Use of Organic Mulch to Cultivate Climate Resilient Cotton for a Sustainable Future

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Abstract

Climate change's threat to global agriculture, especially cotton production, has led to the adoption of mulching as a mitigation strategy. Organic mulches offer environmentally friendly benefits for cotton in challenging environments. A study evaluated various organic mulches' effects on soil properties, cotton yield, and quality in a semi-arid region with limited water and high temperature fluctuations. Results showed that wheat straw, rice, and sugarcane leaves straw maintained moderate soil temperatures (27.3°C to 27.4°C), unlike the control (41.6°C). Soil pH remained stable (7.9 to 8.1), and organic mulches raised soil carbon (0.68% to 0.72% vs. 0.51% control). Nutrient availability increased, with higher nitrogen (0.045% to 0.049%), phosphorus (6.2 mg kg^{-1} to 6.5 mg kg^{-1}), and potassium (89 mg kg^{-1} to 92 mg kg^{-1}) compared to control (0.028%, 5.6 mg kg^{-1}, and 71 mg kg^{-1}). Organic matter content rose (0.77% to 0.81%) versus the control (0.51%). Weed density decreased (4 to 5 weeds m^2 vs. 23 weeds m^2 control) with mulches. Cotton height, bolls per plant, and open-boll weight increased with mulches, elevating cotton yield (2704 kg ha^{-1} to 2743 kg ha^{-1}) over control (2117 kg ha^{-1}), with consistent ginning outturn (36.62% to 37.2%). Cotton quality remained similar, while mulches reduced irrigation frequency (7 irrigations) and total amount (533 mm); control needed more (9 irrigations, 685 mm). Crop water use efficiency improved with mulches (0.50 to 0.51 kg m^{-3} vs. 0.30 kg m^{-3} control). This study highlights organic mulch's potential to enhance soil properties, nutrient availability, weed suppression, cotton yield, and water use efficiency.

Introduction

Climate change has emerged as a major threat to agriculture worldwide, posing significant challenges to crop production, soil health, and overall sustainability (Nguyen et al. 2023). The shifting climate patterns associated with global warming have led to a range of adverse impacts on agricultural systems (Skendžić et al. 2021; Abbass et al. 2022). Altered rainfall patterns, characterized by erratic distribution and changes in the timing and intensity of precipitation have caused difficulties in crop management and reduced overall productivity (Skendžić et al. 2021). Moreover, the increased frequency of extreme weather events, including heat waves, droughts, floods, and storms, has further compounded the challenges faced by farmers (Lee et al. 2023). Rising temperatures, prolonged heat waves and drought stress during critical growth stages of crops can negatively affects crop development and productivity (Brito et al. 2019; AghaKouchak et al. 2020). Furthermore, extreme weather events associated with climate change, such as heavy rainfall and flooding, pose significant challenges to soil health and fertility (Lesk et al. 2022). Intense rainfall can cause soil erosion, leading to the loss of topsoil, essential nutrients, and organic matter (Anabaraonye et al. 2021; Wheeler and Lobley 2021). This erosion can affect soil structure, reduce water-holding capacity, and diminish soil fertility, ultimately hampering crop growth and agricultural productivity (Malik et al. 2022). These adverse conditions can result in significant economic losses and food insecurity. To address the adverse impacts of climate change on agriculture, it is crucial to implement both mitigation and adaptation strategies.

Cotton is an important cash crop, providing income and employment for millions of farmers and workers worldwide (Sahay 2019; Khanpara and Vala 2023). Its high consumer demand drives economic growth, trade, and job creation, making cotton a key contributor to global economies and livelihoods (Mbatha 2020; Abdukhalil 2023). Climate change has wide-ranging and profound effects on cotton production and the cotton industry as a whole. One of the primary impacts is the changing growing conditions for cotton crops. Rising temperatures associated with climate change can lead to heat stress in cotton plants, hindering their growth and development (Abbas 2022). Moreover, altered precipitation patterns can result in droughts or excessive rainfall, both of which can have detrimental effects on cotton crop (Zafar et al. 2021). Drought and changes in rainfall pattern can limit the availability of water for irrigation, which is crucial for cotton farming (Zafar et al. 2021). As a consequence, farmers may face challenges in securing sufficient water resources for their crops, potentially leading to reduced cotton cultivation or increased competition for water with other sectors (Hussain et al. 2020; Chiarelli et al. 2022). In such situations, reliance on irrigation may become more necessary, straining water supplies and adding to production costs.

Mulching is a widely adopted technique wherein materials are placed on the field either before, during, or shortly after sowing. This process aims to provide support and coverage to the soil surface using various materials like crop residues, livestock manure, and even sands (El-Beltagi et al. 2022; Kun et al. 2023). This practice serves multiple purposes such as reducing evaporation, preventing erosion, regulating soil temperature, enhancing soil water retention capability, and inhibiting weed growth

(Iqbal et al. 2020; Prem et al. 2020; El-Beltagi et al. 2022; Anuja et al. 2023). Organic mulch is more environment friendly as it is composed of biodegradable materials like straw, leaves, or compost that serves as a protective shield for the soil, preserving moisture and reducing erosion, and promotes soil health and fertility as the mulch breaks down over time (Iqbal et al. 2020; Kaur et al. 2020; El-Beltagi et al. 2022). Organic mulches play a significant role in mitigating nitrate leaching, improving soil's physical properties, promoting biological activity, harmonizing the nitrogen cycle, contributing organic matter, as well as regulating soil temperature and moisture retention (Iqbal et al. 2020; El-Beltagi et al. 2022; Scavo et al. 2022). Mulching in agricultural fields offers a range of advantages, encompassing the reduction of soil water loss, suppression of weed germination, prevention of soil erosion, and mitigation of water droplet kinetic energy (Prem et al. 2020; El-Beltagi et al. 2022). It contributes to the enhancement of soil structure and facilitates increased earthworm activity within the soil (McTavish and Murphy 2022). Additionally, it has the capacity to lower the soil's pH, thereby augmenting the accessibility of nutrients (El-Beltagi et al. 2022). As organic mulch undergoes decomposition, it imparts nutrients to the soil, prolonging their availability over an extended period (Ma et al. 2021; El-Metwally et al. 2022). The breakdown of organic mulch also accelerates the improvement of soil organic content, thereby enhancing the soil's water retention capacity (Navyashree et al. 2019; El-Beltagi et al. 2022). By curbing evaporation, mulches create an environment where greater moisture is retained close to plant roots, thereby extending the duration during which plants can absorb water (Prem et al. 2020; El-Beltagi et al. 2022).

The mulch acts as an insulating layer, regulating soil temperature and minimizing temperature fluctuations that can stress cotton plants (El-Beltagi et al. 2022; Tang et al. 2023). Moreover, organic mulch acts as a weed suppressor, and can reduces the need for herbicides and manual weed removal, promoting a more environmentally friendly and cost-effective approach to weed control (El-Beltagi et al. 2022; El-Metwally et al. 2022; Monteiro and Santos 2022). By reducing weed competition, cotton plants have better access to essential nutrients and water, allowing for healthier growth and higher yields. In addition, mulch encourages beneficial microbial activity, enhancing nutrient cycling and promoting a robust soil ecosystem (El-Beltagi et al. 2022; Waheed et al. 2023). Healthy soils contribute to increased water infiltration and retention, reducing irrigation needs and enhancing water-use efficiency. Furthermore, organic mulch aids in reducing soil erosion by acting as a physical barrier, preventing raindrops from directly impacting the soil surface (El-Beltagi et al. 2022; Waheed et al. 2023). Hence, mulch mitigates the risk of soil erosion and nutrient runoff, preserving valuable topsoil and safeguarding water quality. Therefore, by employing this natural and environment friendly technique, cotton farmers can enhance soil health, conserve water, control weeds, and promote overall crop productivity while minimizing the reliance on synthetic inputs, and can effectively enhance the long-term viability and environmental sustainability of their cotton cultivation practices. Keeping in mind the impacts of climate change on cotton cultivation, a study was planned to evaluate the influence of different organic mulches on soil, properties and cotton growth and yield.

Materials and Methods

The experiment was conducted in the farmer fields and research station of Rural Education and Economic Development Society (REEDS), Rahim Yar Khan, Pakistan. District Rahim Yar is situated at 28∘ 41' N latitude and 70∘ 30' E longitude and longitude of 70∘ 30' E, and and falls within an extensive alluvial plain located adjacent to the Indus river. It occupies a substantial expanse of an alluvial plain positioned alongside the Indus River. The weather temperatures ranged from 16.4°C in November to 30.5°C in June during 2021 while in 2022, the temperatures varied from 16.7°C in November to 31.0°C in June. Notably, August experienced a substantial increase in rainfall from 43 mm in 2021 to 224 mm in 2022. The humidity levels also showed some variations between the two years, with July displaying the most noticeable difference. This table provides valuable insights into the climate changes during the specified period, aiding in understanding the weather patterns and fluctuations between the two years. Net plot area for individual treatment was 16.60 × 30.50 m while total area 66.40 m × 121.90 m.

Land preparation and crop husbandry

The land preparation for cotton cultivation was an important step in ensuring a good yield. To ensure a favorable seedbed and optimal field tilth, thorough land preparation was carried out in multiple stages. Initially, the field was cultivated twice and then planked before initiating soaking irrigation. After a period, when the field's moisture level reached the desired field capacity, two additional cultivations were performed using a tractor-driven cultivator, followed by further planking. Subsequently, the field was rotavated to achieve a well-prepared seedbed and then beds comprising 75 cm widths were made to improve drainage and facilitate irrigation. Before planting the cotton crop, soil samples to depth of 30 cm (0–15 cm and 15–30 cm) were extracted using an auger. The collected soil samples were meticulously marked with unique numbers for identification purposes. Subsequently, these samples were dispatched to the soil and water testing laboratory situated in District Rahim Yar. For the sowing process, seeds of the cotton variety CKC-3 were used at a rate of 20 kg per hectare (ha^{-1}). The sowing was executed manually, ensuring a spacing of 30 cm between individual plants and 75 cm between rows. To facilitate the study, a randomized complete block design was implemented, with each treatment being replicated three times. The study incorporated three distinct mulch treatments: wheat straw, rice straw, and sugarcane leaves straw, each applied at a rate of 5 tons ha^{-1}. Additionally, a control plot (without mulch) was included in order to facilitate a comparative analysis of the outcomes. For effective nutrient management, fertilizers were administered in accordance with the guidance provided by the Soil and Water Testing Laboratory in Rahim Yar Khan, Pakistan. The fertilizer application encompassed the nitrogen (200 kg ha^{-1}), phosphorus (120 kg ha^{-1}), and potash (100 kg ha^{-1}). The phosphorus and potash, along with one-third of the nitrogen dose, were applied during the sowing process. Subsequently, the remaining nitrogen was distributed evenly in three separate applications: 35 days after planting, during square formation, and at boll formation.

Mulching

Organic mulching serves as an effective technique to enhance soil health, conserve moisture, control weed growth, and promote overall crop performance. In our trial, organic mulching using rice straw at a rate of 5 tons ha^{-1} was used. The application of mulch to cotton field was made when the cotton plants were 30 days because early mulching can interfere with seedling emergence. This is because the mulch can block sunlight and prevent the seedlings from getting enough light to grow. The rice straw mulch was spread evenly over the cotton beds and furrows. The thickness of the mulch layer was 2 inches.

Irrigation water

The crop was irrigated by canal water and each field plot was irrigated independently to ensure precise monitoring and control of soil moisture levels. To facilitate this, a digital soil moisture meter (Misol WH0291, China) was inserted in field to measure soil moisture content accurately. Throughout the crop growth period, daily soil moisture readings were recorded from each plot using the digital soil moisture meter. This enabled us to closely monitor the soil's water content and make informed decisions regarding irrigation scheduling. The irrigation strategy was based on maintaining an optimal soil moisture level of 25% in each plot. Once the average soil moisture content in a plot reached the predetermined threshold of 25%, irrigation was applied to replenish the water deficit and maintain an ideal moisture level for cotton growth and development.

Observations

Accurate and comprehensive observations regarding the different parameters of crop are crucial for drawing meaningful conclusions. The parameters recorded during the study are described briefly.

Soil health and fertility indicators

Soil organic carbon (SOC) plays a pivotal role in maintaining soil health and fertility by exerting influence over vital factors such as soil structure, water retention capacity, nutrient accessibility, and the overall productivity of the soil. To evaluate the presence of soil organic carbon, soil samples were collected from both mulched plots and control areas at a depth of 30 cm (Weissert et al. 2016). These samples were subsequently submitted to the Nuclear Institute for Agriculture and Biology (NIAB) in Faisalabad, Pakistan, where specialized analyses were conducted. Similarly, to ascertain soil pH, nitrogen (N), phosphorus (P), potassium (K), and organic matter (OM) content, soil samples were carefully obtained at the same 30 cm depth and were forwarded to the Soil and Water Testing Laboratory in Rahim Yar Khan, Pakistan, for comprehensive assessment. For a comprehensive understanding of the soil's thermal dynamics, digital soil temperature recorders were strategically inserted into the soil at a depth of 15 cm. This meticulous placement enabled continuous monitoring of soil temperature fluctuations, contributing valuable insights into the complex interplay between soil behavior and environmental factors. In the pursuit of optimizing cotton yields, effective weed management emerged as a fundamental consideration. To mitigate resource competition and promote ideal cotton growth conditions, a precise methodology was adopted. A designated area of 1 square meter was demarcated within three distinct sites of each plot. Within these demarcated zones, weed abundance was methodically tallied, with the resulting counts aggregated and averaged to furnish a comprehensive understanding of the weed population dynamics.

Yield and quality parameters

A randomized selection process was employed to choose ten plants from each specific site within a given plot. The height of each selected plant was meticulously measured from the soil surface to the highest point of the plant. Subsequently, the quantification of bolls per plant was undertaken. The number of bolls borne by each plant serves as a direct determinant of the ultimate cotton yield. Furthermore, the weight of individual bolls holds a notable influence over the final yield outcome. To attain this information, ten cotton plants were arbitrarily designated across three distinct sites within each plot. The mature, open bolls of these selected plants were precisely weighed using a digital balance, and these measurements were subsequently averaged to ensure accurate representation. To evaluate ginning out turn (GOT) and other quality attributes such as fiber length, strength, fineness, and uniformity, harvested cotton samples were transported to the Fiber Testing Laboratory in Rahim Yar Khan. For the determination of GOT, 100 g seed cotton yield samples were obtained from each plot, subsequently undergoing sun drying and cleaning processes prior to ginning. An electrical ginning machine was employed to segregate the lint from the seed cotton. The lint weight was then measured, and the GOT was calculated using the formula outlined in the work by Khan et al. (Khan et al. 2020).

$$\text{Ginning out turn (\%)} = \frac{\text{Lint yield}}{\text{Seed cotton yield}} \times 100$$

For the measurement of fiber length, strength, fineness, and uniformity, a high volume instrument system in Fiber Testing Laboratory, Rahim Yar Khan was used that calculated the fiber length, strength, fineness, and uniformity.

Number of irrigations and water use efficiency (WUE)

Total number of irrigations was documented during the entire crop season. The irrigation strategy was based on maintaining an optimal soil moisture level of 25% in each plot. Soil moisture (%) was noted daily using a digital soil moisture meter (Misol WH0291, China). Once the average soil moisture content in a plot reached the predetermined threshold of 25%, irrigation was applied to replenish the water deficit and maintain an ideal moisture level for cotton growth and development. Water use efficiency in crop production is a measure of how effectively a crop utilizes water to produce a certain amount of biomass or yield. It's a critical parameter to assess the sustainability and productivity of agricultural systems, especially in regions with water scarcity. The water use efficiency of cotton crop was calculated by considering the ratio of economic yield to the amount of water used in irrigation or rainfall (Saeed et al. 2021).

Crop water use efficiency (kg m^{-3}) = Economic yield (kg)/ total amount of water supplied (m^3).

Statistical analysis

The data acquired for the various parameters were subjected to statistical analysis using Statistix 8.1 software (Hussian et al. 2013). To evaluate the variations between the different treatments, a least significant difference (LSD) test was employed at a significance level of 5% (Steel 1997).

Results and Discussion

The results of study showing the impact of different organic mulch treatments on soil properties and nutrient availability are given in Table 1. In terms of soil temperature, the application of all three types of organic mulch contributed to maintaining a relatively moderate average temperature of around 27.3°C to 27.4°C, while the control treatment exhibited a significantly higher soil temperature of 41.6°C. The pH of the soil remained stable across all treatments, approximately at 7.9 to 8.1. One of the notable effects of the organic mulch treatments was on soil carbon content, which serves as an indicator of organic matter input. The application of wheat straw, rice straw, and sugarcane leaf straw mulches led to an increase in soil carbon content to 0.68%, 0.72%, and 0.70%, respectively. In contrast, the control treatment exhibited a lower soil carbon content of 0.51%, highlighting the potential of organic mulch in enriching the soil's organic matter content. Regarding nutrient availability, the organic mulch treatments demonstrated their beneficial impact. Available nitrogen levels increased in the presence of organic mulch, ranging from 0.045–0.049%, compared to the lower nitrogen availability of 0.028% in the control treatment. Similarly, the mulch treatments resulted in higher levels of available phosphorus (ranging from 6.4 mg kg^{-1} to 6.5 mg kg^{-1}) and available potassium (ranging from 89 mg kg^{-1} to 92 mg kg^{-1}) compared to the control treatment's lower values (5.6 mg kg^{-1} for phosphorus and 71 mg kg^{-1} for potassium). Furthermore, the application of organic mulch significantly increased soil organic matter content, with values ranging from 0.77–0.81%. In contrast, the control treatment exhibited a lower organic matter content of 0.51%.

Table 1
Effect of organic mulch on soil and its nutrients availability

Treatments	Soil temp. (°C)	Soil pH	Soil carbon (%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Soil organic matter (%)	Weed population (m^2)	Plant height (cm)	Bolls per plant	Open boll weight (g)	Seed-cotton yield (kg ha^{-1})
Wheat straw @ 5 tons ha^{-1}	27.4 a	7.9 a	0.68 a	0.048 a	6.50 a	89 a	0.78 a	4 b	145 a	35 a	3.10 a	2743 a
Rice straw @ 5 tons ha^{-1}	27.3 a	7.9 a	0.72 a	0.045 a	6.40 a	92 a	0.81 a	4 b	139 a	33 a	3.14 a	2704 a
Sugarcane leaf straw @ 5 tons ha^{-1}	27.4 a	7.9 a	0.70 a	0.049 a	6.43 a	92 a	0.77 a	5 b	142 a	34 a	3.12 a	2713 a
Control (no mulch)	41.6 b	8.1 a	0.51 b	0.028 b	5.60 b	71 b	0.51 b	23 a	102 b	29 b	3.0 b	2117 a
LSD at 5%	2.18	ns	0.11	0.008	0.35	5.47	0.10	1.34	12.45	2.13	0.082	63.72

The observed moderation of soil temperature through organic mulch application is of paramount significance. The ability of mulches to maintain a relatively stable average soil temperature (27.3°C to 27.4°C) is indicative of their role in regulating soil microclimates. Mulches act as a buffer against temperature and moisture fluctuations (Lal 2016), creating a more stable thermal environment conducive to the optimal growth and development of microorganisms and plants (Chen et al. 2014; Gao et al. 2022). By minimizing extreme temperature variations, mulches contribute to fostering favorable conditions for soil organisms, nutrient cycling, and root activity (El-Beltagi et al. 2022; Sun et al. 2022), ultimately enhancing overall agricultural productivity and sustainability.

The notable increase in soil carbon and organic matter content resulting from the application of wheat straw, rice straw, and sugarcane leaf straw mulches is indicative of enhanced organic matter input. This increase reflects improved organic matter input into the soil, which in turn has positive implications for soil health, carbon sequestration, water retention, and overall agricultural sustainability (Turmel et al. 2015). Organic mulches serve as a continuous source of organic matter, which enriches the soil with nutrients and promotes the growth of beneficial soil microorganisms (Bot and Benites 2005; Zhang et al. 2020). As the mulches gradually break down, they release essential nutrients that plants require for growth (Shaji et al. 2021). This influx of organic matter improves soil structure, porosity, and nutrient-holding capacity, resulting in healthier and more productive soils (Menzies Pluer et al. 2020). In addition, organic matter acts as a sponge, aiding in the absorption and retention of moisture during periods of rainfall or irrigation. This, in turn, mitigates water runoff, enhances soil structure, and augments the availability of water to plants during dry spells, contributing to enhanced drought resilience. The introduction of organic matter through mulches significantly boosts the soil's carbon content (Li et al. 2020). Sequestering carbon in the soil helps to mitigate climate change by removing carbon dioxide from the atmosphere and storing it in the soil, acting as a long-term carbon sink (Almaraz et al. 2023). A healthier soil ecosystem translates to better nutrient cycling and enhanced resistance to pest and disease pressures. The observed rise in available nitrogen, phosphorus, and potassium levels in the presence of organic mulch treatments highlights their role in enriching the soil with essential nutrients. As the mulches decompose, they release essential nutrients and organic compounds that nourish plants and foster microbial activity (Shaji et al. 2021). Thus use of organic mulch plays a pivotal role in enriching the nutrient content of the soil as shown in our study (Table 1), thereby supporting plant growth and development (Table 1).

The effects of organic mulch treatments on key aspects of cotton including weed population dynamics, cotton plant growth, boll production and yield-related traits are given in Table 1. The application of organic mulch treatments exhibited a noteworthy impact on weed population control. The wheat straw, rice straw, and sugarcane leaf straw treatments led to a remarkable reduction in weed density, with only 4 to 5 weeds per square meter. In contrast, the control treatment demonstrated a considerably higher weed population of 23 weeds m^2, underscoring the weed-suppressive effect of organic mulch. The significant suppression of weed populations under organic mulch treatments is of paramount importance. The decline in weed population observed with the application of mulches can be attributed to their ability to suppress weed growth by intercepting sunlight necessary for photosynthesis (El-Beltagi et al. 2022). This shading effect disrupts the energy production and metabolic processes of weed plants (Singhal et al. 2020), curbing their growth and ultimately leading to a more favorable environment for cultivated crops. Cotton plant height was positively influenced by the organic mulch treatments. The plants in the wheat straw, rice straw, and sugarcane leaf straw treatments exhibited greater heights, ranging from 139 cm to 145 cm. Conversely, the control treatment resulted in shorter cotton plants, averaging at 102 cm in height. A substantial correlation was observed between organic mulch application and boll production. Cotton plants under the wheat straw, rice straw and sugarcane leaf straw treatments yielded higher numbers of bolls per plant (33 to 35 bolls per plant). In comparison, the control treatment displayed a lower boll count per plant, averaging 29 bolls. Furthermore, the effect of organic mulch extended to open boll weight, a crucial yield-related trait. Open bolls in the wheat straw, rice straw, and sugarcane leaf straw treatments exhibited similar weights, measuring approximately 3.10 g, 3.14 g, and 3.12 g, respectively while the lowest open-boll weight (3.0 g) was recorded in control treatment where mulch was not applied. Perhaps most significantly, organic mulch treatments yielded higher quantities of seed cotton. The application of wheat straw resulted in higher yield (2743 kg ha^{-1}) however non-significant difference with rice straw and sugarcane leaf straw treatments, which yielded 2704 kg ha^{-1} and 2713 kg ha^{-1}, respectively. In contrast, the control treatment yielded 2117 kg ha^{-1}, highlighting the potential of organic mulch to enhance cotton yield. In terms of ginning out turn (Table 2), all treatments exhibited relatively consistent percentages, ranging from 36.62–37.2%. This aspect of yield processing showed no significant variations among the organic mulch treatments and the control treatment. Thus, the application of mulches has demonstrated a comprehensive positive impact on various key parameters of cotton such as plant height, number of bolls, open-boll weight and seed cotton yield. This improvement can be attributed to the cumulative effects of enhanced soil structure, moisture retention, and nutrient availability. As mulches gradually decompose, they contribute organic matter to the soil, fostering improved soil aeration and structure. This favorable soil environment promotes robust root development and overall plant growth, resulting in taller cotton plants. Moreover, the suppression of weeds ensures that cotton plants can fully capitalize on the available resources, resulting in improved crop performance (El-Beltagi et al. 2022). Thus, the overall improvement in cotton yield-related traits, such as boll count and open boll weight, attests to the positive influence of these treatments on cotton productivity (Zhang et al. 2020) that also enhanced the cotton quality parameters such as staple length and fiber uniformity index. Results showed that mulching reduced the frequency of irrigation and overall irrigation water quantity as compared to control treatment. The number of irrigations in the wheat straw, rice straw, and sugarcane leaf straw treatments received 7 irrigations, resulting in a total irrigation amount of 533 mm. In contrast, the control treatment received 9 irrigations, resulting in relatively higher total irrigation amount of 685 mm. Similarly, crop water use efficiency differed significantly in cotton. Notably, organic mulch treatments showcased distinct impacts on crop water use efficiency. The wheat straw, rice straw, and sugarcane leaf straw treatments yielded greater efficiencies ranging from 0.50 to 0.51 kg m^{-3}. In contrast, the control treatment displayed a comparatively lower efficiency value of water use efficiency (0.30 kg m^{-3}). This can be attributed to the protective layer created by the mulch on the soil surface. By forming this barrier, the mulch minimizes direct exposure of the soil to sunlight, wind, and other environmental factors (Shah and Wu 2020; Zheng et al. 2022). Consequently, the rate of evaporation from the soil is lowered. As the mulch layer prevents rapid moisture loss, the soil retains more water for extended periods (Prem et al. 2020). This diminished evaporation and prolonged moisture retention contribute to a decreased demand for frequent irrigation. The impact of organic mulch treatments on key aspects of cotton fiber quality, irrigation practices, and crop water use efficiency are given in Table 2. The length of cotton fibers, known as staple length, displayed minor variations among treatments. The wheat straw, rice straw, and sugarcane leaf straw treatments yielded staple lengths of 28.1 mm to 28.2 mm that was significantly higher than the staple lengths of control treatment, measuring 26.1 mm. Likewise, fiber fineness remained relatively uniform across all mulched treatments (4.2 μg/inch) and control treatment (4.3 μg/inch). Similarly, fiber uniformity index demonstrated minor fluctuations. The wheat straw, rice straw, and sugarcane leaf straw treatments showed the uniformity indices of 92% while the control treatment exhibited a slightly lower index of 89%. Fiber strength, a crucial determinant of cotton quality, appeared consistent across treatments.

Table 2
Effect of organic mulch on quality of cotton, number of irrigations, total irrigation amount and crop water use efficiency

Treatments	Ginning out turn (%)	Staple length (mm)	Fiber fineness (µg/inch)	Fiber uniformity index (%)	Fiber strength (tppsi)	No. of irrigations	Total irrigation water (mm)	Crop water use efficiency ($kg\ m^{-3}$)
Wheat straw @ 5 tons ha^{-1}	37.2 a	28.1 a	4.2	92 a	93.2 a	7 b	533 b	0.51 a
Rice straw @ 5 tons ha^{-1}	37.1 a	28.2 a	4.2	91 a	93.1 a	7 b	533 b	0.50 a
Sugarcane leaf straw @ 5 tons ha^{-1}	37.2 a	28.1 a	4.3	92 a	93.2 a	7 b	533 b	0.50 a
Control (no mulch)	36.6 b	26.1 b	4.3	89 b	93.1 a	9 a	685 a	0.30 b
LSD at 5%	0.32	0.75	ns	0.76	ns	0.45	34.10	0.09

Conclusion

In conclusion, this study demonstrates the significant positive effects of various organic mulch treatments on multiple aspects of cotton production. The application of organic mulches effectively moderated soil temperature, enriched soil carbon content, and improved nutrient availability. These treatments exhibited weed-suppressive effects, promoting healthier cotton plant growth, increased boll production, and enhanced yield-related traits. Moreover, the quality of cotton fiber, such as staple length, fineness, and uniformity, was positively influenced by the organic mulches. Notably, organic mulch treatments contributed to better crop water use efficiency, showcasing their potential for sustainable irrigation practices. These findings collectively highlight the multifaceted benefits of organic mulches in enhancing soil health, cotton growth, yield, and fiber quality, while promoting efficient water utilization in cotton production systems.

Declarations

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Available on request

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Conflicts of Interest

The authors declare that they have no conflicts of interest to report regarding the present study.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: Shahid Saleem, Muhammad Nasir, data collection: Hafeez Ullah, analysis and interpretation of results: Iqbal Hussain, draft manuscript preparation: Madiha Nisar, Saba Sabir. Final reading of manuscript Sidra Fatima, Abdul Khaliq, Syed Ahtisham Masood, Hafiz Abdul Rauf, Fida Hussain. All authors reviewed the results and approved the final version of the manuscript.

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