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# Soil Salinity Impacts on Cotton and Sugarcane Productivity in Sindh's Irrigated Areas

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**ABSTRACT**

Soil salinity has become a significant problem for agricultural productivity in irrigated lands of Sindh, Pakistan and the crops (cotton, sugarcane) are also facing the problem. High amounts of soluble salts in the soil decrease the availability of water, interfere with the uptake of nutrients, and affect the plant's growth leading to tremendous yield losses. This study is aimed at the evaluation and ascertainment of the effects of salinity of irrigation water on cotton and sugarcane growth, physiological traits and agro productive potential of sugarcane and cotton in important irrigated areas of Sindh. Soil samples were taken from several fields of different salinity levels and tested for electrical conductivity, sodium adsorption ratio and nutrient content. Crop growth parameters such as plant height, leaf area and biomass were recorded, whereas yield components were measured at harvests. Results showed that rising soil salinity had a negative impact on both crops resulting in a decline in growth and yield that were more noticeable for sugarcane than for the cotton. Salinity stress was related with reduction of chlorophyll content as well as decreased stomata conductance and imbalance nutrients indicating physiological burden of plants during saline condition. These results highlight the need for urgent management of salt, such as better irrigation and use of salt tolerant cultivars and soil amendments to maintain cotton and sugarcane productivities in the irrigated areas of Pakistan's leading sugar cane and cotton producing provinces-Sindh.

## Introduction

Soil salinity is a great problem of the agriculture in arid and semi-arid regions, where the over irrigation practice is often followed and soluble salts would be accumulated in the soil profile. In Pakistan particularly the Sindh province is affected owing to huge canal irrigation system and high rate of evapotranspiration leads to salt accumulation in the irrigated lands (Qureshi et al., 2017; Akhtar et al., 2018). Cotton and sugarcane which are two most important cash crops of the region are very sensitive to salinity and their productivity is reduced significantly in saline conditions. Soil salinity affects plants to water relationship, nutrient uptake, photosynthetic efficiency and finally, crop yield (Munns & Tester, 2008; Farooq et al., 2015).

Electrical conductivity (EC) commonly is used as a surrogate for soil salinity and sodium adsorption ratio (SAR) provides information of sodicity of soil that may further affect soil structure and permeability. As the saline environments increasing, high EC value and high SAR values effect to the root development and the water uptake adversely leading to the increase in the drought like stress under adequate irrigation (Rengasamy, 2010, Singh et al., 2019). In Sindh the EC's of more than 4 dS/m have been reported for multiple irrigating plots representing moderately to highly saline condition leading to poor growth of cotton and sugarcane (Ali et al., 2019; Hussain et al., 2020).

Cotton (Gossypium hirsutum) is a medium salt tolerant and greater yield losses are explained by the reduction in vegetative growth and reduction in bol size and poor in fibre quality under salinity stress (Ashraf and Foolad, 2007; Ismail et al., 2013). Sugarcane (Saccharum officinarum) on the other hand since it is highly sensitive to salinity as excessive amount of saline content comes down of the length of the stalk and accumulation of biomass and sugar contents (Singh et al., 2015; Sharma et al., 2018). Salinity stress elicit a cascade of physiological and biochemical reactions such as osmotic adjustment, accumulation of compatible solutes such as proline, variation of antioxidant enzymes activities which will determine in the end the plant tolerance (Parida & Das, 2005; Farooq et al., 2015).

Irrigation methods in Sindh While irrigation plays a very vital role in production of crop but it is one of the major ways of salinization in Sindh. Poor drainage and over irrigation, use of saline canal water leading to accumulation of salt in the root zone of the plant makes the situation even worse with respect to limiting the intake of water and nutrients (Qureshi et al., 2017; Akhtar et al., 2018). In addition, the climate change and the increasing temperature further accelerates the rate of evapotranspiration which implies the salts are able to concentrate in the top soil faster which places more stress on crops (Khan et al., 2020; Rengasamy, 2010).

Several strategies have been proposed for alleviating the salinity effects are the use of salt tolerant cultivars, better irrigation schedule, soil amendment such as gypsum as well as integrated nutrient management practices (Ashraf & Foolad, 2007; Ismail et al., 2013). However the implementation at a field level in the province of sowndh is still small and hence there is need to conduct such research on a region specific basis to quantify the impacts of salinity and to establish the management practices for the same. Understanding the relation of soil salinity and crop productivity is very important for sustaining the agricultural output of this region which plays an important role in economy and food security of Pakistan (Farooq et al., 2015; Hussain et al., 2020).

The major objective of present study therefore is to assess the effect of different levels of soil salinity on growth and physiological characters and yield component of cotton and sugarcane in irrigated areas of Sindh. By analyzes of soils physicochemical characteristics and quantitative determination of crop performances, the research aims to identify the critical threshold of salinity at which salinity start to significantly reduce the productivity, and giving recommendations on how to mitigate the salinity induced yield losses. The results will feed to establish the sustainable ways of managing irrigation and soil to ensure the sustainability of the cultivation of cotton and sugarcane in the region in long-term (Singh et al. 2015; Sharma et al., 2018; Ali et al., 2019).

## Literature Review

Soil salinity is a wide-ranging problem in between irrigated agriculture in the world, especially in arid and semi-arid places and is a lead causative which contributes to a decrease in the crop's productivity (Munns, & Tester, 2008; Rengasamy 2010). In Pakistan, irrigated areas of Sindh is extremely vulnerable which occurred due to poor drainage; excessive irrigation or due to use of canal water with high salt content (Qureshi et al. 2017; Akhtar et al. 2018). The salinity stress influence the plants through causing osmotic stress, ion toxicity and nutrient imbalance which finally leads to a decrease in growth and yield (Parida and Das, 2005; Farooq et al, 2015).

Cotton (Gossypium hirsutum) has medium level tolerance to salinity and yield losses is mostly due to the decreased vegetation development and functional disorder of the boll development and decreased fibre qualities (Ashraf & Foolad, 2007; Ismail et al., 2013). Soil salts are formed as a consecutive of accumulations that are formed due to the excessive presence of sodium and chloride in the soil that may interfere to water absorption and photosynthesis that may also lead to retared growth of vegetations and poor yield (Singh et al., 2015. Studies have been carried out in Pakistan and the results show that there is a decrease in the cotton yield with an increase in the soil electrical conductivity (EC) but the soils that have high electrical conductivity (EC more than 4 dS/m) have a higher decrease in the cotton yield (Ali et al., 2019; Hussain et al., 2020). Salt stress also causes physiological changes such as accumulation of compatible solutes such as proline and soluble sugars which is helpful to plants in osmoregulation i.e. to maintenance of turgor pressure i.e. to hold the plant in an erect position (Parida & Das, 2005; Ashraf & Foolad, 2007).

Sugarcane (Saccharum officinarum) is more prone to salinity than cotton due to high concentration of salt in the environment reduce the elongation of the stalk, the accumulation of biomass and sugar content (Sharma et al., 2018; Singh et al., 2015). Excessive sodium brings about the disturbance in the ingestion of nutrients, especially potassium and calcium nutrients, and brings the negative effect on the capacity of producing photosynthesis and causing a further restraint in productivity (Khan et al., 2020). Several researches reported about loss of sugarcane yield more than 30% in those fields with more than 6 dS/m EC comprising the importance of particular management's strategies (Farooq et al., 2015; Hussain et al., 2020).

Physiological responses as stomatal closure,decrease transpiration, decrease chlorophyll content of plant leading to decreased photosynthesis therefore availability of energy to grow, reduced growth (Ashraf and Foolad, 2007; Ismail et al., 2013). Enzymatic and antioxidative systems in plants such as superoxide dismutase, catalase and peroxidase are subject to induction in the plants subjected to the salt stress to limit the oxidative damage by the reactive oxygen species (ROS) (Parida & Das, 2005; Farooq et al., 2015). However, with a high salinity for prolonged periods of time, there is a chance that these defence mechanisms will be overwhelmed leading to a damage to the cell and thereby leading to a reduced crop performance(Sharma et al., 2018).

Irrigation procedures are right correlated to dynamic of salinity. Poor management of irrigation leads to water logging of the low lying areas, and salt getting build up in the root zone increasing the stress on crops [Qureshi et al., 2017; Akhtar et al., 2018]. The use of saline canal water also lead to salinization of soil especially in absence of adequate leach and drainage system (Rangaswami, 2010; Khan et al, 2020). Field studies in Sindh has revealed that fields with high EC of soil are often the fields that have poor drainage facility and repeated irrigation cycles without leaching and hence pose the problem of chronic salinity stress (Ali et al., 2019; Hussain et al., 2020).

For the cotton and the sugarcane, a number of ways of reducing the effects of the salinity have been proposed. The utilisation of salt tolerant cultivars have shown some promise and some of the cotton cultivars are still able to sustain high yield under moderate salinity (Ismail et al, 2013; Ashraf and Foolad, 2007). Sugarcane breeding programmes also take into consideration genotypes having better tolerance to salt etc include availability of efficient ion exclusion, osmotic adjustment (Singh et al., 2015; Sharma et al., 2018). Soil amendments, such as gypsum, organic materials have been reported to improve the soil structure and displace the sodium ions and will increase water infiltration thus countering the negative impacts of salinity (Farooq et al. 2015 ; Khan et al. 2020).

Monitoring and management of the quality of the water in the irrigation is just as important as well. Leaching method, proper irrigation technique and availability of good quality water in canals help controlling lower EC in soil root zone and encouring the growth of crop in saline situation (Rengasamy, 2010; Akhtar et al., 2018). Integrated strategies of tolerant cultivars, improved irrigation and soil amendments are needed for continuance of cotton and sugarcane productivity in irrigated areas of Sindh (Ali et al. 2019; Hussain et al. 2020).

Recent researches have highlighted the importance of knowing the physiology of plants in field conditions since the controlled experiments cannot reflect the complexity of interactions of soil, water and climate (Parida and Das, 2005; Farooq et al, 2015). Studies in Pakistan have revealed regional differences in the amount of salinity impact with some localities showing higher levels of yield reduction owing to the soil texture and irrigation technique coupled with local management decision (Singh et al, 2015; Sharma et al, 2018). Therefore, localized studies are of prime importance in order to build-up effective management strategies found in different agro climatic zones.

In conclusion it can be concluded that the Soil Salinity is one of the of major restricting constraints in productivity of cotton and sugarcane irrigated areas of Sindh. Both the crops show reduction in growth and yield in saline condition sugarcane being more sensitive in comparison to cotton. Physiological and biochemical response in plant is good to cope with the stress but longer duration of exposure to such high salinity overcomes such mechanisms. Effective management strategies such as salt tolerant cultivars, improved irrigation, soil amendments and integrated nutrient management are keys if the productivity is to be sustained. This literature review is a really good foundation for the present study which aims as not only to quantify the salinity effects but also to draw some practical recommendations in order to manage the yield losses caused by salinity in Sindh.

## Methodology

**Study Area**

The study has been undertaken in irrigated agriculture areas of the Sindh province in Pakistan which is a major agriculture producer of cotton and sugarcane. Six representative districts, namely Hyderabad, Sukkur, Nawabshah, Thatta, Mirpurkhas and Larkana on the basis of the irrigation practices, level of salinity and distribution of crops were taken. These areas are characterised by high evapotranspiration, low drainage and periodic water logging - these factors make them susceptible to salinity of soil (Qureshi et al., 2017; Akhtar et al., 2018).

**Experimental Design**

A field based observational study was done based on the plots classified based on Soil Salinity (EC < 2dS/m, moderate: EC 2-4 dS/m and high: EC < 4 dS/m) level. Each category had 5 replicates fields for both cotton and sugarcane fields such as to get spatial representation. Use made of random samples was attempted to put down the bias in the measurements caused by heterogeneity of soil.

**Soil Sampling and Analysis**

Composite samples of the soil of the surface layer (0-20 cm) were collected using the method of sterile auger. A total of 15 composite samples per field were collected from each field in five subsamples from each field. Sealed samples of soil were dried at air and sieved (2 mm) and analysed on:

- Exponentially greaterEq**9 units **greater** Exponentially greater
- These sodium, calcium, and magnesium concentrations are used to calculate the following: - Sodium Adsorption Ratio (SAR) (Richards, 1954).
- Soil pH - pH of the soil in a 1:2.5 soil to water suspension as measured by a digital pH meter.
- Review Paper for the Biology of Striga.Review Paper on Biology of Striga.

**Crop Growth and Physiological Measurements**

For each plot, ten plants were randomly selected for growth assessments:

- **Plant Height:** This is measured from base to apex in maximal vegetative stage.
- **oLeaf Area:** acetone-determinded by the usage of a leaf area meter.
- **Biomass:** (Above ground Fresh and dry weight at the time of harvest).

Physiological parameters included:

- **Chlorophyll Content:** Measurements made with SPAD meter
- **oStomatal Conductance:** Measured using a porometer in order to measure water control during stress from salinity.
- **Relative Water Content (RWC):** Measured after normal gravimetric methods (Barrs & Weatherley, 1962).
- Yield Assessment

Cotton yield components measured were boll number, boll weight and seed cotton yield (per plant). For sugarcane instead, stalk height, cane diameter, number of canes suitable for milling, and cane total yield/ha were measured at harvest.

**Statistical Analysis**

Data analysis was done using the statistical software analysis (SPSS v26). One way analysis of variance (one way- or One way Analysis Of Variance), (or invariable or invariable analysis of variance) or Analysis of Variance (one way or One way Analysis Of Variance) was performed to identify the difference in soil properties, crop growth and yield between the salinity levels.

Tukey's HSD test was used for post-hoc comparison tests. Pearson correlation coefficients were used to measure the relations of soil salinity information (EC and SAR) with the crop factors of performance. Significance was accepted on $p < 0.05$ level.

## Data Analysis & Findings

The results of soil sample analysis from the six irrigated districts in Sindh showed wide variability in salinity level and it affected growth and yield of cotton and sugarcane significantly. Electrical conductivity (EC) values varied between 1.2 and 6.8 dS/m with the high salinity fields mostly recorded in Nawabshah, Thatta and Mirpurkhas. Sodium adsorption ratio (SAR) values were also variable and this showed differential soil sodicity, which affects soil structure and water availability (Qureshi et al., 2017; Rengasamy, 2010).

Cotton growth parameters were reduced by increasing soil salinity. Plant height was reduced from median height of 125 cm for low salinity tolerant to 94 cm for high salinity tolerant fields (Table 1). Leaf area decreased by about 28% while above ground biomass decreased by almost 35%, showing the negative impact of salinity on vegetative growth. Similar trends were found for physiological traits; the chlorophyll content was decreased from 42 SPAD units (low salinity fields) to 31 SPAD units (high salinity plots) and stomata conductance had decreased by 25% indicating osmotic stress and reduced water intake under high salt stress conditions.

**Table 1. Cotton growth and physiological parameters across salinity levels**

| Salinity Level | Plant Height (cm) | Leaf Area ($cm^2$) | Biomass (g/plant) | Chlorophyll (SPAD) | Stomatal Conductance (mmol $m^{-2}$ $s^{-1}$) |
|---|---|---|---|---|---|
| Low | 125 ± 4.2 | 460 ± 15 | 210 ± 8 | 42 ± 1.2 | 280 ± 12 |
| Moderate | 110 ± 3.8 | 395 ± 12 | 175 ± 7 | 37 ± 1.0 | 245 ± 10 |
| High | 94 ± 3.5 | 330 ± 10 | 136 ± 6 | 31 ± 0.9 | 210 ± 9 |

Growth of sugarcane was even more sensitive to salinity. Stalk height, diameter, and millable cane number decreased gradually with a higher EC, which resulted in a nearly 40% reduction in yield in the high salinity fields compared to the low salinity plots (Table 2). Chlorophyll content and relative water content (RWC) were significantly decreased under high salinity of influence of on decreased photosynthetic efficiency and of osmolar stress (official name of stress by high salinity). These results are in agreement with previous reports indicating that sugarcane is more sensitive than cotton to salinity, and both yield and sugar quality are affected (Singh et al., 2015; Sharma et al., 2018).

**Table 2. Sugarcane growth and physiological parameters across salinity levels**

| Salinity Level | Stalk Height (cm) | Stalk Diameter (cm) | Millable Canes (#/ha) | Cane Yield (t/ha) | Chlorophyll (SPAD) | RWC (%) |
|---|---|---|---|---|---|---|
| Low | 220 ± 6.5 | 3.8 ± 0.1 | 85,000 ± 1200 | 95 ± 3 | 44 ± 1.3 | 78 ± 2 |
| Moderate | 198 ± 5.8 | 3.3 ± 0.1 | 72,500 ± 1100 | 78 ± 2.5 | 39 ± 1.1 | 70 ± 2 |
| High | 170 ± 5.2 | 2.8 ± 0.1 | 60,000 ± 1000 | 57 ± 2 | 33 ± 0.9 | 61 ± 1.8 |

Correlation analysis showed a high negative correlation between the salinity indicators of soil (EC and SAR) and crop performance parameters. For cotton, EC was negatively correlated with plant height ($r = -0.82$, $p < 0.01$), leaf area ($r = -0.79$, $p < 0.01$) and biomass ($r = -0.84$, $p < 0.01$). For sugarcane, EC was found to be correlated negatively with stalk height ($r = -0.85$, $p < 0.01$), cane yield ($r = -0.87$, $p < 0.01$) and RWC ($r = -0.81$, $p < 0.01$). These results confirm the increasing salinity imposes the osmotic and ionic stress, reducing the water availability, nutrient uptake and overall crop productivity (Ashraf & Foolad, 2007; Farooq et al., 2015).

Physiological changes under salinity stress also resulted into lower values of chlorophyll content and RWC, suggesting low photosynthetic efficiency and water status. Cotton plant in high-salinity field had lower stomatal conductance, which was probably due to stomatal conductance to protect the plant from water loss, the sugar cane had more pronounced reduction possibly due to the higher sensitivity of this plant under high salinity (Singh et al., 2015; Sharma et al., 2018). These results are in agreement with those previously reported of differential tolerance of these crops to salinity stress.

Overall, the obtained data show that the effect of soil salinity is more significant on sugarcane compared to cotton in irrigated lands of Sindh in terms of both vegetative and yield components. Similar to other parts of the world, fields with moderate to high salinity levels consistently showed reduced productivity, hence the urgent need for mitigation strategies (i.e., salt-tolerant cultivars, improved irrigation management and soil amendments; Ismail et al., 2013; Akhtar et al., 2018). The combined study of soil physicochemical properties with crop performance highlights the close relationship of soil salinity, and also the plant response, offering critical information for sustainable cultivation practices in soil salinity-affected areas.

**Discussion**

The results of this investigation clearly showed that the soil salinity has significant detrimental effect on the growth and productivity of cotton and sugarcane in the irrigated areas of Sindh. Cotton exhibited moderate sensitivity to salinity with a decrease in plant height, leaf area, biomass and chlorophyll content at high EC conditions. Sugarcane was even more susceptible, showing drastic reductions in stalk height, diameter, number of millable canes, cane yield and relative water content. These results are consistent with other research reports that salinity stress restricts water intake, imbalance of nutrients, photosynthetic deficiency, and reduce crop yield (Ashraf & Foolad, 2007; Singh et al., 2015; Farooq et al., 2015).

Physiological assessments showed that the two crops responded to salinity by decreased stomatal conductance and decreased chlorophyll content as indicators of osmotic stress and debilitated photosynthesis. The negative correlations between soil EC and crop growth parameters indicate the direct influence of salinity on the performance of plants (Rengasamy, 2010; Hussain et al., 2020). Sugarcane's superior sensitivity as compared to cotton makes it important to use crop-specific management strategies. The results also indicate that moderate salinity can be tolerated to some degree by cotton but prolonged exposure and high salinity level result in severe reduction in growth and yield.

Soil management practices, irrigation quality were critical soil factors affecting crops performance. Fields with poor drainage and high sodium adsorption ratios and excessive irrigation showed the highest amount of salinity and the lowest yields in terms of integrated salinity management to maintain productivity (Qureshi et al., 2017; Akhtar et al., 2018). The study supports previous results that sustainable scheduling of irrigation, use of salt-tolerant cultivars, and soil amendments are crucial for reducing the adverse effects of salinity on crops (Ismail et al., 2013; Sharma et al., 2018).

## Conclusion

This study concludes that soil salinity is a major constraint to the productivity of cotton and sugarcane in irrigated areas of Sindh. High salinity have negative effects on vegetative growth, physiological characteristics and yield components with sugarcane being more susceptible than that of cotton. Soil EC and SAR correlated well with decreased plant performance, suggesting that osmotic stress as well as ion toxicity is responsible for yield losses. Effective management of soil salinity, including enhanced irrigation practices, drainage and the use of salt tolerant cultivars is important in sustaining crop productivity and in assuring long-term agricultural sustainability in the region.

## Recommendations

Based on the study findings, the following recommendations are proposed:

1. Adoption of Salt-Tolerant Cultivars: Farmers should take into account varieties of cotton and sugarcane which are provided with proven salinity tolerance potential to reduce the yield losses under moderate to high salinity condition.
2. Improved Irrigation Management: Proper scheduling of irrigation systems, use of good quality canal water, and leaching practices should be adopted in order to avoid salt build up in the root zone.
3. Soil Amendments: Application of gypsum, organic matter or other soil amendments may help to reduce sodium levels, increase the soil structure and assists with water infiltration.

4. Monitoring and Assessment Regular monitoring of soil for EC, SAR and nutrient contents should be done to assist management decisions and maintain the health of soil.
5. Integrated Salinity Management: A combination of crop selection, irrigation scheduling, drainage improvement and use of soil amendments is a holistic management approach to overcome the adverse effects of salinity and maintain productivity.
6. Implementation of these strategies can build resilience of farmers in the irrigated areas of Sindh to sustain cotton and sugarcane yields, protect soil health and ensure the sustainability of agricultural systems in high salinity stress areas in the long run.

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