International Journal of Bioresource Science
Citation: IJBS: **08**(02): 69-80, December 2021
DOI: 10.30954/2347-9655.02.2021.2

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

Improving Quantitative and Qualitative Properties of Cotton Through the Use of Organic and Chemical Fertilizers Under Water Deficit Stress Conditions

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Received: 11-09-2021 **Revised:** 21-11-2021 **Accepted:** 12-12-2021

ABSTRACT

Water deficit stress and poor soil fertility in arid and semi-arid regions are the most important factors limiting the growth and yield of cotton plants. A factorial experiment was conducted in a randomized complete block design in a research farm in the Ardabil (Moghan), Iran, in the 2019-2020 crop year with three replications. Experimental treatments included moisture levels at three levels (40, 60, and 80% of field capacity) and fertilizer application at four levels (vermicompost, cattle manure, chemical fertilizers (urea and triple superphosphate), and control). The results showed that the content of photosynthetic pigments decreased significantly with delay in irrigation. At the same time, the highest amounts of proline, malondialdehyde, and hydrogen peroxide were observed in irrigation conditions of 40% moisture of field capacity. Application of organic and chemical fertilizers compared to the control showed a significant effect on increasing the chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids. The relative water content, nitrogen, phosphorus, potassium, and oil percentage increased by 32, 24, 23, and 26% in optimal irrigation conditions and 28, 21, 15, and 20% in moderate stress conditions and 23, 16, 14, and 19, respectively, in severe stress conditions due to vermicompost application compared to treatment without fertilizer. Due to vermicompost application in irrigation conditions, maximum grain yield (2558.33 kg ha^{-1}), fiber yield (1117.04 kg ha^{-1}), oil yield (651.81 kg ha^{-1}), and oil percentage (25.48%) were obtained, with 80% of field capacity obtained. Based on the results of this study, it can be concluded that in conditions of low irrigation, the application of organic fertilizers is more effective in improving the quantitative and qualitative characteristics of cotton. It is better to increase the yield of agricultural products from vermicompost and cattle manure instead of chemical fertilizers, to be used to reduce environmental pollution and their production costs to achieve a sustainable agricultural.

HIGHLIGHTS

- Cotton production in arid and semi-arid regions is adversely affected by water deficit stress and poor soil fertility.
- Photosynthetic pigments decreased significantly with delay in irrigation.
- Application of organic and chemical fertilizers significantly increasing chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids yield and oil yield of cotton.

Keywords: Dehydration stress, Sustainable agriculture, Vermicompost, Manure

How to cite this article: Heydarzadeh, S., Hosseinpour, A., Gitari, H., Maitra, S. and Rahimi, A. (2021). Improving Quantitative and Qualitative Properties of Cotton Through the Use of Organic and Chemical Fertilizers Under Water Deficit Stress Conditions. *Int. J. Bioresource Sci.*, **08**(02): 69-80.

Source of Support: None; **Conflict of Interest:** None

Cotton (*Gossypium*) is a perennial plant grown commercially as an annual in many parts of the world. Cotton buds are the most widely used component of the plant. They are the starting raw material for many products, including textiles, edible oil, paper, livestock feed, and medicinal compounds (Loka *et al*. 2020). Cotton fiber has many beneficial properties (comfort, color retention, absorbency, strength). The residual seed meal or hulls from its lubrication are also used for animal feed (Gao *et al*. 2020; Panda *et al*. 2020).

Cotton is highly vulnerable to water deficit stress, particularly during the flowering and boll formation stages (Singh *et al*. 2021). The enhancement of drought tolerance for scientists is challenging since, under drought, the plant itself adopts different techniques in combating stress depending on the level of water stress and the duration of water stress on the plant (Ul-Allah *et al*. 2021). Examining biochemical traits/ characters under stressful conditions can help us understand adaptation mechanisms to a harsher context (Li *et al*. 2020). Water deficit stress (drought) is also a key constraint to agricultural productivity (Amirnia *et al*. 2019; Nyawade *et al*. 2021; Seleiman *et al*. 2021). Reduction in photosynthetic capacity and rises in leaf senescence are indicators of water deficit stress, and they adversely impact crop development (Shavkiev *et al*. 2020; Raza *et al*. 2021). Other impacts of water stress include decreased cell growth, expansion of the leaves, assimilation of translocation and transpiration, protein synthesis, and chlorophyll (Amirnia *et al*. 2019; Nasar *et al*. 2021; Singh *et al*. 2021). Also, the net absorption of CO_2 and most of the physiological processes of cotton plants are reduced under water stress conditions (Shavkiev *et al*. 2020). Another adverse effect of drought stress is the nutritional imbalance in plants, resulting in retarded growth, a situation that can be corrected to some extent by providing the necessary elements through the soil (Nyawade *et al*. 2020; Shavkiev *et al*. 2020).

The application of chemical fertilizer has been significantly expanded as the quickest technique to compensate soil nutrients for their deficiency and increase crop production (Nyawade *et al*. 2020). Nonetheless, the use of such fertilizers causes environmental pollution and ecological harm and, in many circumstances, raises production costs (Gitari *et al*. 2019; Rahimi *et al*. 2019). The leaching of nitrogen-containing fertilizers with high loading rates into the subsoil can pollute groundwater (Nyawade *et al*. 2019; Bairwa *et al*. 2020). Organic fertilizers improve the soil's organic matter and fertility by enhancing soil chemical characteristics such as pH, cation capacity, micro-organism activity, and nutrient availability (Maitra *et al*. 2020; Cevheri *et al*. 2021; Faridvand *et al*. 2021; Maitra and Gitari 2020). Vermicompost is rich in growth hormones and vitamins, which improve the microbial activity in the soil and helps in the long-term storage of nutrients with minimal environmental effects (Rahimi *et al*. 2019). Cattle manures are a nutrient-rich organic source for plants' sustainable production (Iren and Aminu, 2017). They provide plant macro-and micro-nutrient requirements and increase organic matter in the soil, plant nutrient absorbability, and relative C: N balance, resulting in increased plant growth and development (Yarami and Sepaskhah, 2015; Rahimi *et al*. 2019; Heydarzadeh *et al*. 2021). Thus, this study was designed and conducted to investigate the effect of different irrigation levels and organic and chemical fertilizers on the quantitative and qualitative characteristics of cotton plants.

MATERIALS AND METHODS

The study was carried out as a factorial experiment based on a randomized complete block design with 12 treatments and three replications in the (Moghan), Iran, in the 2019-2020 growing season. The first factor was assigned to the irrigation regime at three levels (40, 60, and 80% of field capacity). The second factor was assigned to applying fertilizers at sowing time at four levels: vermicompost, cattle manure, chemical fertilizers (urea and triple superphosphate), and control in which no fertilizer was applied. Time-domain reflectometry was used during the growing season to measure soil moisture content (θv) at depths of 0–30 cm (Kamali and Mahdian 2009). Irrigation treatments were applied after planting between the 4^{th} and 5^{th} leaf stage. Application of vermicompost (10 t ha^{-1}) and cattle manure (30 t ha^{-1}) was done to the respective plots simultaneously as the land preparation operation and was thoroughly mixed with the soil. Also, in the treatment of chemical fertilizer, 100 kg ha^{-1} of nitrogen fertilizer and 60 kg ha^{-1} of triple superphosphate fertilizer were used. Some characteristics of vermicompost and cattle manure used in this study are presented in Table 1. The soil had a clayey texture (with 23% silt, 42% clay, and 35% sand), 0.56 dS m^{-1} electrical conductivity (EC), 7.95 pH, 0.54% nitrogen, 10.12 mg kg^{-1} available phosphorus, and 407 mg kg^{-1} available potassium.

The distance between the rows was 50 cm, whereas the one between the plants on the row was 15 cm. In this experiment, cotton of Khordad cultivar with 97% vigor and 99% purity was used. The cotton seeds were disinfected with carboxin thiram fungicide in a ratio of two per thousand before sowing. The land was prepared in May using a plow and two discs perpendicular. Seed sowing was done manually in the second half of June. Immediately, irrigation took place, and subsequent irrigations were carried out every seven days until the plant was fully established. Harvesting of cotton grains and fibers was done in two stages based on the opening of the bolls. To measure the fiber and grain yield in each plot, an experiment was performed from two middle rows after removing the marginal effects from an area of 1 m^2.

To evaluate the studied characteristics in the entire flowering stage of the leaves of the upper part of each experimental plot, five plants were randomly selected and analyzed for chlorophyll and carotenoid content using Arnon (1967) method. Shaw and Leskovar's (2015) method determined the relative water content (Eq. 1).

$$\text{RWC (\%)} = \left(\frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}}\right) * 100 \quad \ldots(1)$$

Malondialdehyde was evaluated with slight variation according to the thiobarbituric acid (TBA) reaction, whereby 0.5 g of fresh leaf tissue was ground in 1 mL of 5% trichloroacetic acid (TCA). The extract was centrifuged at 4000 rpm at room temperature for 10 minutes. 2 mL of the extract was added to 2 mL of 0.6 % TBA and was placed in a bain-marie for 10 minutes. The absorbance of the samples was read at 532, 600, and 450 nm, and the amount of malondialdehyde was calculated according to Eq. 2 (Zhou *et al*. 2004):

$$\text{MDA} = 645 \times (\text{A532} - \text{A600}) - 0.56 \times \text{A450} \quad \ldots(2)$$

Hydrogen peroxide was measured by the method of Bo *et al*. (2016) using a spectrophotometer at a wavelength of 390 nm. Here, 0.5 g of leaf sample was homogenized in 5 mL of 0.1% TCA, and the samples were centrifuged at 15,000 rpm at 4°C for 15 minutes. Then, 0.5 mL of supernatant, 0.5 mL of 10 mM potassium phosphate (buffered at a pH of 7), and 1 mL of 1 M potassium iodide were added. The protocol of ninhydrin reagent determined proline content. The absorption of the samples was measured at 515 nm with a spectrophotometer (Paquin and Lechasseur, 1979).

The nutrients of the cotton plant were measured as per AOAC standard by dry digestion method using nitric, hydrochloric, and perchloric acids (AOAC, 2005). To measure the nutrient content of cotton leaves, dried samples were milled, digested, and analyzed with combustion (4 h at 500 °C) of the grain samples. The plant ashes (5 mg) were digested in 1 ml of concentrated HCl. The samples were then filtered, and the phosphorus (P) content was determined calorimetrically by the vanadomolybdate method. A spectrophotometer was used to measure leaf phosphorus, and a flame photometer was used to measure potassium content (Waling *et al*. 1989). Measurement of the percentage leaf nitrogen was determined by Kjeldahl method (Rossi *et al*. 2004). The seed oil percentage was measured by Soxhlet method using benzene (Joshi *et al*. 1998). The following Eq calculated oil yield. 3:

$$\text{Oil yield} = \text{Oil percentage} \times \text{Seed yield} \quad \ldots(3)$$

After ensuring that the data were average, statistical analyses were done using the SAS 9.1 software. Means were compared by Duncan's test at the $p < 0.05$ level, and graphs were drawn in Excel.

RESULTS AND DISCUSSION

The results of variance analysis showed that the content of photosynthetic pigments, proline content, malondialdehyde, and hydrogen peroxide was affected by the simple effect of irrigation conditions and fertilizer application (Table 2). The interaction effect of experimental treatments (irrigation conditions × fertilizer application) on relative water content, percentage of nitrogen, percentage of phosphorus, percentage of potassium, grain yield,

Table 1: Some chemical properties of organic fertilizer used in this study

Organic fertilizer	EC (dSm^{-1})	pH	K	P	N	Organic Matter
				(%)		
Cattle manure	7.64	7.48	1.1	1.14	1.69	38
Vermicompost	3.81	7.2	1.85	2.3	1.45	30

Table 2: Analysis of variance of some quantitative and qualitative traits of cotton plant affected by the moisture levels and fertilizer

Source of variation	df	Chlorophyll a	Chlorophyll b	Total chlorophyll	Cartonoid	RWC	Proline	MDA	H_2O_2	N	P	K	Seed yield	Fiber yield	Oil	Oil yield
Repetition	2	0.01	0.001	0.02	0.001	1.44	0.91	1.30	0.08	0.0007	0.0001	0.001	104.43	72.83	0.003	13.37
Irrigation (Irr)	2	0.45**	0.05**	0.81**	0.03**	611.48**	92.71**	150.90**	6.62**	0.78**	0.003**	0.10**	1148297.23**	253853.32**	1.86**	83441.96**
Fertilizer (Fer)	3	0.80**	0.31**	1.94**	0.02**	806.01**	33.58**	66.69**	2.01**	0.80**	0.005**	0.14**	619789.68**	47937.11**	1.95**	48260.62**
Irr × Fer	6	0.003ns	0.0001ns	0.004ns	0.00004ns	81.46**	2.26ns	6.95ns	0.04ns	0.03*	0.0005**	0.01**	36302.91**	3579.27**	0.07**	3105.46**
Error	22	0.01	0.0009	0.008	0.0007	2.13	0.94	3.33	0.09	0.01	0.00008	0.002	6791.25	612.72	0.02	514.55
C. V (%)		8.26	4.55	4.68	6.96	2.27	8.07	8.54	9.04	3.53	3.36	3.98	4.41	2.81	1.59	4.95

**, ** and ns, Significant at 5% and 1% levels of probability, non-significant, respectively.*

Table 3: Comparison of qualitatively traits of cotton plants affected by moisture levels

Moisture levels	Chlorophyll a (mg g^{-1} FW)	Chlorophyll b (mg g^{-1} FW)	Total chlorophyll (mg g^{-1} FW)	Cartonoid (mg g^{-1} FW)	Proline (μmol g^{-1} FW)	MDA (μmol g^{-1} FW)	H_2O_2 (μmol g^{-1} FW)
80% of field capacity	1.44±0.16a	0.74±0.05a	2.18±0.15a	0.44±0.09a	8.86±0.19b	17.88±1.10 c	2.62 ±0.05c
60% of field capacity	1.21±0.13b	0.67±0.06b	1.89±0.07b	0.39±0.06b	13.43±0.09a	21.25±0.09 b	3.67±0.07 b
40% of field capacity	1.05±0.15c	0.61±0.08c	1.66±0.08c	0.34±0.25c	13.90±1.12a	24.97±0.04 a	4.05± 0.09a

Different letters down the column indicate a significant difference in the probability level of 5% with LSD test.

fiber yield, oil percentage, and oil yield of cotton was significant (Table 2).

Photosynthetic pigments content

According to mean comparison results, the content of photosynthetic pigments (chlorophyll a, b, total, and carotenoid) with delay in irrigation decreased significantly (Table 3). While the application of organic and chemical fertilizers compared to the control had a significant effect on increasing the content of photosynthetic pigments, so that the highest content of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids 1.44, 0.74, 2.18, and 0.44 mg g^{-1} FW, respectively, were observed in plants treated with vermicompost. Also, the application of cattle manure and vermicompost had a similar effect on chlorophyll content. In addition, chlorophyll b and carotenoids did not show a statistically significant difference due to the application of cattle and chemical fertilizers. In comparison, the lowest content of chlorophyll a (0.91 mg g^{-1} FW), chlorophyll b (0.53 mg g^{-1} FW), total chlorophyll (1.44 mg g^{-1} FW), and carotenoids (0.33 mg g^{-1} FW) were observed in the treatment without fertilizer application (Table 4). Previous studies indicated that the amount of chlorophyll in plants under stress was reduced, which led to a decrease in the ratio of absorbed light by the plants (Amirnia *et al*. 2019; Singh *et al*. 2021). Under conditions of water scarcity, the proline concentration increases.

Table 4: Comparison of qualitatively traits of cotton plant affected by fertilizer

Fertilizer	Chlorophyll a (mg g^{-1} FW)	Chlorophyll b (mg g^{-1} FW)	Total chlorophyll (mg g^{-1} FW)	Cartonoid (mg g^{-1} FW)	Proline (μmol g^{-1} FW)	MDA (μmol g^{-1} FW)	H_2O_2 (μmol g^{-1} FW)
Vermicompost	1.56±0.19a	0.95±0.12a	2.51±0.15a	0.47±0.09a	10.13±1.51d	17.94±1.10 c	2.90±0.09 d
Cattle manure	1.41±0.08a	0.62±0.09b	2.04±0.08b	0.38±0.11b	11.20±0.65c	20.62±1.01b	3.24±0.09 c
Chemical fertilizers	1.06±0.11b	0.60±0.06b	1.67±0.09c	0.38±0.08b	12.28±0.11b	21.45±0.56 b	3.66±0.06 b
Control	0.91±0.08c	0.53±0.04c	1.44±0.11d	0.33±0.08c	14.64±1.05a	24.30±0.89 a	3.98±1.15 a

Different letters down the column indicate a significant difference in the probability level of 5% with LSD test.

Since both chlorophyll and proline are synthesized by a common preceding agent called glutamate, boosting proline synthesis under water deficiency stress reduces chlorophyll synthesis (Amirnia *et al*. 2019; Singh *et al*. 2021). There is a positive link between leaf N and chlorophyll content because N contributes to the structure of chlorophyll (Amirnia *et al*. 2019). The amount of nutrients the plant receives from the soil is related to chlorophyll biosynthesis. Cevheri *et al*. (2021) found that the impacts of water deficit stress and nitrogen insufficiency were indirectly decreased by organic fertilizers by absorbing moisture and retaining the ammonium-N, and by limiting nitrogen leaching. Thus, the chlorophyll content has increased. In general, proper usage of components like nitrogen can prevent dramatic decreases in chlorophyll in plants under water scarcity stress (Amirnia *et al*. 2019). As a result, nitrogen deficiency hinders photosynthesis, which reduces plant growth and, in turn, leads to long-term plant performance and production (Rahimi *et al*. 2019, 2021).

Malondialdehyde

According to the results, delay in irrigation significantly increased the concentration of malondialdehyde in cotton (Table 3). While the use of organic and chemical fertilizers had an influential role in reducing the amount of malondialdehyde, the maximum and minimum concentrations of 24.30 and 17.94 μmol g^{-1} FW, respectively, in the treatment without fertilizer (control) and vermicompost were obtained (Table 4). Underwater deficit stress, a high concentration of malondialdehyde in 40% of field capacity plants may be accompanied by an increase in H_2O_2 accumulation in plants, which can reflect the rate of membrane lipids peroxidative damage. The protection of the host plants versus oxidative damage stress via the increased activity of the antioxidant enzyme is responsible for ROS removal, implying a low concentration of hydrogen peroxide accumulation (Semwal *et al*. 2021; Galviz *et al*. 2021). The use of organic fertilizers contributes to the production of peroxyl radical scavengers, cell stability against free radicals, and the provision of a robust suppression system for ROS (Cevheri *et al*. 2021; Faridvand *et al*. 2021). The application of vermicompost in cotton plants reduced the effects of moisture stress by increasing the availability of moisture and nutrients, reducing lipid peroxidation of the membrane and the amount of malondialdehyde (Cevheri *et al*. 2021).

Hydrogen peroxide

Based on mean comparison results, the amount of hydrogen peroxide increased with a delay in irrigation (Table 3). In the treatment of organic and chemical fertilizers, the highest (3.98 μmol g^{-1} FW) and the lowest (2.89 μmol g^{-1} FW) of hydrogen peroxide were observed in the control treatment and application of vermicompost (Table 4). Generally, water deficiency stress can cause excessive accumulation of ROS within plants, resulting in an imbalance of O^{2-} and H_2O_2, and consequently, oxidative disruption of many bio-molecules (Chen *et al*. 2020). Antioxidant activity was improved in plants with vermicompost and cattle manure application treatment, which might lead to reduced production of H_2O_2 (Cevheri *et al*. 2021). In our research, water deficit conditions triggered a significant rise in H_2O_2 content, while ROS accumulation was decreased to a different extent in vermicompost plants.

Proline

The results showed that the highest concentration of proline (13.90 mg g^{-1} FW) was observed under irrigation conditions of 40% of field capacity. In contrast, with irrigation conditions of 60% of field capacity, there was a statistically significant difference (Table 3). In addition, in the treatments of organic and chemical fertilizers, the control treatment with 14.64 mg g^{-1} FW had the highest concentration of proline, while the lowest one (10.13 mg g^{-1} FW) was obtained from vermicompost fertilizer (Table 4). During stress, proline, as a protective compatible solute, is increased to maintain the activity of other proteins that facilitates water uptake and protects the cells from the accumulation of ROS (Amirnia *et al*. 2019; Chen *et al*. 2020). Application of organic fertilizer provides suitable and ideal conditions (using water relations and better nutrition) for plant growth, so they can temporarily escape the drought stress conditions and suffer more minor damage, and as a result, the amount of proline compared to control plants shows more minor increase (Cevheri *et al*. 2021).

Relative water content

The results showed that the highest relative water content (82%) was obtained in vermicompost application treatment under 80% of field capacity irrigation conditions, which did not show a statistically significant difference with cattle manure application treatment. At all irrigation levels, the relative water content in the treatment of organic and chemical fertilizers compared to the control treatment was significantly increased, but the least (50%) was obtained in the treatment of no fertilizer under 40% field capacity (Table 5). The reduction of relative water content due to water deficit stress has a positive and high correlation with soil moisture content. Decreasing the relative water content and closing the stomata is the first effect of water deficit stress, which reduces the yield by disrupting the synthesis of photosynthetic materials (Ghahfarokhi *et al*. 2015; Nasar *et al*. 2021; Raza *et al*. 2021). Also, reducing the growth and root activity and increasing the rate of evaporation and transpiration from the plant community are influential factors in reducing the relative water content (Liang *et al*. 2021; Hassan *et al*. 2020). The application of vermicompost and cattle manure to the soil by improving the physical properties of the soil, creating more space for water infiltration by modifying and granulating the soil, and by establishing bonds with water molecules to prevent water evaporation has improved moisture availability by the plant, which is probably the case, increasing the relative water content of cotton leaves under water deficit stress (Cevheri *et al*. 2021).

Nitrogen

The results showed that the highest content of cotton leaf nitrogen (3.61%) was observed in vermicompost fertilizer treatment and irrigation conditions of 80% of field capacity. With the delay in irrigation, the nitrogen content of cotton leaves decreased significantly, while the application of organic and chemical fertilizers compared to the control had a significant effect on increasing the amount of nitrogen in each irrigation level. So that the lowest content of cotton leaf nitrogen (2.43%) was obtained in the control treatment (without fertilizer application) and irrigation conditions of 40% of field capacity (Table 5). It has been reported that the uptake of nutrients by plants under water deficit stress is reduced due to reduced transpiration, disruption of the active transmission system, and membrane permeability, which reduce the root absorption force (Amirnia *et al*. 2019; Hafez *et al*. 2021; Nyawade *et al*. 2020). It seems that the use of vermicompost, compost and cattle manure has a vital role in the formation and stability of soil aggregates and through improving the amount of nutrient uptake through root development and nutrient availability in the soil and the subsequent increase in growth, development, and biomass of the cotton plant, caused a significant improvement in nitrogen concentration (Cevheri *et al*. 2021).

Phosphorus

According to mean comparison results, applying organic and chemical fertilizers in comparison with the control treatment increased the phosphorus content of cotton leaves in all three irrigation levels. As a result, the highest and lowest cotton phosphorus content of 0.36 and 0.256%, respectively, were obtained in the vermicompost fertilization treatment under irrigation conditions, 80% of field capacity, and the treatment without fertilizer application under irrigation conditions, 40% of field capacity (Table 5). Phosphorus deficiency is one

Table 5: Comparison of quantitative and qualitative traits of cotton plant affected by the interaction of moisture levels and fertilizer

Moisture levels	Fertilizer	RWC (%)	N (%)	P (%)	K (%)	Seed yield (kg ha^{-1})	Fiber yield (kg ha^{-1})	Oil (%)	Oil yield (kg ha^{-1})
80% of field capacity	Vermicompost	82.11 ± 0.87a	3.61 ± 2.32 a	0.358 ± 0.004a	1.60 ± 0.09a	2558.33 ± 41.69a	1117.04 ± 15.06a	25.48 ± 0.04a	651.81 ± 11.59 a
	Cattle manure	80.25 ± 3.31a	3.44 ± 2.07 ab	0.322 ± 0.005b	1.29 ± 0.19c	2361.60 ± 46.69b	1047.41 ± 31.34b	25.18 ± 0.17 b	594.66 ± 15.76 b
	Chemical fertilizers	74.14 ± 1.09b	3.02 ± 1.11 de	0.294 ± 0.002cd	1.27 ± 0.22cd	1962.32 ± 28.04de	938.42 ± 8.13de	24.57 ± 0.03 de	482.27 ± 7.39 de
	Control	55.53 ± 1.35e	2.74 ± 0.52 fgh	0.277 ± 0.005e	1.19 ± 0.15de	1727.51 ± 58.96 fg	843.10 ± 15.28 g	24.12 ± 0.11 fg	416.76 ± 16.07 fg
60% of field capacity	Vermicompost	75.32 ± 0.76b	3.27 ± 1.62 bc	0.308 ± 0.003bc	1.41 ± 0.22b	2170.04 ± 85.56c	1001.85 ± 27.15 c	24.92 ± 0.16 c	540.99 ± 24.70 c
	Cattle manure	61.80 ± 4.23d	3.11 ± 1.39 cd	0.305 ± 0.005c	1.28 ± 0.11cd	2036.80 ± 102.75cd	960.92 ± 30.80 cd	24.68 ± 0.19 d	502.90 ± 29.16 cd
	Chemical fertilizers	59.52 ± 1.28d	2.86 ± 0.77 ef	0.283 ± 0.007de	1.26 ± 0.14cd	1828.11 ± 56.30ef	900.82 ± 15.33 ef	24.30 ± 0.10 f	444.35 ± 15.55 ef
	Control	53.87 ± 0.89ef	2.58 ± 0.34 hi	0.259 ± 0.005f	1.14 ± 0.13ef	1602.20 ± 107.11gh	756.74 ± 26.00 h	23.78 ± 0.11 hi	381.18 ± 27.03 gh
40% of field capacity	Vermicompost	64.52 ± 1.56c	2.89 ± 0.83 ef	0.296 ± 0.003cd	1.29 ± 0.11c	1700.28 ± 23.04fg	874.10 ± 6.34 fg	24.34 ± 0.05ef	413.93 ± 6.32 fg
	Cattle manure	60.02 ± 1.35d	2.80 ± 0.64 fg	0.285 ± 0.005de	1.27 ± 0.12cd	1625.33 ± 133.62 gh	737.43 ± 35.47 hi	24.21 ± 0.24fg	393.74 ± 36.29 gh
	Chemical fertilizers	52.90 ± 0.85f	2.65 ± 0.67 gh	0.281 ± 0.003de	1.10 ± 0.12fg	1506.08 ± 25.51 h	705.77 ± 10.39 i	23.99 ± 0.05 gh	361.35 ± 6.82 h
	Control	49.68 ± 0.93g	2.43 ± 1.09i	0.253 ± 0.003f	1.03 ± 0.13g	1321.05 ± 10.34i	661.77 ± 8.33j	23.66 ± 0.04 i	312.51 ± 2.69 i

Different letters indicate a significant difference in the probability level of 5% with LSD test.

of the first effects of water deficit stress in plants, probably due to reduced phosphorus distribution, reduced solubility of nutrients, and poor absorption by plant roots (Wang *et al*. 2020). So, the application of organic fertilizer by accelerating soil acidity, soil aeration, balanced provision of most nutrients, gradual release of nutrients during plant growth, preventing leaching, and increasing the solubility of nutrients accelerates and improves phosphorus uptake by roots (Hafez *et al*. 2021; Rahimi *et al*. 2019; Parecido *et al*. 2021).

Potassium

Based on the results, the application of organic and chemical fertilizers compared to the control at each irrigation level had an influential role in potassium uptake. In that case, the highest and lowest potassium of cotton leaves were obtained with the content of 1.60 and 1.03%, respectively, due to vermicompost fertilization and without the application of fertilizer treatment in irrigation conditions of 80 and 40% of field capacity (Table 5). Reduction of potassium uptake under water deficit stress can be attributed to reducing nutrient flow from soil to the plant by decreasing soil water (Rahimi *et al*. 2019). As a result, the use of vermicompost, compost, and cattle manure plays a vital role in the formation and stability of soil aggregates and, as a result, improves the uptake and availability of potassium (Mahboub *et al*. 2020) by increasing the vegetative growth of the plant and subsequent root development.

Grain yield

The highest grain yield of cotton (2558.33 kg ha^{-1}) was obtained in vermicompost fertilizer treatment under 80% of field capacity irrigation conditions. So that with delay in irrigation, the amount of grain yield decreased significantly, while the application of organic and chemical fertilizers compared to the control had a significant effect on increasing grain yield at each irrigation level. However, the lowest grain yield (1321.05 kg ha^{-1}) was obtained from the treatment without the application of fertilizer (control) under irrigation conditions of 40% of field capacity (Table 5). Lack of water shortens the period of seed filling and earlier maturation of plants, reduces the photosynthesis of leaves, reduces the production of nutrients, and thus reduces the vegetative and reproductive organs, which can ultimately reduce plant yield (Ul-Allah *et al*. 2021). Due to the positive effect of organic fertilizers on water relations of the host plant, nutrient cycle, and availability, an increase in nutrient uptake under vermicompost and cattle manure treatment can increase the yield of cotton (Meena *et al*. 2019). Researchers in the study of the effect of organic fertilizer application on cotton grain yield under water stress showed that with the application of low water stress in cotton plants, vermicompost and cattle manure had a positive effect on grain yield (Cevheri *et al*. 2021).

Fiber yield

According to the results, with increasing water deficit stress, the amount of fiber yield decreased. So the highest-fiber yield (1117.04 kg ha^{-1}) was observed from vermicompost fertilizer treatment under 80% of field capacity irrigation conditions. However, treatment without fertilizer with 661.77 kg ha^{-1} under irrigation conditions 40% of field capacity had the lowest fiber yield (Table 5). By increasing irrigation, the uptake of water and nutrients in the plant increases, which will lead to an overall increase in total weight of the plant biomass, but water deficit stress, uptake of water and nutrients, leaf area, plant growth rate, plant growth period and area reduce plant photosynthesis. All of these factors ultimately lead to reduced production of cotton plant fiber yield (Ul-Allah *et al*. 2021). Meena *et al*. (2019) and Cevheri *et al*. (2021) reported that the yield of cotton fibers increased by increasing water use efficiency and improving the absorption and access to nutrients when there was the application of organic fertilizers.

Oil percentages

According to the results, the highest amount of cottonseed oil (25.48%) was observed in vermicompost fertilizer treatment and irrigation conditions of 80% of field capacity. So that the percentage of cottonseed oil decreased with increasing water deficit stress, while the use of organic and chemical fertilizers compared to the control had a significant effect on increasing the percentage of seed oil at each irrigation level. At the same time, the lowest amount of cottonseed oil (23.66%) was obtained in the treatment without fertilizer application and irrigation conditions of 40% of field capacity (Table 5). The stage of grain filling or granulation was introduced as the most sensitive stage of the plant in terms of the effect of water deficit stress on the percentage of seed oil (Akbari *et al*. 2020). This may be due to the oxidation of some polyunsaturated fatty acids and the reduction of the ability of carbohydrates to convert to oil under stress (Yang *et al*. 2017). The application of organic fertilizers through the availability of nutrients, especially nitrogen and phosphorus, have improved growth and photosynthesis and, consequently, increased the percentage of cottonseed oil (Meena *et al*. 2019).

Oil yield

The results showed that the oil yield decreased significantly with delays in irrigation. So that the highest oil yield with the amount of 651.81 kg ha^{-1} was observed in the treatment of vermicompost under irrigation conditions and 80% of field capacity. On the other hand, the lowest value of the mentioned trait with the amount of 312.51 kg ha^{-1} was obtained in irrigation conditions of 40% of field capacity and without fertilizer treatment (control) (Table 5). Oil yield is affected by grain yield and oil percentage, and any factor that increases or decreases these traits also affects oil yield. According to the increasing oil yield in the treatment of vermicompost under irrigation conditions, 80% field capacity had the most significant effect on increasing oil yield. The increase in oil yield under optimal irrigation treatment conditions is due to the simultaneous increase in grain yield and oil percentage due to vermicompost and cattle manure. Therefore, the use of cattle manure due to increased access to nutrients and water, which is an influential factor in stimulating the growth and photosynthesis of plants, has improved the conditions for growth production of photosynthetic materials and thus increased grain yield and seed oil of cotton under water deficit stress (Moosavi, 2019). Increasing oil yield due to the use of organic fertilizers is related to increasing the activity of beneficial microorganisms, improving soil porosity, increasing water storage capacity in the soil, increasing the availability of plant nutrients in the soil, increasing nutrient uptake by plants, and improving plant nutrition (Meena *et al*. 2019).

CONCLUSION

According to the results of this study, the content of photosynthetic pigments of cotton plants was significantly reduced with delay in irrigation. While the use of organic and chemical fertilizers compared to the control showed a significant effect on increasing the content of photosynthetic pigments. The concentration of proline, malondialdehyde and hydrogen peroxide increased with the increasing severity of water deficit stress. Still, the use of vermicompost fertilizer significantly reduced the damage caused by water deficit stress. The use of vermicompost and cattle manure in comparison with chemical fertilizer at all irrigation levels had the most significant effect on increasing the relative water content, nitrogen, phosphorus, potassium, oil percentage, grain yield, fiber yield, and oil yield of the cotton plant. Vermicompost treatment under optimal irrigation conditions increased grain yield, fiber yield, and oil yield of a cotton plant by 48, 40, and 52%, respectively, compared to the treatment without fertilizer application (control) under severe stress conditions. From the obtained results, it can be concluded that the use of vermicompost and cattle manure by reducing the oxidative damage caused by drought and increasing the content of photosynthetic pigments, as an effective strategy to improve soil fertility and increase nutrient uptake in water stress conditions, improves the grain and fiber yield of cotton plants.

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