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Impacts of Nitrogen Fertilizer Application and Mulching on the Morpho-Physiological and Yield-Related Traits in Cotton

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Abstract: Cotton is a global cash crop with a significant contribution in the world economy. Optimum nutrient and water supply are most important for sustainable cotton production under warmer and dry environments. Field experiments were carried out to evaluate the cumulative impacts of various nitrogen doses and mulches on sustainable cotton production under semi-arid conditions during 2018 and 2019. Four nitrogen doses; 0, 70, 140, and 210 kg ha^{-1} and three types of mulch: control (without mulch), natural mulch (5 tons/ha wheat straw), and chemical mulch (methanol (30%). Nitrogen 210 kg ha^{-1} with natural mulching increased 40.5% gunning out turn, 30.0% fiber length, 31.7% fiber strength, 32.6% fiber fineness, 20.8% fiber uniformity, and 34.0% fiber elongation. Shoot nitrogen, phosphorous, potassium, calcium, and magnesium contents were maximum where 210 kg ha^{-1} nitrogen and mulch was applied. Natural mulch reduced the soil temperature as compared to chemical and no mulch conditions. The soil temperature was 0.5 to 1.8 °C lower in mulching treatments as compared to the control. Maximum economic yield was around 90% higher in natural mulch with the 210 kg ha^{-1} nitrogen application. It is concluded that optimum nitrogen application with natural mulch not only enhanced plant growth and development but also induced sustainability in quality cotton production under semi-arid conditions.

Keywords: nitrogen management; mulching type; cotton productivity; cotton physiology; cotton quality; semi-arid environment

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Citation: Hussain, K.; Ilyas, A.; Ali, S.; Bibi, I.; Shakil, Q.; Farid, M.U.; Saqib, Z.A.; Habib, A.; HAKKI, E.E. Impacts of Nitrogen Fertilizer Application and Mulching on the Morpho-Physiological and Yield-Related Traits in Cotton. *Agriculture* **2023**, *13*, 12. https://doi.org/10.3390/agriculture13010012

Academic Editors: Jose L. Gabriel and Diana Martín-Lammerding

Received: 22 October 2022
Revised: 12 December 2022
Accepted: 13 December 2022
Published: 21 December 2022

1. Introduction

Cotton (*Gossypium hirsutum* L.) is known as "White Gold" and is very sensitive to climatic conditions [1]. It is the cash crop of Pakistan and considered the backbone of the country's economy. Cotton shares 0.6% in the gross domestic production of Pakistan, 3.1% value addition in agriculture, around 2079-thousand-hectare area under cultivation with 7.064 million bales production during 2020–2021 [2]. The area under cultivation and overall production was lower than previous years due to low water availability, unfavorable climatic conditions, and loss of grower interest as compared to other major crops, in particular sugarcane [2]. It is also playing a major role in foreign exchange earnings [3]. Cotton exhibits an indeterminate growth habit and is mostly grown for fiber production [4]. Pakistan stands in the 4th position of cotton producing countries while China is in the top position, followed by India, USA, Brazil, Uzbekistan, and Turkey.

Crop management factors, such as nutrient, water, seed bed preparation, and weed control, are crucial for sustainable cotton production after climatic factors. However, the introduction of Bacillus thuringiensis (Cry1and Cry2) genes through genetic engineering not only improved cotton resistivity against insects [5] but also increased soluble protein content, leaf N content, free amino acid, greater glutamate pyruvic transaminase, and nitrate reductase activity at the reproductive stage. The uninterrupted supply of plant essential nutrients to the crop is very important for successful cotton production. Several studies on different doses of fertilizer were carried out to optimize the nutrient requirement for sustainable cotton production in various cotton producing zones [6–8]. N is an essential nutrient required in a large quantity for increasing and optimizing cotton production [9]. Nitrogen application in proper dose not only increases the number of leaves, leaf area, light interception, photosynthetic activity, fiber quality, and lint yield [10], but also increase salinity and drought resistance in cotton. On the other hand, nitrogen deficiency can induce a drastic decrease in plant growth and development which inhibits boll formation and premature senescence in the cotton crop [10]. Moreover, modern cotton cultivars with high nutrient absorption and low fertilizer requirement are needed for efficient conversion of nutrients into the final production [11].

Cotton is sensitive to a limited moisture supply during the growing season and this is another main factor that determines cotton productivity [12]. A water deficit can cause severe reduction in nutrient uptake, deteriorate photosynthesis, root growth, boll formation, fiber thickness, and fruit production [12]. Scientists are suggesting various resource saving agro-technologies for enhancing nutrient and water use efficiencies in the cotton crop [13]. Mulching is an important resource conserving agro-technology, very effective in conserving soil and water resources in the cotton crop planted under dry conditions [14,15]. The cotton crop is grown in the summer season with high temperatures and solar radiation. The optimum soil temperature is very important for normal plant growth and development, which can be achieved with the application of mulch in order to shade the soil during summer season [16]. Various mulching materials are being used to enhance plant growth and development by modifying the soil microclimate [17]. Mulches derived from biomaterial are called natural mulches and are organic origin [18]. Natural mulches are not often available in large quantities, are inconsistent and labor intensive; however, various chemicals mulches, such as plastic, methanol mulch, etc., are quite effective. Several studies confirmed cotton yield improvement with plastic mulch by conserving soil moisture and increasing soil temperature, but few indicated a yield decrease as well by suppressing plant growth [19]. Methanol applications stimulate plant hormones in cotton which increase plant growth, boll number per m^2, lint and seed cotton yield [20,21].

The importance of cotton in the world economy has a central position. It provides raw material to the textile industry, so it is indirectly a large source of foreign exchange. It is also a good source of edible oil and major source of edible oil in many countries. As far as environmental adaptability is concerned, agronomic factors, such as sowing time, nitrogen, phosphorus fertilization, soil moisture availability, plant protection, etc., and climatic factor, such as temperature, humidity, and rainfall, are major influential factors on cotton production. The semi-arid areas have variable conditions of droughts and rainfall, creating water scarcity conditions. In these areas, balanced nutrition, proper soil moisture availability, and favorable temperature ensure the cotton production which was our hypothesis as well. In light of the above discussion, the study was planned to investigate the integrated effect of nitrogen fertilizer application and mulching on cotton yield, physiological, and quality parameters under semi-arid conditions.

2. Materials and Methods

2.1. Site Description

The study was executed at a farmer's field in Multan (30°11′52″ N 71°28′11″ E) south Punjab-Pakistan during 2018 and 2019. Multan features an arid climate with very hot summers and mild winters. The normal annual precipitation measures 186 mm. The highest recorded temperature is approximately 52 °C and the lowest temperature is approximately 10 °C. The climatic conditions of 2018–2019 are presented in Figure 1. Wheat, cotton, sugarcane, and maize are the main crops and the wheat-cotton cropping system is the major cropping of the area. The soil of the study area was clay loam in nature (USDA system of classification) [22].

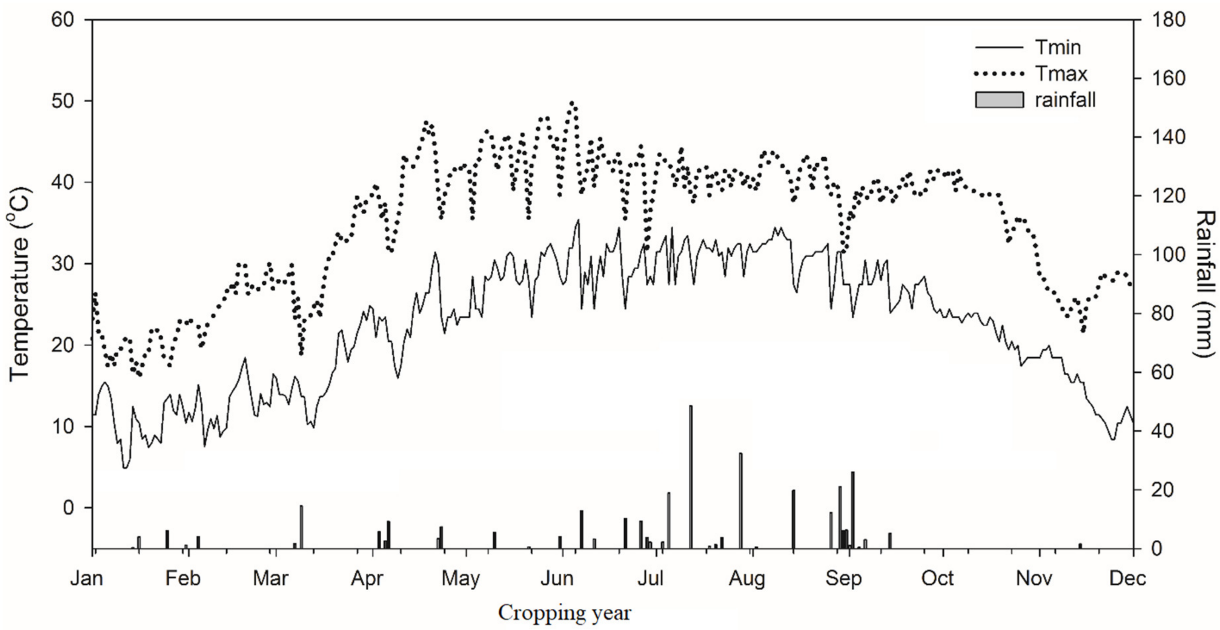

Figure 1. Climatic conditions of the study area during 2018–2019.

2.2. Experimental Description

Cultivar MNH-886 was used for sowing the crop with a seed rate of 20 kg ha^{-1}. Cultivar MNH-886 is used for cultivation in various regions of Pakistan, having a high seed cotton yield and desirable fiber characteristics. It is developed through hybridization of three parents [(FH-207 × MNH-770) × Bollgard^{-1}] at the Cotton Research Station Multan, Pakistan. A plot strip of 10 × 10 m was used for the study and ridges were made with R × R distance of 75 cm while plant-to-plant distance was maintained at 30 cm. The soil was ploughed twice up to a 30 cm depth to obtain an optimum soil condition for root growth and seedling establishment. Di-ammonium Phosphate (DAP) was used for the application of phosphorous at the recommended rate of 120 kg ha while potassium was applied as potassium nitrate at the rate of 100 kg ha^{-1}. All the phosphorous and potassium was applied at the time of sowing. Nitrogen was applied in the form of urea in four equal splits (first the time of planting, second at 35 day after planting, third at square formation, and fourth split at boll formation). Randomized complete block design with factorial arrangement was used for the study and each plot/treatment was repeated three times. The treatments were types of mulches, i.e., natural mulch (Wheat straw @ 5 tons ha^{-1}), chemical mulch (foliar spray of 30% methanol), control (without mulch), and nitrogen doses (70, 140, 210 kg ha^{-1} and control (0 kg N ha^{-1}). The wheat straw was applied after complete germination of the crop while methanol (30% v/v) was sprayed fortnightly just after initiation of square formation in four sprays (150 liters per hectare).

2.3. Data Acquisition

2.3.1. Yield and Quality Parameters

One square meter area from two different parts of experimental units was selected randomly to calculate biomass yield, economic yield, seed yield, and lint yield. The representative samples of lint from each experimental unit were used to calculate fiber length, fiber strength, fiber fineness, and fiber uniformity from each treatment per replication. For Ginning out turn (GOT), 100 g seed cotton yield was collected as sub samples from each plot. The samples were sun dried and cleaned before ginning. An electrical ginning machine was used for the ginning of the samples. Later on, the weight of lint was measured and GOT was calculated as

$$\text{Ginning out turn } (\%) = \frac{\text{The lint yield}}{\text{Seed cotton yield}} \times 100 \tag{1}$$

A high volume instrument system called an HVI system was used for the measurements of fiber length, strength, fineness, and uniformity.

Chlorophyll contents were estimated in fresh leaves by the method described by Lichtenthaler and Buschmann [23]. For determination of plant physiological parameters, plant samples were dried, grounded, and sieved with a 2-mm mesh. Out of these, 0.5 g samples were placed in a tube having 10 ml of 50% perchloric acid and 1 ml concentrated sulfuric acid, followed by decomposition by heating on a hot plate. Total N was analyzed by Kjeldahl distillation [24], P_2O_5 was determined by the Olsen method with a spectrophotometer (Shimadzu 1900i Japan) [25], and K_2O using the ammonium acetate extraction method using a flame photometer (Sherwood 410 UK) [26].

2.3.2. Soil Moisture Contents and Temperature

Soil moisture contents were measured 12 times per growing season by taking auger samples at 0–5, 5–20, 20–35, and 35–50 cm soil depth. The samples were weighed and oven dried at 105 °C for around 48 hours until a constant weight, whereas soil bulk density was determined using the intact core method [27].

Digital soil temperature recorders were installed at a 20 cm soil depth for monitoring the soil temperature with an one-hour interval, automatically connected with a data logger. The power was supplied through a battery connected with a solar panel.

The variation among treatments were similar during both years of the study and the data of all parameters are averaged across both years for easy understanding.

2.3.3. Statistical Analysis

SAS, Vol. 9.2 (Inc., Cary, CA, USA) was used for statistical analysis. The general linear model (PROC GLM) was used for statistical analysis of the number of mature bolls per plant, boll weight, seed cotton yield, fiber length, fiber strength, fiber fineness, chlorophyll contents, and fiber uniformity. Pairwise comparison of treatments was done using Tukey's Honest Significant Difference test at p = 0.05.

3. Results

3.1. Effect of Fertilizer Rates and Mulch Types on Physiological Parameters of Cotton

The physiological parameters were significantly affected by the various fertilizer doses and mulching applications (Table 1). Among nitrogen doses, the maximum effect was observed under the 210 kg ha^{-1} N application, whereas both chemical and natural mulch effect was similar under individual analysis of all physiological parameters (Table S1). Under interactive effects, maximum chlorophyll contents were observed in plants treated with the 210 kg ha^{-1} nitrogen application under natural mulch. Lowest chlorophyll contents were observed in the cotton plant treated without fertilizer irrespective of mulching type. The chlorophyll contents were increased more than 200% in plants that received the 210 kg ha^{-1} nitrogen application as compared to plants that received no fertilizer application, while more than 16% as compared to plants that received 140 kg ha^{-1} nitrogen application under the natural mulching condition.

Table 1. Effects of nitrogen (N) fertilization and mulches on physiological parameters in cotton during 2018–2019.

N (kg ha^{-1})	Mulch Type	Physiological Parameters					
		Chl Contents (mg mL^{-1})	Nitrogen (mg kg^{-1})	Phosphorus (mg kg^{-1})	Potassium (mg kg^{-1})	Calcium (mg kg^{-1})	Magnesium (mg kg^{-1})
0	Control	0.61 ^{e}	1.42 ^{d}	3.69 ^{e}	129.0 ^{d}	12.21 ^{d}	6.53 ^{d}
	Chemical mulch	0.68 ^{e}	1.45 ^{d}	3.77 ^{e}	134.2 ^{d}	12.28 ^{d}	6.65 ^{d}
	Natural mulch	0.72 ^{e}	1.46 ^{d}	4.17 ^{d}	147.7 ^{c}	12.30 ^{d}	6.69 ^{d}
70	Control	1.24 ^{d}	2.72 ^{c}	4.36 ^{c}	153.7 ^{c}	14.00 ^{c}	7.35 ^{c}
	Chemical mulch	1.40 ^{cd}	2.78 ^{c}	4.46 ^{bc}	168.8 ^{b}	14.05 ^{c}	7.38 ^{c}
	Natural mulch	1.51 ^{c}	2.80 ^{c}	4.53 ^{b}	171.0 ^{b}	14.08 ^{c}	7.50 ^{c}
140	Control	1.68 ^{c}	2.90 ^{b}	4.69 ^{ab}	176.4 ^{ab}	14.34 ^{b}	8.29 ^{b}
	Chemical mulch	1.65 ^{c}	2.94 ^{ab}	4.83 ^{a}	182.7 ^{a}	14.41 ^{b}	8.33 ^{b}
	Natural mulch	1.94 ^{b}	2.99 ^{ab}	4.89 ^{a}	187.5 ^{a}	14.41 ^{b}	8.45 ^{b}
210	Control	1.93 ^{b}	3.01 ^{a}	4.92 ^{a}	190.7 ^{a}	14.63 ^{a}	8.67 ^{a}
	Chemical mulch	2.12 ^{a}	3.06 ^{a}	4.96 ^{a}	193.0 ^{a}	14.70 ^{a}	8.71 ^{a}
	Natural mulch	2.26 ^{a}	3.08 ^{a}	4.99 ^{a}	196.2 ^{a}	14.74 ^{a}	8.78 ^{a}
LSD		0.15	0.09	1.2	8.3	1.5	1.3
CV		2.01	2.12	3.9	5.1	4.5	4.3

The treatment means with same letters are not statistically significant at 5% probability level. Chl = chlorophyll, LSD = least significant difference, CV = coefficient of variance

The effect of nitrogen fertilization and mulch types on shoot nitrogen contents was statistically significant (Table 1). The nitrogen concentration in the plants' part increased with the increase of nitrogen application. Statistically highest nitrogen contents were observed in plants that received 210 kg ha^{-1} nitrogen with and without mulch application. The lowest nitrogen contents in plants were obtained from plants having no nitrogen fertilizer application irrespective of mulching types. Shoot phosphorous concentration consistently increased with the increase of nitrogen fertilization rates and (Table 1) a significant difference was apparently observed especially at the 140 and 210 kg ha^{-1} nitrogen application with mulching types. Compared to the non-fertilized control, the increase in shoot phosphorous contents was 35.5% in cotton plants with the 210 kg N ha^{-1} applied in the natural mulch treatments. Statistically lowest phosphorous contents were obtained from cotton planted without nitrogen application. Variability in shoot calcium contents was prominently observed with the variability of nitrogen fertilizer application and mulch type (Table 1). Statistically highest calcium concentration was observed in plant shoots fertilized with 210 kg nitrogen per hectare irrespective of mulch application. Calcium contents were 20% higher in plants treated with 210 kg N ha^{-1} than plants without fertilization, while lowest calcium contents were obtained from plants that received no nitrogen fertilization. Magnesium shoot content trends were similar with calcium concentration in plant shoots.

The soil temperature was reduced with the application of mulch during the growing season. Natural mulch (wheat straw) decreased the soil temperature more as compared to chemical mulch and the control (without mulch) during the whole cropping season (Figure 2). The highest soil temperature was measured in the plots having no mulch material. Soil volumetric water contents were higher in the natural mulch, closely followed by the chemical mulch. Lowest volumetric water contents were observed in the plots having no mulch application during the cropping season (Figure 3).

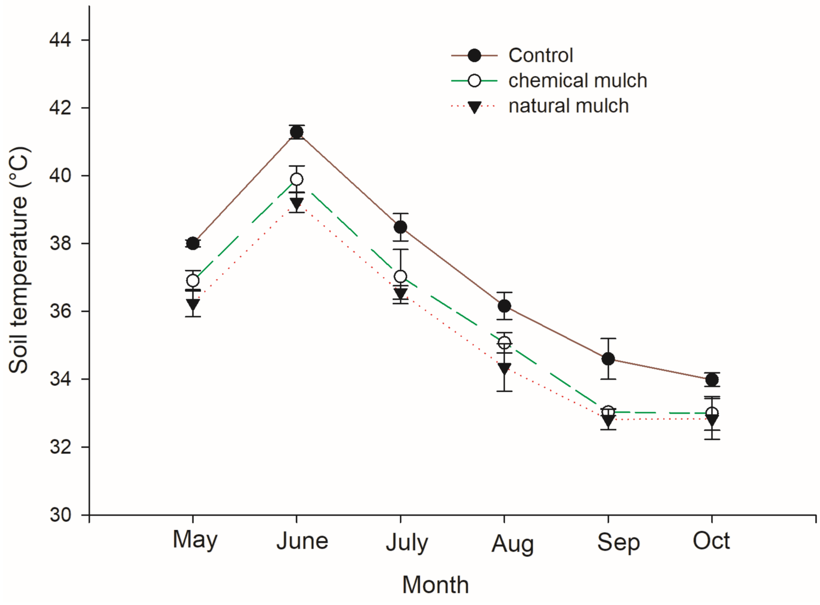

Figure 2. Impact of mulch on soil temperature during crop growing season during 2018–2019.

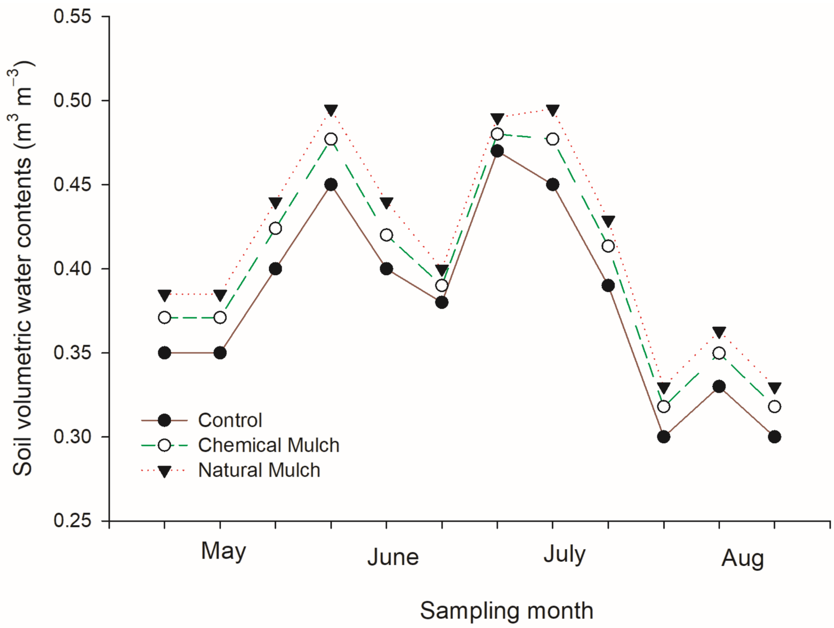

Figure 3. Impact of mulch on soil volumetric water contents during 2018–2019.

3.2. Effect of Fertilizer Rates and Mulch Types on Quality Parameters of Cotton

The effect of nitrogen application rates and mulch types was statistically significant on quality parameters, such as ginning out turn, fiber length, fiber strength, fiber fineness, fiber uniformity, and fiber elongation of cotton (Table 2). Individual effects showed that 210 kg N per ha application improved all quality parameters better as compared rest N application methods while chemical and natural mulch improved quality parameters statistically similar under individual effects (Table S2). Ginning out turn (GOT) was increased with the increase of nitrogen application. Maximum GOT (41.40%) was obtained from plants treated with 210 kg nitrogen per hectare application under natural mulch, which was 40.5%

higher as compared to the control without fertilization while minimum GOT (29.45%) was indicated in the control treatment without fertilization.

Table 2. Effects of nitrogen fertilization with mulch application on quality parameters of cotton during 2018–2019.

N (kg ha^{-1})	Mulch Type	Quality Parameters					
		GOT (%)	F Length (mm)	F Strength (g tex^{-1})	F Fineness (µg inch^{-1})	F Uniformity (%)	F Elongation (%)
0	Control	29.45 ^{c}	24.68 ^{c}	23.38 ^{d}	3.90 ^{d}	44.76 ^{d}	10.13 ^{c}
	Chemical mulch	30.01 ^{c}	24.75 ^{c}	23.63 ^{d}	3.93 ^{d}	45.14 ^{d}	10.25 ^{c}
	Natural mulch	30.23 ^{c}	24.97 ^{c}	23.89 ^{d}	3.96 ^{d}	45.46 ^{d}	10.29 ^{c}
70	Control	32.55 ^{c}	28.89 ^{b}	24.44 ^{cd}	4.13 ^{cd}	47.63 ^{c}	12.66 ^{b}
	Chemical mulch	33.95 ^{c}	29.10 ^{b}	24.90 ^{c}	4.38 ^{c}	48.40 ^{c}	12.70 ^{b}
	Natural mulch	35.55 ^{b}	29.20 ^{b}	24.97 ^{c}	4.44 ^{bc}	48.74 ^{c}	13.18 ^{ab}
140	Control	35.90 ^{b}	29.39 ^{b}	25.28 ^{c}	4.69 ^{b}	50.91 ^{b}	13.05 ^{ab}
	Chemical mulch	37.80 ^{a}	29.67 ^{a}	26.67 ^{bc}	4.76 ^{ab}	51.76 ^{b}	13.09 ^{ab}
	Natural mulch	38.90 ^{a}	30.09 ^{a}	27.01 ^{b}	5.07 ^{a}	51.77 ^{b}	13.25 ^{a}
210	Control	40.10 ^{a}	30.30 ^{a}	28.38 ^{ab}	5.04 ^{a}	53.38 ^{a}	13.24 ^{a}
	Chemical mulch	41.30 ^{a}	30.57 ^{a}	29.04 ^{a}	5.09 ^{a}	53.94 ^{a}	13.34 ^{a}
	Natural mulch	41.40 ^{a}	31.92 ^{a}	30.79 ^{a}	5.17 ^{a}	54.09 ^{a}	13.58 ^{a}
LSD		0.7	1.2	0.4	0.3	0.90	0.53
CV		5.2	2.8	3.9	1.4	4.7	1.9

The treatment means with same letters are not statistically significant at 5% probability level. GOT = ginning out turn, F = fiber, LSD = least significant difference, CV = coefficient of variance.

The increase in nitrogen application enhanced the fiber length in the cotton crop. The fiber length was maximum (31.92 mm), around 30% and 9% higher in the crop applied with the 210 kg ha^{-1} nitrogen fertilizer under natural mulch as compared to non-fertilized control treatments and plots that received the 110 kg ha^{-1} nitrogen fertilizer, respectively. Lowest fiber length (24.68 mm) was obtained from treatment having no nitrogen fertilization.

Statistically significant differences in fiber strength were observed. The maximum fiber strength (30.79 g tex^{-1}) was observed in crop plants with the 210 kg ha^{-1} nitrogen application under natural mulch, while the lowest strength value (23.38 g tex^{-1}) was observed in the non-fertilized control treatment. Moreover, application of the 210 kg nitrogen under natural mulch enhances 31.69% fiber strength as compared to the control treatment without nitrogen fertilization.

The increase in nitrogen fertilizer application enhanced the fiber fineness in cotton. Statistically fine fiber quality (5.17µg inch^{-1}) was observed in the treatment that received the 210 kg ha^{-1} nitrogen fertilization with natural mulch while fineness was lowest (3.90 µg inch^{-1}) in no fertilization control treatment. Nitrogen fertilizer application at the rate of 210 kg ha^{-1} enhanced fiber fineness by 32.56% as compared to non-fertilized control plants.

The fiber uniformity was increased with an increase in the nitrogen fertilizer application irrespective of mulching type. The fiber uniformity increased 20.84% with enhancing the nitrogen application at the rate 210 kg ha^{-1} as compared to no nitrogen fertilizer application plants. Maximum fiber uniformity (54.09%) was at the 210 kg N ha^{-1} application under natural mulch, closely followed by the 140 kg N ha^{-1} application while minimum fiber uniformity (44.76%) was observed in non-fertilized treatments.

Fiber elongation in cotton was also governed by the application of nitrogen fertilization and mulch type. Statistically highest fiber elongation (13.58%) was obtained with the application of nitrogen fertilizer at the rate 210 kg ha^{-1} under natural mulch. Lowest fiber elongation (10.13%) was induced by non-application of nitrogenous fertilizer. The fertilizer application (210 kg ha^{-1}) enhanced fiber elongation by 34% as compared to no fertilizer applied control treatment.

3.3. Effect of Fertilizer Rates and Mulch Types on Yield Parameters of Cotton

Application of nitrogen at 210 kg ha^{-1} statistically showed a maximum effect on yield parameters as compared to rest of the nitrogen rates, however, both chemical and natural mulch effect was statistically similar but higher than control under individual effects (Table S3). Under interactive analysis, cotton total yield significantly increased with the increase in N application rates and the mulching types during both experimental years (Table 3). The trends of cotton total yield during two growing seasons were almost similar without large variations and was averaged across the years. The average cotton total yield was the maximum (7.7 t ha^{-1}) in natural mulch under the 210 kg ha^{-1} nitrogen application, which was statistically at par with the control, and chemical mulch under the 210 kg ha^{-1} nitrogen application. Lowest total cotton yield averaged across the year was observed in treatments where no fertilizer was applied to the crop.

Table 3. Effects of nitrogen fertilization with mulch application on total biomass, economic, seed, and lint yields of cotton during 2018–2019.

N(kg ha^{-1})	Mulch Type	Yield Parameters (t ha^{-1})				
		Total YIELD	Biomass Yield	Economic Yield	Seed Yield	Lint Yield
0	Control	4.5 ^{d}	2.4 ^{bc}	2.1 ^{c}	1.4 ^{c}	0.67 ^{c}
	Chemical mulch	4.8 ^{d}	2.5 ^{b}	2.2 ^{c}	1.5 ^{c}	0.69 ^{c}
	Natural mulch	4.9 ^{d}	2.5 ^{b}	2.3 ^{c}	1.6 ^{c}	0.70 ^{c}
70	Control	5.4 ^{c}	2.7 ^{b}	2.7 ^{c}	1.8 ^{b}	0.95 ^{c}
	Chemical mulch	5.6 ^{c}	2.7 ^{b}	2.9 ^{bc}	1.9 ^{b}	1.00 ^{b}
	Natural mulch	5.8 ^{c}	2.8 ^{b}	3.0 ^{b}	2.0 ^{b}	1.00 ^{b}
140	Control	6.6 ^{b}	3.4 ^{a}	3.2 ^{b}	2.1 ^{ab}	1.14 ^{b}
	Chemical mulch	6.8 ^{b}	3.5 ^{a}	3.3 ^{b}	2.2 ^{a}	1.15 ^{b}
	Natural mulch	6.9 ^{ab}	3.6 ^{a}	3.3 ^{b}	2.1 ^{ab}	1.25 ^{a}
210	Control	7.3 ^{a}	3.6 ^{a}	3.7 ^{ab}	2.3 ^{a}	1.36 ^{a}
	Chemical mulch	7.4 ^{a}	3.6 ^{a}	3.8 ^{a}	2.4 ^{a}	1.41 ^{a}
	Natural mulch	7.7 ^{a}	3.7 ^{a}	4.0 ^{a}	2.5 ^{a}	1.51 ^{a}
LSD		0.4	0.3	0.4	0.3	0.2
CV		4.8	4.2	3.9	3.9	5.3

The treatment means with same letters are not statistically significant at 5% probability level. LSD = least significant difference, CV = coefficient of variance.

The average biomass yield was statistically affected by the mulching type and nitrogen dozes (Table 3). The maximum biomass yield (3.7 t ha^{-1}) was observed in the treatments where natural mulch and 210 kg ha^{-1} nitrogen was applied, which was statistically at par with all mulch treatments with the 140 kg ha^{-1} nitrogen application. The lowest cotton biomass yield averaged across the year was observed in treatments where no fertilizer was applied to the crop. Th economic yield significantly increased with the increase in nitrogen application rates and the mulching (Table 3). The maximum economic yield was observed in natural and chemical mulch with the 210 kg^{-1} nitrogen application, around 77 to 90%

higher as compared to the control treatment with no fertilizer application. The minimum economic yield was obtained from treatments without mulch.

Additionally, seed and lint yields were significantly ($p < 0.05$) influenced by nitrogen application rates, mulching, and their interactions. Cotton seed yield increased by 78.5, 71.42, and 64.2% at an application of 210 kg N ha^{-1} with natural, chemical, and without mulching, respectively, as compared to no fertilizer application treatment. Moreover, cotton seed yield increased by 50, 57, and 50% at 140 kg N ha^{-1} with natural, chemical, and without mulching, respectively. The highest seed yield was obtained with application of 210 kg N ha^{-1} under natural mulching treatment, increasing by 13.67% as compared to treatment with application of 140 kg N ha^{-1} under natural mulching conditions. The lint yield was 125, 110, 102% higher at application of 210 kg N ha^{-1} with natural, chemical, and without mulching, respectively, as compared to no fertilizer application. The highest lint yield (1.51 t ha^{-1}) was obtained from treatment applied with 210 kg N ha^{-1} under natural mulch, while the lowest lint yield was obtained from the control treatment.

4. Discussion

Cotton is a major fiber crop worldwide, with additional benefits of oil production. The cotton crop is a climate sensitive crop, and its production can be enhanced through agronomic management and insect-pest invasion control. Among climatic factors, temperature, rainfall, and relative humidity significantly affect cotton production. Cotton productivity under harsh conditions like semi-arid environments is always dependent on balanced nutrient application and optimum moisture availability [1,11,12]. In semi-arid environments, soil moisture is a limiting factor and this coupled with a high temperature during the cotton growing season causes the loss of fruiting, ultimately reducing the cotton yield.

The soil temperature increased with the increase of the air temperature during both growing seasons, but the soil temperature was 0.5 to 1.8 °C lower in mulching treatments as compared to the control. A lower temperature in mulch treatments probably created favorable conditions for plant growth and development and ultimately enhanced yield. Earlier studies also indicated the same effects and observed that mulching with crop residues decreased soil temperature and soil bulk density, as well improved soil physical conditions [17,28], which were translated into a better yield. Natural mulch with wheat straw reduced the soil temperature more as compared to chemical mulch and the control because of deposition of crop residues as mulch reduces the soil temperature around 2–7 °C at a 15 cm soil depth, as indicated in various experiments [14,15,29].

Mulching is helpful for moisture conservation in environments facing high temperatures during the summer season with a limited supply of water. Mulches reduce the soil evaporation by reducing the Capillarity [30]. Mulching enhanced moisture conservation and ensured its availability for a longer period. Proper moisture availability during the active growth phase is crucial for cotton productivity, especially when the air temperature is high. Furthermore, mulching improves efficient use of irrigation water and precipitation by maintaining balance between transpiration and evaporation [18,19,31]. Previous research indicated that straw mulch significantly affects soil moisture conditions by improving soil moisture [19,23], which triggers efficient nutrient use and enhanced crop productivity.

The concentration of shoot nitrogen, phosphorous, potassium, calcium, and magnesium were high in the 210 kg ha^{-1} nitrogen application with natural and chemical mulch as compared to the control. This is an indication of high nutrient availability and use by cotton plants under a better moisture environment, which again translated into cotton productivity. Allanov et al. [17] indicated a 54, 35, 47, 19, and 32% increase in shoot nitrogen, phosphorous, potassium, calcium, and magnesium, respectively at the 280 kg N ha^{-1} application with natural mulches as compared to the control without fertilizer and mulch application. Plant chlorophyll content increased with the increase of nitrogen application along with mulch application in the cotton crop. Increasing the nitrogen application increases the nitrogen availability to plants and ultimately, higher nitrogen uptake. Nitrogen and plant chlorophyll contents are proportional to each other [32] and important for yield formation and quality enhancement.

Cotton quality parameters are improved with the increase of nitrogen and mulch application [17]. Optimum nitrogen application and its use is very crucial for cotton productivity and quality improvement [10]. Cotton biomass, economic, seed, lint, and total yield are proportionate with nitrogen application up to the optimum level [17,33]. Several studies indicated an increase in cotton yield-related parameters with the increase of nitrogen application and mulching [17,34]. The yield increase in cotton with nitrogen and mulch application is due to the positive impact of mulch on lowering the soil temperature and provision of optimum moisture during the active growing period, while optimum nitrogen enhanced the growth and development of cotton [17]. Low water availability to the cotton crop causes shedding of the flower bud, reduces fiber elongation, plant height, and fiber quality, especially in semi-arid conditions. Soil moisture conservation through mulching coupled with optimum nitrogen fertilizer application enhances cotton biomass, economic, seed, lint, and total yield with high GOT, fiber length, fiber strength, fiber fineness, fiber uniformity, and fiber elongation.

5. Conclusions

Cotton productivity under semi-arid environments is dependent on balanced nutrient application and optimum moisture availability. Optimum nitrogen fertilization with mulching enhanced cotton yield and quality under field conditions. Moreover, mulching reduced the soil temperature, improved the soil moisture conditions during warmer periods of the cotton growing season, which created favorable growing conditions for the cotton crop. Chemical mulch was as effective as straw mulch in enhancing physiological, quality, and yield parameters of cotton under optimum nitrogen application conditions. Chemical mulch would be suitable in areas with limited availability of natural mulch. Nitrogen application at the rate 210 kg ha^{-1} is optimum for sustainable cotton production and application of natural mulch is helpful in inducing favorable temperature and soil moisture conditions for proper cotton growth under dry and warmer climatic conditions of semi-arid environments.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agriculture13010012/s1, Table S1: Individual effects of Nitrogen rates (a) and mulch types (b) on physiological parameters of cotton. Table S2: Individual effects of Nitrogen rates (a) and mulch types (b) on quality parameters of cotton. Table S3: Individual effects of Nitrogen rates (a) and mulch types (b) on yield parameters of cotton.

Author Contributions: Conceptualization, K.H. and A.I.; methodology, K.H., A.I. and S.A.; software, S.A.; validation, K.H., A.I., S.A. and I.B.; formal analysis, K.H., A.I., S.A., I.B., A.H., M.U.F. and Z.A.S.; investigation, K.H., A.I. and E.E.H.; resources, K.H. and Q.S.; data curation, K.H., A.I., S.A., I.B., M.U.F., Z.A.S. and A.H.; writing—original draft preparation, K.H., A.I., S.A., I.B., M.U.F., Z.A.S., Q.S. and E.E.H.; writing—review and editing, K.H., A.I., S.A., I.B., M.U.F., Z.A.S., Q.S. and E.E.H.; funding acquisition, K.H. and Q.S.; All authors have read and agreed to the published version of the manuscript.

Funding: Higher Education Commission of Pakistan Research Project No. HEC/2018-20056: NCRA-017, NUST, Islamabad and in part by the Precision Agriculture and Analytics Lab (PAAL), National Centre in Big Data and Cloud Computing (NCBC), University of Agriculture, Faisalabad, Pakistan.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data will be available on request to corresponding author.

Acknowledgments: The authors are thankful to Higher Education Commission Pakistan for providing the funding for the research. The authors are also thankful to Ch. Farooq Ahmad for providing the research area and facilitating the research activities at his farm. The authors acknowledge the financial support provided in part by the NCRA-017, NUST, Islamabad, and in part by the Precision Agriculture and Analytics Lab (PAAL), National Centre in Big Data and Cloud Computing (NCBC), University of Agriculture, Faisalabad, Pakistan.

Conflicts of Interest: The authors declare no conflict of interest.

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