c
@ 300 kg ha-1	60.06b	56.23e	53.60g	56.63b
@ 400 kg ha-1	62.53a	57.83cd	56.30e	58.88 a
Means	58.72a	54.13b	51.51c	

TABLE. 13 HARVEST INDEX (%) OF WHEAT AS AFFECTED BY SULPHURIC ACID IN COMBINATION WITH DIFFERENT SALINITY LEVELS

Sulphuric Acid Levels	Salinity Levels			
	S1 = 0.33 dsm-1	S2 = 5.5 dsm-1	S3 = 7.75 dsm-1	Mean
No sulphuric acid	35.00g	32.00j	29.00l	32.000e
@ 100 kg ha-1	37.06e	34.23h	31.00k	34.100d
@ 200 kg ha-1	39.16c	36.30f	33.20i	36.222c
@ 300 kg ha-1	41.00b	38.43d	35.80f	38.411b
@ 400 kg ha-1	43.73a	40.33b	38.03d	40.700a
Means	39.193a	36.260b	33.407c	

STRAW YIELD (G POT^{-1})

Straw yield per pot across different salinity levels, with an overall mean of 50.66. SA @ 100 kg ha-1 showed a slight increase in straw yield per pot across all salinity levels compared to the control, suggesting a potential benefit of this low sulphuric acid concentration on straw production. SA @ 200 kg ha-1 further improved straw yield per pot, especially noticeable in higher salinity conditions. This indicates that this level of sulphuric acid might positively affect straw yield under salinity stress. SA @ 300 kg ha-1 showed continued upward trend in straw yield per pot, particularly in lower salinity conditions. The increase at the highest salinity level

(S3), suggest a potential threshold for sulphuric acid effectiveness. SA @ 400 kg ha-1 exhibited the highest straw yield per pot in all conditions, especially in the highest salinity level (S3). Salinity level S1 (0.33 dsm-1) resulted in the highest straw yield per pot across all sulphuric acid treatments, indicating that straw production in wheat is most efficient under low-salinity conditions. S2 (5.5 dsm-1 moderate salinity) showed a moderate impact on straw yield, with gradual improvements observed with increasing sulphuric acid applications, suggesting some mitigation of salinity stress. S3 (7.75 dsm-1 high salinity) exhibited the lowest straw yield per pot, although improvements were noted with higher sulphuric acid levels. The interaction between sulphuric acid levels and salinity levels revealed a complex influence on straw yield in wheat. Lower concentrations of sulphuric acid provided modest benefits, while higher concentrations increasingly improved straw yield, particularly under moderate to high salinity stress. Our results are similar to Cha-um et al. (2004) who reported that higher levels of salt concentration produce toxic effect on straw yield of wheat and increases in salinity level cause reduction in straw yield of wheat. The response of plants exposed to salinity stress is a decrease in plant canopy, which reduces plant straw yield.

HARVEST INDEX (%)

The harvest index of 35.00% at low salinity (S1), 32.00% at medium salinity (S2) and 29.00% at high salinity (S3), with an overall mean of 32.00%. SA @ 100 kg ha-1 resulted in slight increase in the harvest index across all salinity levels compared to the control, indicating a potential benefit of low sulphuric acid concentration on the harvest index (Mean: 34.10%). SA @ 200 kg ha-1 indicated further improvement in the harvest index, especially noticeable in higher salinity conditions with 36.22%. This suggests that this level of sulphuric acid might positively influence the harvest index under salinity stress. SA @ 300 kg ha-1 showed a continue trend of increasing the harvest index, particularly in lower salinity conditions, but less pronounced at the highest salinity level. SA @ 400 kg ha-1 showed the highest harvest index in all conditions, especially in the highest salinity level, indicating a specific advantage of this sulphuric acid concentration under extreme salinity conditions. Salinity Level S1 (0.33 dsm-1 Low salinity) generally resulted in a higher harvest index across all sulphuric acid treatments, indicating that the harvest index is most positively affected under low-salinity conditions. S2 (5.5 dsm-1 moderate salinity) had a moderate impact on the harvest index, with gradual improvements seen with increasing sulphuric acid applications, suggesting some mitigation of salinity stress. S3 (7.75 dsm-1 high salinity) typically exhibited the lowest harvest index, although improvements were noted with application of higher sulphuric acid levels, indicating that sulphuric acid can partially counteract the negative impact of high salinity on the harvest index. The interaction between sulphuric acid levels and salinity levels reveals a complex influence on the harvest index of wheat. Lower concentrations of sulphuric acid provided modest benefits, while higher concentrations increasingly improved the harvest index, particularly under moderate to high salinity stress.

CONCLUSION

This study highlights potential of sulphuric acid for enhancing the yield (yield contributing parameters) and growth of wheat under saline conditions. To fully utilize sulphuric acid's benefits while preventing negative consequences, this highlights the critical need for specific and sensible regulatory measures about the adjustments in sulphuric acid levels especially in soils with different salt levels. The outcome has important results for creating agronomic strategies to improve wheat yield in saline soils, which is a major problem in farming environments

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