



Research Article

Mulching for Enhanced Cotton Production in Saline Soils

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Abstract | Salinity is a major risk to cotton cultivation. In salinity, soluble salts are gathered in the root zone of plants causing ionic and osmotic disproportion. However, by way of a superior field-management opportunity, buildup of soluble salts in rhizosphere can be managed by applying soil mulching which reduces water evaporation from soil hence limits upward movement of salts. Moreover, it also reserves soil moisture, increases utilizing efficiencies of nutrient and water hence improves crop yield. Critical research gaps exist in understanding the long-term effectiveness of various mulching materials on cotton yield and soil health in saline soils. Comparative analyses between organic and inorganic mulches and mechanistic understanding of salt reduction in the rhizosphere are limited, impeding tailored mulching strategies for enhanced cotton production sustainability in saline environments. This two years field study (2019 and 2020) explored the influence of various mulching treatments on cotton productivity in saline conditions. Experimental treatments were control (conventional), plastic mulch (PM), wheat straw mulch (WSM), farm yard manure mulch (FYMM) and FYMM + WSM. Mulching significantly increased soil water contents (32%), hydraulic conductivity (5%) whereas reduced soil salt contents (67%) and bulk density (12%) compared to control especially where FYMM + WSM were applied. This treatment also gave higher values of soil organic matter (43%), total nitrogen (31%) and available phosphorous (62%) than control. Physiological parameters including stomatal conductance (14%), photosynthetic rate (50%), transpiration rate (44%), and Na⁺/K⁺ ratio (29%) were also improved by mulching especially in FYMM + WSM. Higher values of yield-related components; plant population (34%), plant height (14%), total number of bolls per plant (44%), average boll weight (30%), and seed cotton yield (50%) were also documented in FYMM + WSM. Economic analysis revealed that FYMM + WSM were the most economically feasible option with 30% higher benefit cost ratio (BCR) than control. Therefore, it is recommended that the bed tops should be covered with FYMM + WSM at the time of sowing to obtain improved growth, yield, and economic benefits in cotton cultivation under saline conditions.

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Introduction

Soil and water salinization, scarcity of water resources and environmental pollution are some prominent landmarks of the commencement of the 21st century (Shrivastava and Kumar, 2015). Salinity affects crop growth mainly in three ways *i.e.* low external water potential causes high osmotic stress, higher quantities of sodium (Na) and chloride (Cl) ions cause ion toxicity and improper acquisition and transportation of essential nutrients causes imbalanced nutrition (Farooq *et al.*, 2015). Cotton, not only a main fiber crop but also has other usage like production of biofuels and edible oil. Cotton productivity has been affected by many environmental stresses however globally the prime cause of reduction in cotton productivity is the soil salinization (Sharif *et al.*, 2019). Cotton can withstand only a mild exposure of salinity and the threshold level for salinity of cotton is 7.7 ds m⁻¹ (Sharif *et al.*, 2019). Salinity inhibits the germination of cotton seed as it reduces the water uptake capacity of seed as well as growth is affected by the disturbance in ion uptake mechanism by salinity hence the plant is unable to uptake essential nutrients (Wang *et al.*, 2011; Munawar *et al.*, 2021). Salinity also cause cellular injury in the transpiring leaves of plants due to buildup of enormous quantities of salt within the leaves (Khan *et al.*, 1995; Munawar *et al.*, 2021). Injury to leaf cells results in the suppression of stomatal conductance. Research has shown a direct relationship between crop growth rate and stomatal conductance: the higher the stomatal conductance, the greater the absorption of carbon dioxide (CO₂) by leaves, leading to increased energy production and facilitating vigorous growth. Nonetheless, CO₂ fixation is decreased under salinity hence the leakage of electron into O₂ produces reactive oxygen species (ROS) (Ahammed *et al.*, 2018; Munawar *et al.*, 2021). Therefore, all cotton attributes including growth and development (canopy growth, leaf area, root-to-shoot ratio, fresh and dry weight, plant height), physiological (photosynthesis, transpiration rate, stomatal conductance), total yield and predominantly quality of fiber are significantly affected under saline soil conditions (Loka *et al.*, 2011; Munawar *et al.*, 2021).

Several natural and/or human induced processes results in salinization of soil and water such as irrigating using saline water can elevate soil salinity levels beyond what the crop can tolerate (Flavio and Marcos, 2002). Moreover, other reasons which are causing soil

salinization uptake by plants and evaporation from the soil surface. These processes lead to an increase in the concentration of soluble salts in the rhizosphere, as the quantity of salt in the root zone is directly related to the amount of water extracted through these activities (Flavio and Marcos, 2002). The movement of water and salt in soil typically adheres to the basic principle that “salt follows water and water follows salt.” As a result, many elements, including rainfall, ground water soil texture, temperature and evaporation, can influence salinity of soil (Du *et al.*, 2021; Li *et al.*, 2023). Hence, it is vital to control soil water evaporation in a way that minimizes salt accumulation and enhances the physicochemical attributes of soil to reduce excessive salt buildup in the root zone.

Mulching comprises using organic materials (farm-yard manure, grasses, straw and crop residues) or inorganic/synthetic constituents (gravels and polyethylene sheets) to cover the top of soil. Mulching reduces the water evaporation through soil surface thereby augmenting soil water reserves available for plant uptake (Li *et al.*, 2023). As main cause of increase of soluble salts quantities in rhizosphere is the evaporation hence inhibition of evaporation by the application of mulch results in decrease in salt buildup in rhizosphere, hence mulching presents a better option to manage soil salinity in field conditions (Taia *et al.*, 2016). Likewise, Yin *et al.* (2021) found that applying mulch can also decrease salt accumulation in the rhizosphere by inhibiting evaporation. Mulches also help in carbon sequestration as after decomposition by soil microbes they add the organic matter to soil (Taia *et al.*, 2016). Minimizing soil disturbance and enhancing crop residue accumulation through straw mulching leads to soil water conservation and decrease in soil temperature (Zhang *et al.*, 2011; Taia *et al.*, 2016). Additionally, Zhang *et al.* (2005) observed improved grain yield and water use efficiency (WUE) resulting from reduced soil evaporation through straw mulching. Moreover, the significance of application of plastic mulch in enhancing crop productivity under saline conditions is also well known as it not only reduced evaporation from soil surface but also reduce mechanical disturbance on soil surface and make favorable soil microclimate by regulating temperature dissemination, maintenance of dampness and supplying CO₂ to the stomata of lower leaves in small plants (Taia *et al.*, 2016). Additionally, plastic mulch aids in regulating soil temperature (Ghosh *et al.*, 2006; Taia *et al.*, 2016), suppressing weed populations (Khamare

and Marble, 2023), and preventing nitrate leaching (Amin *et al.*, 2021).

Research on mulching for enhanced cotton production in saline soils faces several critical gaps. Firstly, there is a dearth of long-term studies evaluating the sustained effectiveness of various mulching materials on cotton yield and soil health in saline environments. Secondly, comparative analyses between organic and inorganic mulches in mitigating soil salinity and their specific impacts on cotton growth remain limited, hindering the development of tailored mulching strategies. Additionally, the mechanistic understanding of how mulching reduces salt accumulation in the rhizosphere and its subsequent influence on cotton physiology and fiber quality is lacking, impeding the optimization of mulching practices for saline soil management. Closing these gaps is essential for advancing mulching techniques to enhance cotton production sustainability in saline soils. While the beneficial effects of mulching in decreasing soil salinity have been widely researched, there is comparatively less documentation on its potential to reduce salt accumulation and mitigate the impact of salinity on cotton germination, growth, and productivity. Consequently, this study was devised to assess the efficacy of both organic and inorganic mulches in reducing salt accumulation in the soil root zone, as well as their influence on cotton growth and productivity.

Materials and Methods

Experimental site

The experiment was conducted at the Agronomic Research Station in Khanewal, Pakistan, situated at a latitude of 30°18' 35.95" N, a longitude of 71°59' 40.14" E, and an elevation of 454 m, for two years; 2019 and 2020. Climate of this region is arid with sandy loam soil. The chemical properties of the soils were as; a pH of 8.6, EC 4 ds cm⁻¹, nitrogen (N) content 0.06%, phosphorous (P) content 6.90 ppm and K content 206.70 ppm.

Weather conditions

Figure 1 is presenting the weather of the experimental area during both growing seasons; 2019 and 2020. In the year 2019, during growing period the maximum temperature noted was 47°C though in 2020 the maximum temperature noted was 45°C. Moreover, in the year 2019, during growing period the least temperature recorded was 14°C whereas in 2020 it

was 12°C. In case of rain fall, total rainfall recorded in growing period of 2019 was 290 mm while it was 196 mm in 2020.

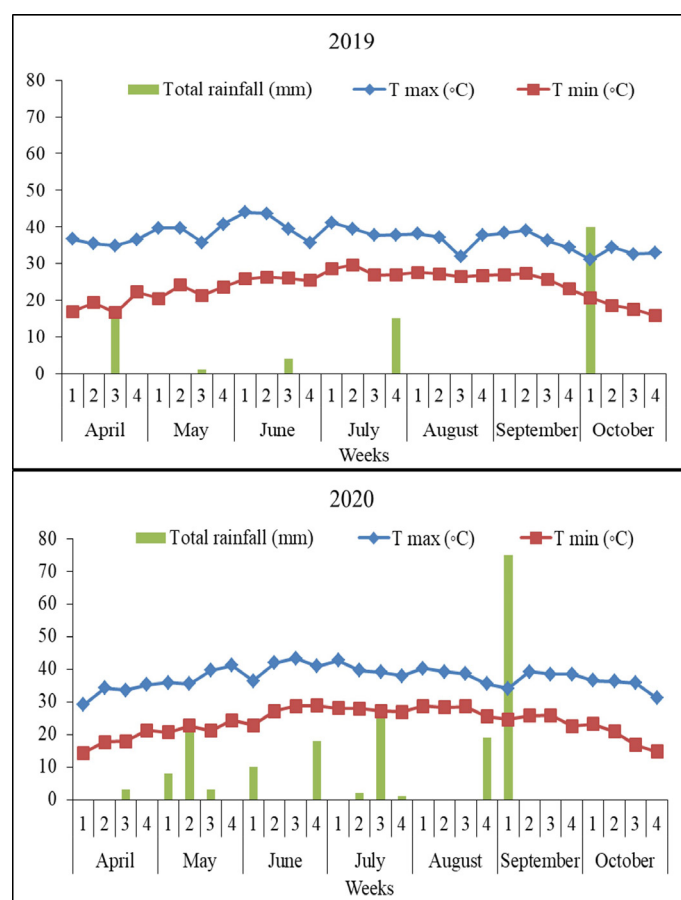


Figure 1: Weather conditions of the experimental site during the course of study in years 2019 and 2020.

T max= Average maximum temperature; *T min*= Average minimum temperature

Experimental design and treatments

The experimental treatments consisted of five distinct mulching treatments: control (conventional), PM, WSM, FYMM, and FYMM + WSM. The experiment followed a randomized complete block design, replicated in triplicate, with a net plot size of 9.0 × 4.5 m.

Crop husbandry

Following wheat harvesting, land preparation involved two cultivations, followed by one planking. The entire crop received fertilization: 247 kg ha⁻¹ N as urea, 99 kg ha⁻¹ P as single superphosphate (SSP), 94 kg ha⁻¹ K as sulfate of potash (SOP), 12 kg ha⁻¹ zinc sulfate (33%), and 6 kg ha⁻¹ boric acid (17%). During seed bed preparation, the entire amount of P, K, zinc sulfate, and boric acid was applied to the soil, while N was applied in four equal splits (at sowing, squaring, flowering, and boll formation). Nitrogen was applied

in furrows immediately after irrigation. Beds with dimensions of 75 cm on the bed top and 75 cm in the furrow were made using a tractor-drawn bed shaper. All mulching treatments were applied on the top of the beds before sowing after seed bed preparation. In the treatments where FYM and wheat straw mulch were applied alone the amount of material was 20 and 15 Mg ha⁻¹, respectively; whereas in treatment where wheat straw + FYM mulch was applied, the quantity of mulch materials was 10 and 7.5 Mg ha⁻¹ respectively. In plastic mulch treatment, beds were covered with black plastic sheet however holes were made in sheet to facilitate the dibbling of cotton seed. Cotton was sown at a seed rate of 15 kg ha⁻¹ using test variety named; MNH-1050. Sowing was performed manually on both sides of the bed using dibbling method maintaining plant-to-plant distance of 30 cm. To manage weeds, a pre-emergence herbicide, Pendimethylene (Stomp), was sprayed immediately after sowing at a rate of 2457 ml ha⁻¹. Crop was gap filled at six days after sowing (DAS) whereas thinning was performed at 25 DAS. A total of fourteen irrigations were scheduled, with the first irrigation applied at 4 DAS, followed by the 2nd, 3rd, and 4th irrigations at 7-day intervals. Subsequent irrigations were administered at 12-day intervals as per the crop's requirements, with irrigation applied in furrows. Three pickings were conducted during each growing season.

Observations

Soil parameters

Gravimetric measurements of the soil water content were made at intervals of roughly 30 days during the crop-growing season, at depths of 0–6 and 6–12 cm. The locations for soil sampling were selected to be as near to the center of plot as feasible, and in between two rows of crop. To quantify the salt content of the soil, samples were dried in air and grinded such that they could fit through a 2 mm mesh screen. The extraction ratio of 1:5 (EC1:5) was employed to document the salt content of the soil by an electrical conductivity meter (LE438, Mettler Toledo, Shanghai, China). Next, using Yang *et al.* (2022) method, the EC1:5 values were translated to the salt concentration in percent (total salt, TS);

$$TS = 2.47 EC1:5 + 0.26$$

Furthermore, measurements were made of the 0–6 cm and 6–12 cm soil depths for physical indexes like soil bulk density (BD), saturated water conductivi-

ty (Ks), and saturated water content (SWC), along with nutrient indexes like soil organic matter (OM), total nitrogen (TN), and available phosphorus (AP). The constant head test (Shao *et al.*, 2006) was used to quantify Ks, and the cutting ring method (Lu, 1999) was used to assess bulk density. Kjeldahl distillation was used to measure TN, potassium dichromate-external heating was used to assess organic matter, and sodium bicarbonate extraction molybdenum antimony anti colorimetry was used to analyze AP (Lu, 1999).

Physiological parameters

Numerous physiological characteristics were measured, including transpiration, stomatal conductance, photosynthesis, and the Na/K ratio. The measurements were taken sixty days following seeding. The fourth leaf from the top of each treatment's plant was used to measure the stomatal conductance (mmol m⁻² s⁻¹) and net photosynthetic rate (μmol m⁻² s⁻¹) using an open infrared gas exchange system with a PDF of 375 μmol m⁻² s⁻¹ and a CO₂ concentration of 405 ppm (LI- 6400, LICOR, Lincoln, NE, USA) (Ismail *et al.*, 2014; Basahi *et al.*, 2016; Hassan *et al.*, 2018). The transpiration value from the porometer was divided by 10,000 and multiplied by 1000 to determine the relative value of the transpiration rate (mmol m⁻² s⁻¹). Using a flame photometer (Model: Jenway PFP 7), the concentrations of Na⁺ and K⁺ were recorded in order to obtain the Na⁺/K⁺ ratio. Prior to being digested, 0.05 g of the leaf material was placed in digestion tubes. For the purpose of digestion, 1 milliliter of concentrated H₂SO₄ was then added to the dried sample. All of the tubes were incubated at room temperature for an entire night in the dark. The tubes were moved to a digesting block the following day, when 0.5 ml of 35% H₂O₂ was added, and they were heated to 350°C until fumes began to appear. The digesting tubes were taken out of the block to cool after heating for 30 minutes. After slowly adding 0.5 ml of water, the tubes were put back into the digesting block. The procedure described above was carried out again and again until the digesting material's color became transparent. Next, 25 ml of the volumetric flasks were filled with the digestion extract. The extract was utilized to assess K⁺ and Na⁺ after it had been filtered.

Yield and yield components

At maturity, twenty plants from each treatment were randomly marked and tagged to record yield-related variables. Using the meter rod, the plant height

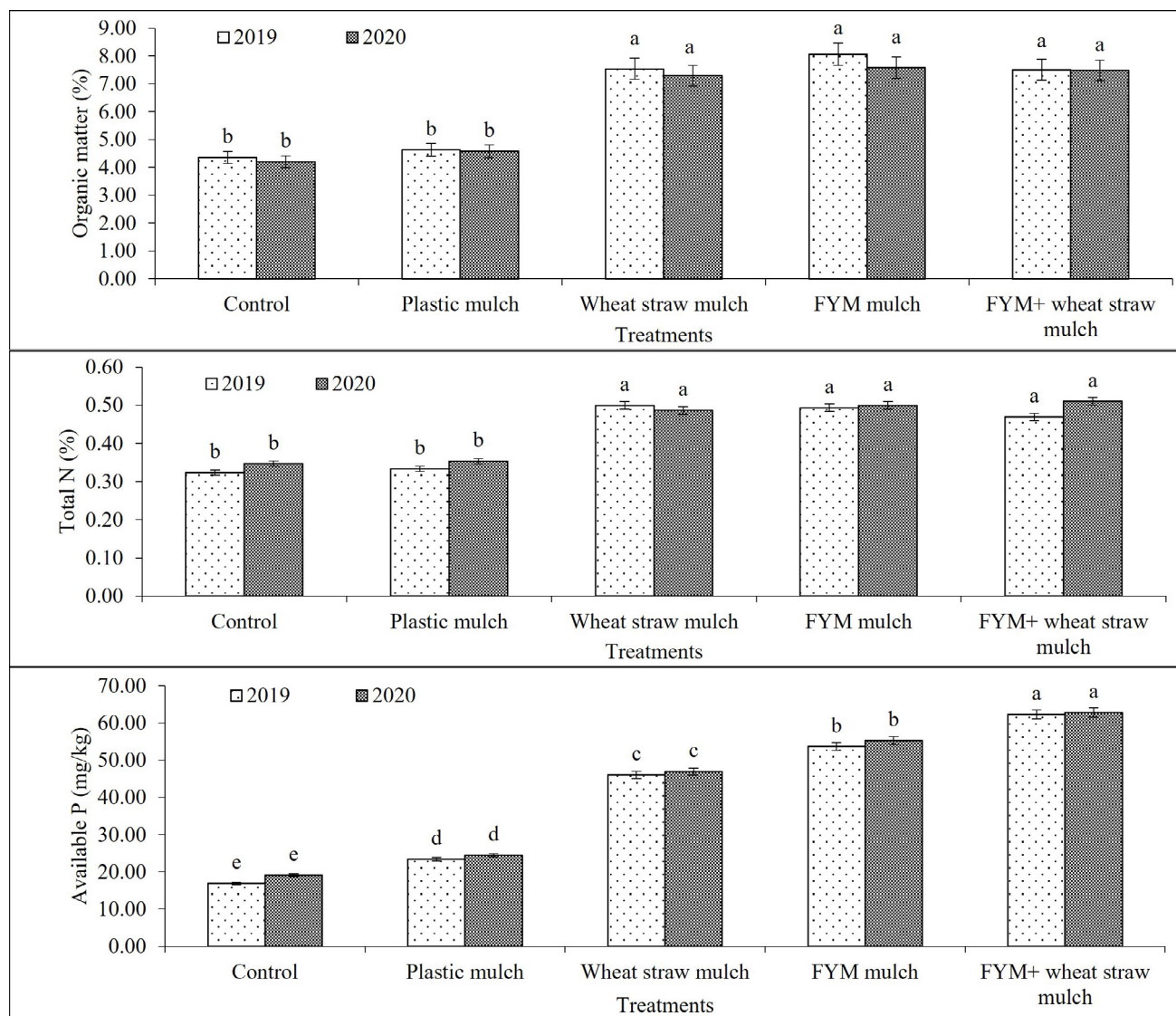


Figure 2a: Effect of various mulching treatments on soil organic matter, total nitrogen and available phosphorous in cotton cultivation

Means sharing same case letter do not differ significantly at $p \leq 0.05$

was calculated in centimeters. These candidate plants monopodial branches were counted and each plant's sympodial branches were noted. In a similar manner, counting the number of bolls on these labeled plants allowed for the recording of the quantity of bolls per plant. For each replicate, 50 bolls from each treatment were taken, weighted using a weight balance, and the result was the average boll weight. The weight balance (electric compact scale: GT-500) was used to determine the total plot picking weight (in kg), and from there, the yield of cotton was converted to kg per hectare using the unit method to record the seed yield of each treatment.

Economic analysis

The gross income per hectare (Rs.) was calculated by multiplying seed cotton yield (kg ha^{-1}) by the market

rate (Rs. /kg) of seed cotton (Byerlee, 1988). Fixed and variable costs per hectare (Rs. /ha) were calculated by combining the costs associated with standard field operations and treatment-specific expenses, respectively. The total cost of production (Rs. /ha) was obtained by combining the fixed and variable costs. Net income (Rs. /ha) was calculated by deducting the total cost of production from the gross income. The benefit-cost ratio (BCR) for each treatment was determined by dividing the net income by the total cost of production.

Statistical analysis

Fisher's analysis of variance was utilized to evaluate the data using STATISTIX 8.1 statistical software (Statistix, analytical software, Statistix; Tallahassee, FL, USA, 1985-2003) (Steel *et al.*, 1997). Means

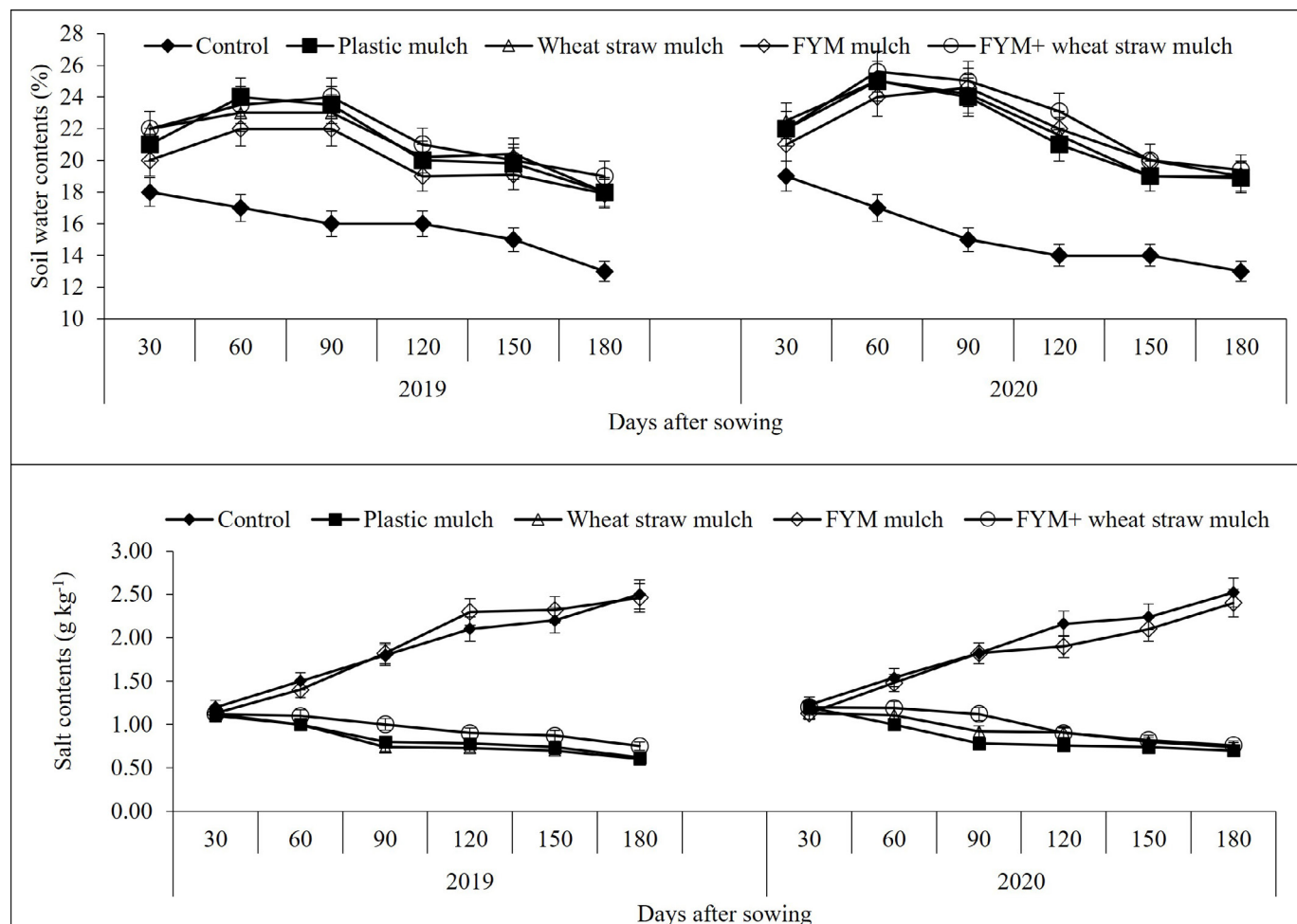


Figure 2b: Effect of various mulching treatments on soil water contents and salt contents in cotton cultivation. Means sharing same case letter do not differ significantly at p 0.05

were compared using the Least Significance Difference (LSD) test at the 5% probability level. Excel sheet from Microsoft Office (2010) was used to visually represent the data.

Results and Discussion

Soil parameters

Mulching increased soil water contents as compared with control (Figure 2a) however highest soil water contents from 0 to 180 days after sowing were recorded in FYMM + WSM treatment whereas minimum soil water contents were recorded in control. It has been reported that soil water contents can be reserved by applying mulch as it inhibit soil evaporation (Yang *et al.*, 2022). Furthermore, the highest soil water contents under FYMM + WSM treatment might be attributable to addition of organic matter by mulching, which loosens the soil, reduces its density, and increases its capacity to save water (Yang *et al.*, 2022). Several studies have confirmed that mulching helps to lessen evaporation and preserve soil water. Using

the Aqua Crop model, Zhang *et al.* (2021) assessed the geographical effects of mulching and discovered that PM enhanced soil water storage and considerably diminished unrequired evaporation. In contrast to control treatment, Li *et al.* (2018) found that the treatments of PM, gravel-sand, and WSM increased the average soil water storage in wheat cultivation.

Mulching treatments affected salt contents of soil during both years of study (Figure 2b). High salt contents were noted in control and FYMM treatments while lower salt contents were noted in PM, WSM and FYMM + WSM treatments than control. Reduction in soil evaporation was the main reason behind this hence accumulation of salt in root zone was decreased moreover soil salt contents might be reduced due to leaching of salts as higher soil water contents are observed under mulching (Li *et al.*, 2023). Likewise, Mohammad *et al.* (2018) demonstrated that electrical conductivity of soil is reduced by mulching. Moreover, all mulch materials i.e. FYM, rice straw, and PM, efficiently decreased the buildup

Table 1: Effect of various mulching treatments on bulk density, saturated water conductivity and saturated water contents in cotton cultivation.

Treatments	Bulk density (g/cm ³)			Saturated water conductivity (cm/d)			Saturated water contents (%)		
	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
Control	1.44a	1.41a	1.43	10.63d	10.53e	10.58	37.52e	37.53c	37.53
Plastic mulch	1.41a	1.40a	1.41	12.58c	12.83d	12.70	38.25d	38.35b	38.30
Wheat straw mulch	1.32c	1.34c	1.37	13.90a	13.96b	13.42	39.42b	39.36a	38.90
FYM mulch	1.37b	1.37b	1.33	13.32b	13.52c	13.93	38.86c	38.93ab	39.39
FYM+ wheat straw mulch	1.27d	1.29d	1.28	14.11a	14.22a	14.16	39.87a	39.22a	39.55
LSD p 0.05	0.03	0.03	-	0.30	0.09	-	0.24	0.60	-

Means sharing same case letter do not differ significantly at *p* 0.05.

of salt in rhizosphere, as demonstrated by [El-Mageed et al. \(2016\)](#). Besides, the average soil salt content under FYMM treatment increased than control treatment because the FYM contains salt ([Wang et al., 2022](#)). Application of manures in higher amount produces undesirable effect on plants because they produce soil salinization, according to [Hao and Chang \(2003\)](#). [Yao et al. \(2007\)](#) also evaluated the potential for secondary soil salinization by the ongoing application of pigeon and chicken manure to garden soil, which led to a modest pH drop and an increase in soil salinity from low to moderate levels.

Mulch treatments significantly affected BD, Ks and SWC of soil during both year of study ([Table 1](#)). During both years, lowest BD was recorded in FYMM + WSM treatment, followed by WSM treatment which was followed by FYMM treatment whereas highest BD was recorded in control as well as in PM treatment ([Table 1](#)). During 2019, highest Ks was recorded in FYMM + WSM treatment and WSM treatments followed by FYMM treatment which was followed by PM treatment whereas lowest Ks was recorded in control. However, during 2020, highest Ks was recorded in FYMM + WSM treatment followed by WSM treatment which was followed by FYMM and PM treatments while lowest Ks was recorded in control ([Table 1](#)). In case of SWC, during 2019, highest SWC were recorded in FYMM + WSM treatment followed by WSM treatment which was followed by FYMM and PM treatments while lowest SWC was recorded in control ([Table 1](#)). However, during 2020, highest SWC were recorded in FYMM + WSM and WSM treatments which were statistically at par with FYMM treatment followed by PM treatment whereas lowest SWC were recorded in control.

Addition of crop residues in the form of mulch to cultivated soils helps to improve soil quality and productivity through its favorable effects on soil properties ([Jordan et al., 2010](#)). As application of crop residue mulches to cultivated soils increases the organic matter content ([Jordan et al., 2010](#)). According to [Qamar et al. \(2015\)](#), organic mulch affects the physical characteristics of the soil, such as temperature, moisture conservation, BD, and penetration resistance, all of which are favorable to crop growth and development. Sand, silt, and clay are among the soil particles that are aggregated into larger particles by adding OM to the soil through organic mulches ([Guo and Liu, 2022](#)). Particle aggregation increases porosity, which lowers the BD of soil ([Guo and Liu, 2022](#)). To a lesser extent, BD can also be changed when organic material of low density replaces inorganic material of higher density in soil ([Athira et al., 2019](#)). Furthermore, mulching clearly affected the infiltration characteristic (Ks) and soil retention capabilities (capillary water holding capacity, SWC). In current investigation, mulching also raised the soil's Ks. According to [Cal and Barik \(2020\)](#), soil Ks is the capacity of water or a solution to flow through soil pores at a specific time scale. Physical characteristics of soil, including BD, aggregation, effective porosity, and soil particle shapes and sizes, are associated with hydraulic conductivity ([Campos et al., 2020](#)). The relationship between BD and Ks is often negative: as BD increases, Ks decrease. As it is already discussed that BD is a degree of soil mass per unit volume, and it indicates how the soil compacted is. As BD increases, pore spaces within the soil decrease in size and number. Pore spaces are crucial for water movement in soil; larger pores facilitate faster movement of water, while smaller pores impede it ([Athira et al., 2019](#)). Therefore, as BD increases and pore spaces become smaller, Ks decreases because

there are fewer pathways for water to flow through the soil. [Uzoma and Onwuka \(2018\)](#) observed that mulching enhances soil porosity, resulting in a significant improvement in saturated hydraulic conductivity. According to [Papadopoulos *et al.* \(2009\)](#), larger soil pores facilitate easier water transmission through the soil. These results are consistent with the findings of [Dec *et al.* \(2008\)](#). Additionally, [Gulser and Candemir \(2014\)](#) emphasized that saturated hydraulic conductivity is closely linked to soil porosity and pore size distribution. The increased Ks in mulched soil can be attributed to the capacity of mulch materials to boost percolation and water retention ([Rar and Singh, 2004](#)). [Bhart and Khera \(2006\)](#) also reported that Ks was higher in mulched soil compared to bare soil.

Moreover, organic mulching also reduced SWC of soil as compared with control and PM ([Crnobrna *et al.*, 2022](#)). The maximum quantity of water that soil can hold is known as its SWC. It is strongly associated with the overall porosity of soil ([Rawls *et al.*, 2004](#)). The incorporation of OM into soil positively influences its SWC through various mechanisms. Organic matter enhances water holding capacity of soil by absorbing and retaining moisture, leading to increased water availability at saturation ([Feifel *et al.*, 2023](#)). It also strengthens the structure of the soil by encouraging the development of stable aggregates and expanding the pore spaces that allow water to enter and be stored. As organic matter decomposes, it contributes to the development of macro-pores and micro-pores, further enhancing soil porosity and water-holding capacity. Moreover, organic matter reduces soil BD by physically disrupting soil particles and promoting aggregation, creating more pore spaces within the soil. As a result, soils with higher levels of OM show higher SWC, which is encouraging for the growth and development of plants ([Feifel *et al.*, 2023](#)). Mulching materials influence the soil moisture environment primarily through their abilities to retain water, permit water flow, and decompose ([Zhang *et al.*, 2023](#)). This effect occurs because mulching physically inhibits vertical evaporation from the soil by blocking direct sunlight and reduces surface water runoff ([Saglam *et al.*, 2017](#)), thereby conserving soil moisture. Additionally, some organic mulches function like sponges, absorbing rainfall and irrigation water, which helps to prevent runoff and supply water when crops need it ([Iqbal *et al.*, 2020](#)). [Zhao *et al.* \(2014\)](#) also found that mulched soils retained more moisture than bare soils. During both years of study higher soil

OM was recorded in FYMM + WSM, FYMM and WSM treatments whereas lower soil OM was recorded in PM and control ([Figure 2](#)). Likewise higher soil TN contents were recorded in FYMM + WSM, FYMM and WSM treatments whereas lower soil TN contents were recorded in PM and control. Likewise, during both years higher AP contents were recorded in FYMM + WSM, FYMM and WSM treatments whereas lower soil AP contents were recorded in PM and control. The three main markers of soil nutrients that influence crop productivity and soil fertility are AP, TN, and soil OM. According to [Carter \(2002\)](#), organic mulches have been revealed to enhance the physical, chemical, and biological qualities of soil through their decomposition and subsequent release of nutrients. Organic mulching, according to [Youkhanna and Idol \(2011\)](#), improves soil moisture conservation by increasing OM through decomposition. Additionally, mulching with organic material raises the amount of OM in soil that can enhance the physico-chemical characteristics of soil besides the activities of microbes present in soil ([Chaparro *et al.*, 2012](#)). Hence in present study the rise in soil OM contents is owing to the application of organic mulches which added OM to soil. [Bajoriene *et al.* \(2013\)](#) noted that natural organic mulch gradually decomposes and contributes organic material to the soil. Similarly, [Ampofo \(2018\)](#) found that using organic materials for mulching enhances the soil's organic matter content. Total N contents were also increased by the application of organic mulches because as they decompose, release N into the soil ([Lou *et al.*, 2022](#)). This N comes from the organic matter present in the mulch. Microorganisms break down the mulch, releasing N in a form that plants can uptake ([Grzyb *et al.*, 2021](#)). Over time, this can lead to improvement in TN content of soil ([Sun *et al.*, 2021](#)). Moreover, the elevated TN contents are also likely to be the result of reduced water infiltration and flow beneath the mulches, therefore reduced N leaching ([Pi *et al.*, 2017](#)). Furthermore, numerous investigations have shown that mulching had a major impact on the amount of P that was available in various layers of soils ([Thankamani *et al.*, 2016](#)). According to [Qu *et al.* \(2019\)](#), the organic mulches had a considerable impact on the available P content. Despite the fact that [Muttaleb \(2018\)](#) showed that the mulching treatment resulted in noticeably higher AP values. It can be owing to the direct influence of the OM which add up nutrient into the soil after decomposition by soil microorganisms as well as the increased contents of AP are also owing to the better

hydrothermal conditions, more root system proliferation, and suppression of weed growth by mulching that have reduced P mining (Rahmani *et al.*, 2021).

Physiological parameters

It was found that mulching treatments significantly affected stomatal conductance, photosynthetic rate, transpiration rate and Na^+/K^+ ratio during both years of study (Figure 3). Maximum stomatal conductance was recorded in FYMM + WSM treatment followed by WSM treatment which was followed by FYMM treatment whereas minimum stomatal conductance was recorded in control. Likewise maximum photosynthetic rate was recorded in FYMM + WSM treatment followed by WSM treatment which was followed by FYMM treatment whereas minimum photosynthetic rate was recorded in control. Similarly maximum transpiration rate was recorded in FYMM + WSM treatment followed by WSM treatment which was followed by FYMM treatment whereas minimum transpiration rate was recorded in control. Moreover, maximum Na^+/K^+ ratio was recorded in FYMM + WSM treatment followed by WSM treatment which was followed by FYMM treatment whereas minimum Na^+/K^+ ratio was recorded in control.

Because soil mulching reduces evaporation and the upward migration of salts in rhizosphere (Zhao *et al.*, 2014; Chen *et al.*, 2016), it shields plant from harmful influence of salinity on growth and yield. According to Sharipova *et al.* (2022) plants are impacted by salinity in terms of stomatal conductance, photosynthetic rate, transpiration rate, and Na^+/K^+ ratio. It is commonly recognized that, even in osmotically adjusted plants, salt stress lowers root hydraulic conductivity, which lowers water transport from roots to shoot (Neto *et al.*, 2004). According to Atta *et al.* (2023), this reduction in water flow brought on by salt stress may produce a drop in leaf water content, which would prompt stomatal closure to preserve the water status of the leaves. Hence better stomatal conductance in plants with mulching treatments is by reason of the less buildup of salt in root zone as compared to control that protected plant from harmful effect of salinity. Moreover, the photosynthetic rate is also linked to the stomatal conductance as reduced stomatal conductance consequently causes restriction for the diffusion of CO_2 into the leaf cell for photosynthesis (Balasubramaniam *et al.*, 2023). Salt-induced reduction in photosynthetic activity, however, is closely linked to a number of factors (Pan *et al.*,

2021). These factors include altered activities of enzymes (Al-Hinai *et al.*, 2022), inhibition of biosynthesis of chlorophyll (Qin *et al.*, 2021), destruction of photosynthetic machinery (Tokarz *et al.*, 2021), limitation in the flow of electron from photosystem II (PSII) to photosystem I (PSI) (He *et al.*, 2021), dissipation of non-photochemical heat energy (Kilili and Haworth, 2017), alteration in expression of genes (Seo *et al.*, 2020), and decreased CO_2 supply as a result of hydrostatic closure of stomata (Farooq *et al.*, 2017). Pseudo-cyclic electron transport owing to inhibition of electron transport chain as a result of salinity causes buildup of ROS (Al-Farsi *et al.*, 2020; Yan *et al.*, 2021; Zahra *et al.*, 2021). It hinders, for example, the transfer of PSII electrons from the primary quinone acceptor (QA) to the secondary quinone acceptor (QB), which leads to the build-up of electrons available for charge recombination and the potential for oxidative burst (Ahanger and Agarwal, 2017). This can cause harm to photosynthetic proteins and the PSII reaction center (Zhang *et al.*, 2014; Huihui *et al.*, 2020) as well as hinder the machinery that repairs PSII (Allakhverdiev *et al.*, 2002; Zahra *et al.*, 2022). Furthermore, cyclic electron transport around PSI and cytochrome b6f is hindered by salt stress, which reduces photo-protection (Yue *et al.*, 2019). Mulching also improved transpiration rate in cotton plants which is also due to less buildup of salts in rhizosphere owing to mulch application. The decrease in rate of transpiration due to salinity is also the result of salt induced inhibition of stomatal conductance, as the way through which plants transpire is stomata, (Nishida *et al.*, 2008; Mohamed *et al.*, 2020) hence leading to less transpiration rate. Similarly in case of Na^+/K^+ ratio, in present study lower Na^+/K^+ ratio was recorded in mulch treatments as compared with control which is also due to the positive effect of controlling the salt accumulation by mulching in root zone. When the Na^+ content of growth medium rises due to salt, the plant absorbs more Na^+ than K^+ , which causes an increase in K^+ outflow from cell and a rise in the Na/K ratio (Atta *et al.*, 2023). Excessive Na^+ inflow under salt stress promotes disturbance of ion channel, replacement of nutrients and depolarization of membrane, which results in anomalies in the absorption and assimilation of nutrients (Gaikwad *et al.*, 2022).

Yield and yield components

During 2019, it was recorded that mulching treatments significantly affected plant population, plant

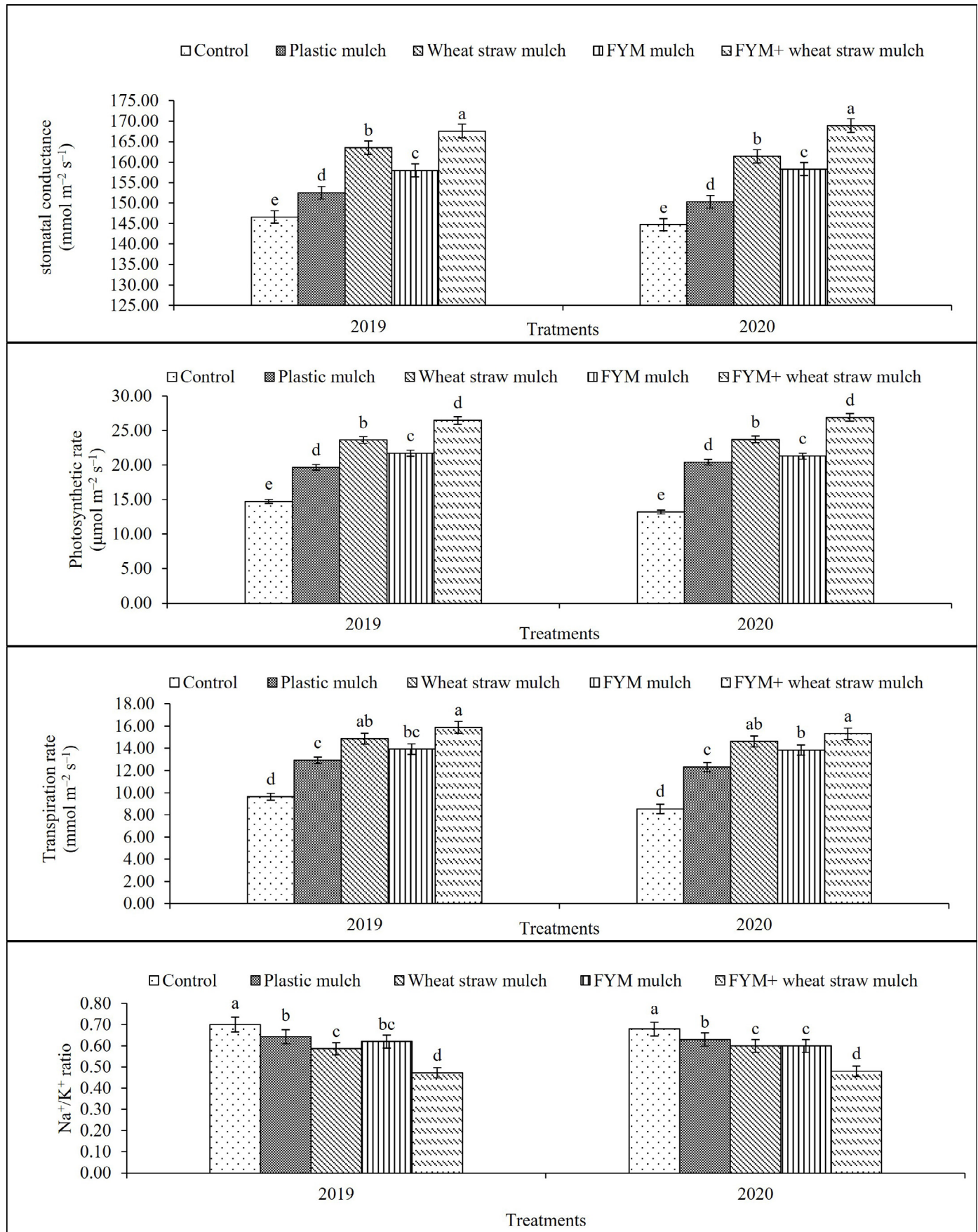


Figure 3: Effect of various mulching treatments on physiological parameters of cotton

height, total number of bolls per plant, average boll weight and seed cotton yield, however effect of mulching treatments was non-significant on monopodial branches per plant (Table 2). Maximum plant

population was recorded in FYMM + WSM treatment followed by WSM treatment and FYMM treatments which were followed by PM treatments whereas least plant population was recorded in control. Regarding plant height, higher was recorded in WSM and FYMM + WSM treatments which were followed by FYMM and PM treatments whereas least plant height was recorded in control. In case of total number of bolls per plant, higher were noted in FYMM + WSM treatment followed by WSM and FYMM treatments which were followed by PM treatment whereas least number of total bolls per plant was noted in control. Moreover, higher average boll weight was noted in FYMM + WSM treatment followed by WSM and FYMM treatments which were followed by PM treatment whereas least average boll weight was noted in control. Additionally higher seed cotton yield was noted in FYMM + WSM treatment followed by WSM which was followed by FYMM and PM treatments whereas least seed cotton yield was noted in control.

Likewise, during 2020, it was recorded that mulching treatments significantly affected plant population, plant height, total number of bolls per plant, average boll weight and seed cotton yield, however effect of mulching treatments was non-significant for monopodial branches per plant. Maximum plant population was recorded in PM, WSM, FYMM and FYMM + WSM treatments whereas least plant population was noted in control. Regarding plant height, higher was recorded in WSM, FYMM and FYMM + WSM treatments which were followed by PM treatments whereas least plant height was noted in control. In case of total number of bolls per plant, higher were recorded in FYMM + WSM treatment that was statistically at par WSM treatment followed by FYMM treatment which was followed by PM treatment whereas least number of total bolls per plant was noted in control. Moreover, higher average boll weight was recorded in WSM and FYMM + WSM treatments followed by FYMM and PM treatments whereas least average boll weight was noted in control. Additionally higher seed cotton yield was recorded in FYMM + WSM treatment that was statistically at par with WSM treatment followed by FYMM treatment which was followed by PM treatment whereas least seed cotton yield was noted in control.

Both crop yield and yield components improved with the use of FYMM + WSM. Mulching has a positive

Table 2: Effect of various mulching treatments on yield and yield components of cotton.

Treatments	Plant population /ha				Plant height (cm)				Monopodial branches per plant				Total number of bolls per plant				Average boll weight (g)				Seed cotton yield (kg ha ⁻¹)			
	2019	2020	Mean		2019	2020	Mean		2019	2020	Mean		2019	2020	Mean		2019	2020	Mean		2019	2020	Mean	
Control	55773 D	26420 B	41097		139 B	133 B	136		1	1	1		22 D	14 D	18		1.55 D	2.20 C	1.88		1136 D	519 C	828	
Plastic mulch	56751 C	54732 A	55742		151 AB	132 B	142		2	2	2		25 C	19 C	22		1.99 C	2.43 B	2.21		1626 C	741 BC	1184	
Wheat straw mulch	58715 B	62963 A	60839		158 A	153 A	156		2	2	2		27 B	31 AB	29		2.30 B	2.67 A	2.49		1898 B	1012 AB	1455	
FYMM mulch	58708 B	58848 A	58778		152 AB	153 A	153		2	2	2		27 B	28 B	28		2.37 B	2.50 B	2.44		1723 C	947 B	1335	
FYMM+ wheat straw mulch	61636 A	63374 A	62505		160 A	155 A	158		2	2	2		29 A	35 A	32		2.67 A	2.70 A	2.69		2071 A	1259 A	1665	
LSD p 0.05	229	15221	-		16.37	6.20	-		ns	ns	-		1.29	4.66	-		0.20	0.16	-		100.59	292.43	-	

Means sharing same case letter do not differ significantly at p 0.05.

*ns= non-significant

image in agricultural productivity since it offers numerous benefits. First, according to Zhou *et al.* (2009), it is crucial in minimizing soil moisture loss, which improves crop productivity, WUE, and precipitation use efficiency. Secondly, it maintains the temperature of the topsoil, which is advantageous for seed germination and root formation in the initial phases of plant growth (Zhang *et al.*, 2023). Thirdly, it modifies soil fertility and microbial biomass, improving soil quality and raising yield (Huo *et al.*, 2017). Fourth, it promotes the recycling of mineral nutrients that are critical to crop yield and preserves the balance of soil organic carbon (Wang *et al.*, 2017). Fifth, it facilitates soil metabolism by increasing soil enzyme activity (Elfstrand *et al.*, 2007). Sixth, it inhibits weed development by decreasing biomass and weed density, which enhances crop growth through improved resource utilization (Splawski *et al.*, 2016). Additionally, using organic mulches as cover materials reduces runoff volumes and increases the soil's ability to absorb water during rainy events (Jordán *et al.*, 2010). It improves the structure and stability of soil aggregates (de Luna *et al.*, 2023). As a result, mulching's several positive impacts increased cotton crop output overall and crop growth.

Table 3: *Economic analysis of various mulching treatments in cotton cultivation for two years of study (2019 and 2020).*

Treatments	Cost of production (Rs. /ha)	Gross income (Rs. /ha)	Net income (Rs. /ha)	Benefit cost ratio
Control	217212	268938	51726	1:1.24
Plastic mulch	380712	384638	3926	1:1.01
Wheat straw mulch	369212	472875	103663	1:1.28
FYM mulch	234212	385125	150913	1:1.64
FYM+ wheat straw mulch	301712	541125	239413	1:1.79

Economic analysis

Economic analysis of two years 2019 and 2020 has been presented in Table 3. It is found that among mulching treatments higher cost of production was required for PM treatment followed by WSM treatments which was followed by FYMM + WSM treatment whereas lowest cost of production was required by FYMM treatment. However, in case of gross income, among mulching treatments higher gross income was incurred by FYMM + WSM treatment followed by WSM treatment which was followed by

FYMM treatment whereas lowest gross income was incurred by PM treatment. However, regarding net income, higher net income was recorded in FYMM + WSM treatment followed by FYMM treatment which was followed by WSM treatment whereas lowest net income was incurred by PM treatment. Similarly in case of BCR, higher BCR was recorded in FYMM + WSM treatment followed by WSM treatment which was followed by FYMM treatment whereas lowest BCR was recorded in PM treatment. Hence in present study the most economically feasible treatment is the application of FYMM + WSM in cotton which is not only beneficial in improving growth and yield but also an economical approach.

Conclusions and Recommendations

Overall, the results demonstrate that mulching treatments exert significant effects on various parameters related to soil properties, physiological responses, yield-related components, and economic aspects in cotton cultivation. Farm yard manure + WSM emerged as the most favorable treatment, reducing soil salinity, enhancing soil fertility, promoting better physiological functions and ultimately leading to higher yields and economic returns. This suggests that adopting FYMM + WSM can offer a sustainable and economically viable approach for cotton production, providing benefits not only in terms of agronomic performance but also in terms of economic profitability. Therefore, it is recommended that the bed tops should be covered with FYMM (10 Mg ha⁻¹) + WSM (7.5 Mg ha⁻¹) at the time of sowing to obtain improved growth, yield, and economic benefits in cotton cultivation under saline conditions. These findings underscore the importance of mulching practices in enhancing agricultural sustainability and profitability, especially in cotton cultivation systems.

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Novelty Statement

Mulching has been extensively explored to control

weeds and to improve microclimate in crop production. However, only few studies are available those have investigated the mulching to reduce salt accumulation in rhizosphere under saline soil conditions especially in cotton cultivation. Hence this study was planned to explore the mulching in improving cotton productivity in salt affected soils.

Author's Contribution

Muhammad Iqbal: Performed write up of paper.

Saba Iqbal: Performed execution of experiment, data collection, analysis and write up.

Asmat Ullah: Contributed in proof reading, tabulation of data, formation of graphs.

Arbab Jahangeer: Contributed in plagiarism removal, Naveed Akhtar performed Proof reading and editing.

Tahira Tabassum, Ali Zohaib and Naveed Ramzan: Ccontributed in roof reading and editing of the manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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