Journal of King Saud University - Science 36 (2024) 103445

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Full Length Article

Glycine betaine application improved seed cotton yield and economic returns under deficit irrigation

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ARTICLE INFO

Keywords:
Osmolyte
Deficit irrigation
Carbon emission
Emission factor

ABSTRACT

Background: Deficit irrigation exerts devastating effects on the productivity and economic returns of cotton crop, as well as carbon dioxide (CO_2) emission from soil. Osmolytes play a significant role in facilitating the adaptation of cotton plants to abiotic stresses and improve productivity.
Methods: This study investigated the effects of different osmolytes (glycine betaine, ascorbic acid, salicylic acid 100 mg L^{-1} each) and deficit irrigation (50 %-I_{50}, 75 %-I_{75}, and 100 %-I_{100}) on seed cotton yield, greenhouse gas emission (CO_2-C), emission factor (EFs) and economic returns of cotton in Southern Anatolia, Türkiye.
Results: Deficit irrigation and osmolyte treatment, both separately and in combination, had a substantial impact on seed cotton yield, CO_2-C emission and EFs. The lowest (3800 kg ha^{-1}) and the highest (4746 kg ha^{-1}) seed cotton yield was noted under I_{50}, and I_{100} treatments, respectively. Similarly, no osmolyte application and application of glycine betaine resulted in the lowest (4097 kg ha^{-1}) and the highest (4545 kg ha^{-1}) seed cotton yield, respectively. The interactive effect indicated that application of glycine betaine and salicylic acid produced better yield than control treatment under all irrigation treatments. The lowest (1.55) and the highest (1.94 mg) CO_2-C emission (mg CO_2-C m^{-2} h^{-1}) was recorded for I_{50}, and I_{100} treatments respectively. Likewise, the lowest (1.52) and the highest (2.19) daily carbon emission were recorded for salicylic acid and glycine betaine application, respectively. The lowest and the highest EFs values were observed for glycine betaine and ascorbic acid application, respectively. Application of glycine betaine resulted in the highest economic returns under all irrigation treatments which was comparable to salicylic acid, whereas the lower economic returns were recorded for control treatment.
Conclusion: It is concluded that application of glycine betaine can be used to improve seed cotton yield and economic returns under deficit irrigation. Similarly, glycine betaine proved helpful in reducing CO_2-C emission under deficit irrigation compared to normal irrigation.

1. Introduction

Low profitability, high energy use, greenhouse gas emissions due to intensive use of fertilizers and tillage practices, drought, salinity, floods, pest infestation, and evolution of herbicide and pesticide resistance are threatening cotton production around the world (Mollaee et al., 2019). Global climate changes characterized by gradual rise in temperatures and adverse regional consequences of temperature and precipitation alterations are further aggravating the difficulties in cotton production (Li et al., 2024). Precipitation plays a crucial role in growth and maturation of cotton plants. Inadequate precipitation-mediated drought is considered a significant abiotic stress, significantly curtailing cotton yield (Guo et al., 2024). Climate projections have revealed that Türkiye is expected to significantly affect from global warming (Demircan et al., 2017) and recent reports suggested that the country is warming at a higher rate than the rest of the world (Zittis et al., 2022). Hence, effective exploitation of available water resources is inevitable for sustainable cotton production. Elevated temperature and reduced

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https://doi.org/10.1016/j.jksus.2024.103445
Received 19 December 2023; Received in revised form 27 August 2024; Accepted 6 September 2024
Available online 8 September 2024

precipitation are the expected consequences of climate change in Türkiye, which would reduce the available water resources. Hence, there is a dire need to conserve and efficiently utilize available water. Cotton production in the southeastern Anatolia region requires 700–800 mm water by drip irrigation method. Although the region receives ~450 mm rainfall during the whole year, only 2 % of this (~10–12 mm) is received during the cotton growing season. Therefore, irrigation becomes inevitable for cotton production.

Harran plain in Türkiye is the major cotton cultivation region producing 25 % of the country's total production (Çullu et al., 2022). The development of major irrigation project [Southeastern Anatolia Project (GAP)] in 1995 has increased the cotton cultivation in the region due to surplus irrigation water supply (Aydogdu et al., 2018). Cotton crop requires higher amount of water (700–800 mm water by drip irrigation method), particularly in Harran plain (Cetin, 2020); however, altered precipitation regimes (no or minimum rainfall during the cotton growing season) could lower water availability in the region (Demircan et al., 2017). Nevertheless, the number of irrigations required for successful crop production will increase due to the extreme temperature, causing excessive use of underground and surface water resources (Hussain et al., 2018). Therefore, agronomic practices aimed at improving irrigation water use efficiency would be required to sustain cotton production in the Harran plain.

Irrigation practices exert significant impacts on the soil microbial activities and subsequently emission of greenhouse gases such as CO_2, N_2O and CH_4 (Sapkota et al., 2020). Increased emission of these gases could decrease available water resources because of global warming. Different irrigation systems exhibit significant variation in the emission of greenhouse gases (Wu et al., 2014) and deficit irrigation is known to lower the emission of these gases (Gultekin et al., 2023). Nevertheless, greenhouse gas emissions of soils under different tillage systems increased after the irrigation as compared to pre-irrigation (Calderón and Jackson, 2002). The increased emission after irrigation is associated with an increased soil moisture content and an improvement in soil physical quality and biological activity. Deficit irrigation is a viable alternative to full irrigation for lowering greenhouse gas emissions (Martínez-Nicolás et al., 2019). Reducing irrigation quantity to a certain extent did not alter the yield of pomegranate (Martínez-Nicolás et al., 2019). Nevertheless, combination of deficit irrigation and osmolytes could provide comparable yield to full irrigation (Ünlü et al., 2011). Moreover, deficit irrigation significantly reduces the emission of greenhouse gases (Hou et al., 2019). Therefore, combination of deficit irrigation and osmolytes could prove a viable alternative to sustain cotton yield and lower greenhouse gas emissions.

Osmolytes such as salicylic acid, ascorbic acid, and glycine betaine are exogenously applied to plant leaves under deficit irrigation. Several earlier studies have indicated that application of salicylic acid, ascorbic acid, and glycine betaine improved cotton productivity under deficit irrigation practices (Arekhi et al., 2023; Mahdi et al., 2020). These substances stimulate defensive response against biotic and abiotic stresses (Mehta and Vyas, 2023). Glycine betaine is used as foliar spray and mixed with irrigation water to improve the negative effects of water stress and increase crop yield (Hussain et al., 2008). These osmolytes improve cotton productivity under water deficit by multiple mechanisms, including maintaining water balance, protecting cellular structures, and enhancing photosynthesis and growth under water deficit conditions. However, the impact of these substances on CO_2 emissions in cotton crop under water deficit conditions remains elusive.

The objective of this study was to investigate the impact of osmolyte treatments and deficit irrigation on seed cotton yield, CO_2 emissions, and economic returns of cotton crop. The practice of deficit irrigation was believed to have the potential to decrease both crop productivity and CO_2 emissions. It was hypothesized that providing osmolytes during deficit irrigation will help decrease crop loss and CO_2 emissions.

2. Materials and methods

2.1. Experimental site and soil properties

The study was carried out in the research fields of the Harran University, Şanlıurfa, Türkiye during cotton growing season of 2021. Soil pH of experimental site was 7.92, and the organic matter content was 1.12 % (Ramazanoglu, 2019). Some soil properties are given in Table 1.

The average monthly temperature during the cotton growing season was 28.7 °C, total precipitation was 31.2 kg m^{-2}, and relative humidity was 31.2 %. The long-term average monthly temperature was 26.2 °C, total precipitation was 91.1 kg m^{-2}, and relative humidity was 38.3 %. The cotton-growing season was drier compared to the long-term climate data of the study area (Fig. 1).

2.2. Experimental design and treatments

The study was conducted according to randomized complete block design with split-plot arrangements. The 'Fiona' cotton genotype frequently cultivated in the Harran plain was used as experimental material. The irrigation treatments [50 % (I_{50}), 75 % (I_{75}), and 100 % (I_{100})] of crop water requirement constituted the main plots, while osmolyte application [glycine betaine (100 mg L^{-1}), ascorbic acid (100 mg L^{-1}), salicylic acid (100 mg L^{-1}), and control (no application of osmolyte)] constituted the sub-plots. Each plot was comprised of five rows (12 m long). The spacing between rows 70 cm, while the spacing inside each row ranged between 10 and 12 cm. A buffer zone of three meters was established between the blocks and the plots. The experiment had a total of 36 plots. A total of 100 kg N (in the form of 46 % urea) and 100 kg P (in the form of a composite containing 20 % N and 20 % P_2O_5) per hectare were applied to the crop. The whole amount of P and 50 % N were applied at sowing, while the remaining N was applied with 2nd and 4th irrigation in two equal splits. Turkish soils are generally high in potassium; therefore, it was not applied.

2.3. Irrigation treatments

Seeds were sown on May 5, 2021, followed by the application of 40 mm irrigation. An extra 20 mm irrigation was applied to achieve uniform germination and disrupt the formation of a surface crust. The irrigation treatments were initiated on July 5, 2021, using drip irrigation method. The methodology suggested by James (1982) was used to calculate the volume of water required for irrigation (Eq. (1)).

$$I = A \times E_p \times k_{cp} \times P \quad (1)$$

Here, 'I' = volume of irrigation water in liters, A=area, Ep = 7-day cumulative class A pan evaporation in millimeters, kcp = Pan coefficient, and P=plant cover percentage. Evaporation from a class A pan was measured over seven days to determine irrigation water amount. Evaporation rate multiplied by vegetation percentage (P) calculated the irrigation quantity for each irrigation treatment (50 %, 75 %, and 100 %) (Table 2).

2.4. Osmolyte application and crop yield

Ascorbic acid, glycine betaine, salicylic acid were applied to plants at 100 mg L^{-1} doses (Aziz et al., 2018) twice during the growing season. The doses were selected based on the best performance ones for different crops in earlier studies (Aziz et al., 2018). The first and second application was done on the 45th and 60th day after planting, respectively. The crop was manually harvested three times at maturity and yield per hectare was calculated using the method explained by Worley et al. (1976). The seed cotton harvested from the central two rows of each plot, excluding one row on each side was quantified and weighed. This weight was then used to determine the yield per hectare, based on the

Table 1
Physical and chemical properties of experimental site.

Depth (cm)	pH	Organicmatter (%)	Lime(%)	Plant Nutrients (mg kg^{-1})						
				P	K	Mg	Fe	Zn	Cu	Mn
0–30	7.92	1.12	29.6	4.70	180	303	3.46	0.72	4.64	0.44

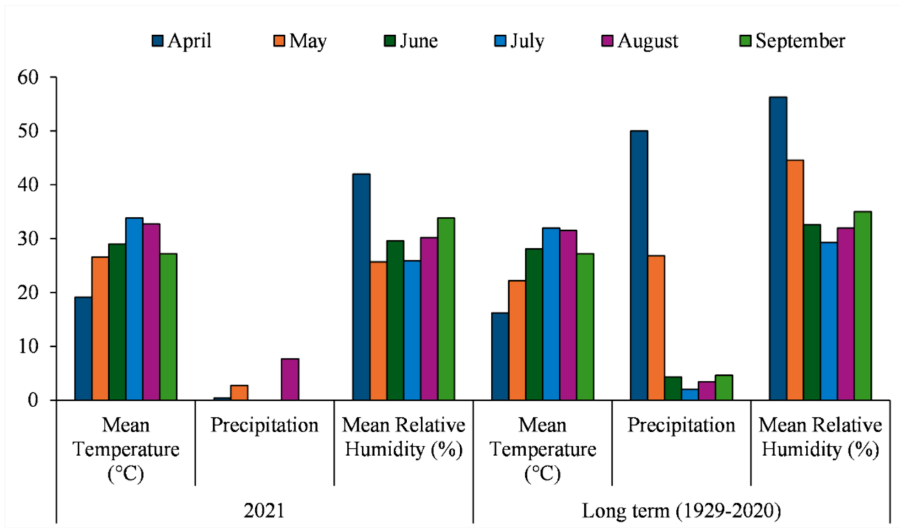

Fig. 1. Weather data of the experimental site during cotton growing seasons and long-term climatic conditions of the region.

Table 2
Irrigation treatments and schedule during the cotton growing season.

				Amount of Irrigation Water (IW)		
Dates	E_o	P	Total E_o	50 %	75 %	100 %
28.06.2021	73	0.4	29.2	14.6	21.9	29.2
05.07.2021	86	0.45	38.7	19.35	29.025	38.7
12.07.2021	108	0.5	54	27	40.5	54
19.07.2021	104	0.55	57.2	28.6	42.9	57.2
26.07.2021	103	0.6	61.8	30.9	46.35	61.8
02.08.2021	102	0.75	76.5	38.25	57.375	76.5
09.08.2021	97	0.9	87.3	43.65	65.475	87.3
16.08.2021	90	1	90	45	67.5	90
23.08.2021	76.5	1	76.5	38.25	57.375	76.5
30.08.2021	72	1	72	36	54	72
06.09.2021	66	1	66	33	49.5	66
Total			709.2	354.6	531.9	709.2

area of the central two rows (10 m × 1.4 m = 14 m^2).

2.4.1. CO_2-C emission and emissions factor

The PVC containers (19 cm diameter, 22 cm height) were used to measure CO_2 emission from the soil. The 40 ml of NaOH was added to 50 ml tubes following the removal of the organic residues from the soil surface. The tubes were closed with PVC containers. The measurements were repeated every week. The CO_2 released from the soil was calculated using sodium hydroxide (NaOH) solution (Equation (2) (Anderson, 1982).

$$CO_2 \text{ amount } \left(\text{mg } CO_2 \text{ m}^{-2} \text{ day}^{-1}\right) = (T - C) \times N \times E \times \frac{Vtr - Vti}{A \times t} \tag{2}$$

Where; T=amount of HCl used in the control, C=amount of HCl used for the sample, N=normality of HCl, E=conversion factor (convert to C:12 or CO_2:22), Vtr = amount of NaOH received, Vti = amount of NaOH used in titration, A=area (m^2), and t = incubation period (day).

Emission factors (EFs) of a plant can be obtained by dividing the cumulative R_s during the development period by the crop yield. It expresses the amount of CO_2 corresponding to kg product obtained in unit area. The EFs was calculated by using the Equation (3).

$$EFs(\text{kg } CO_2 \text{ kg}^{-1}) = \text{kg } CO_2 \text{ m}^{-2}/\text{kg product m}^{-2} \tag{3}$$

2.5. Statistical analysis

The collected data were evaluated by employing Analysis of Variance (ANOVA) approach (Steel et al., 1997). The data underwent the Shapiro-Wilk normality test, which confirmed that the data followed normal distribution. Hence, the analysis was conducted using the raw original data. The data was analyzed using a Two-way ANOVA to determine the significance, and the means were compared using Tukey's HSD post-hoc test, in cases the ANOVA indicated significant differences. The analyses were performed by using SPSS statistical software version 21.0 (IBM, 2012).

2.6. Economic analysis

The economic feasibility of the employed treatments was determined through an economic analysis. The costs incurred on crop production practices from sowing to harvesting (i.e., land rent, seed, irrigation, fertilizers, labor costs, weeding, insecticides and herbicides, harvesting etc.) and income gained from the seed cotton yield were computed. The expenditure was deducted from the gross income to compute the net income. The benefit:cost ratio was computed by dividing the gross income to the expenditures.

3. Results

3.1. *Effect of osmolytes and deficit irrigation on daily CO_2-C emission* (mg CO_2-C m^{-2} h^{-1})

The individual and interactive effects of irrigation levels and osmolytes significantly ($p < 0.01$) altered CO_2-C emission. The lowest (1.55) and the highest (1.94) carbon emission were recorded for 50 % deficit

(I_{50}) and 100 % irrigation (I_{100}) treatments, respectively. Similarly, the lowest (1.52) and the highest (2.19) carbon emission were noted for salicylic acid and glycine betaine application, respectively. Regarding interactions, the lowest (1.13) and the highest (2.42 mg) carbon emission ess recorded for I_{50} × salicylic acid and I_{100} × salicylic acid interactions, respectively.

The lowest CO_2-C emission from individual and interactive effects of different irrigation levels and osmolyte applications was measured in the 18th week (Fig. 2). The individual and interactive effects of different irrigation levels and osmolyte applications significantly ($p < 0.01$) affected CO_2-C emission from soil. The lowest (10.91) and the highest (12.73) carbon emission was recorded for I_{50} and I_{75} irrigation treatments, respectively. Likewise, the lowest (11.56) and the highest (11.85) emission were observed for control and glycine betaine application, respectively. Regarding interactive effect, I50 × salicylic acid and I75 × salicylic acid resulted in the lowest (10.04) and the highest (13.61) carbon emission, respectively.

3.2. Effects of deficit irrigation and osmolyte application on cumulative CO_2-C emission

The highest (90.10 ± 0.06 mg kg^{-1} soil) and the lowest (80.59 ± 0.45 mg kg^{-1} soil) total CO_2-C emission in I_{50} × osmolytes' interaction was recorded for I_{50} × control and I_{50} × glycine betaine application, respectively. Similarly, I_{75} × osmolytes' interaction indicated that the highest (85.27 ± 0.22 mg kg^{-1} soil) and the lowest (82.89 ± 0.07 mg kg^{-1} soil) total CO_2-C emission was recorded for I_{75} × salicylic acid treatment, and I_{75} × glycine betaine treatments, respectively. The decrease in CO_2-C emission for I_{75} × glycine betaine application was 1.7 % compared to the I_{75} × control treatment. The CO_2-C emission in all other osmolyte treatments increased compared to the control except glycine betaine. Likewise, I_{100} × osmolytes' interaction indicated that the highest (89.89 ± 0.45 mg kg^{-1} soil) and the lowest (85.68 ± 0.39 mg kg^{-1} soil) total CO_2-C emission was observed for I_{100} × glycine betaine, and I_{100} × salicylic acid application, respectively. The I_{100} ×

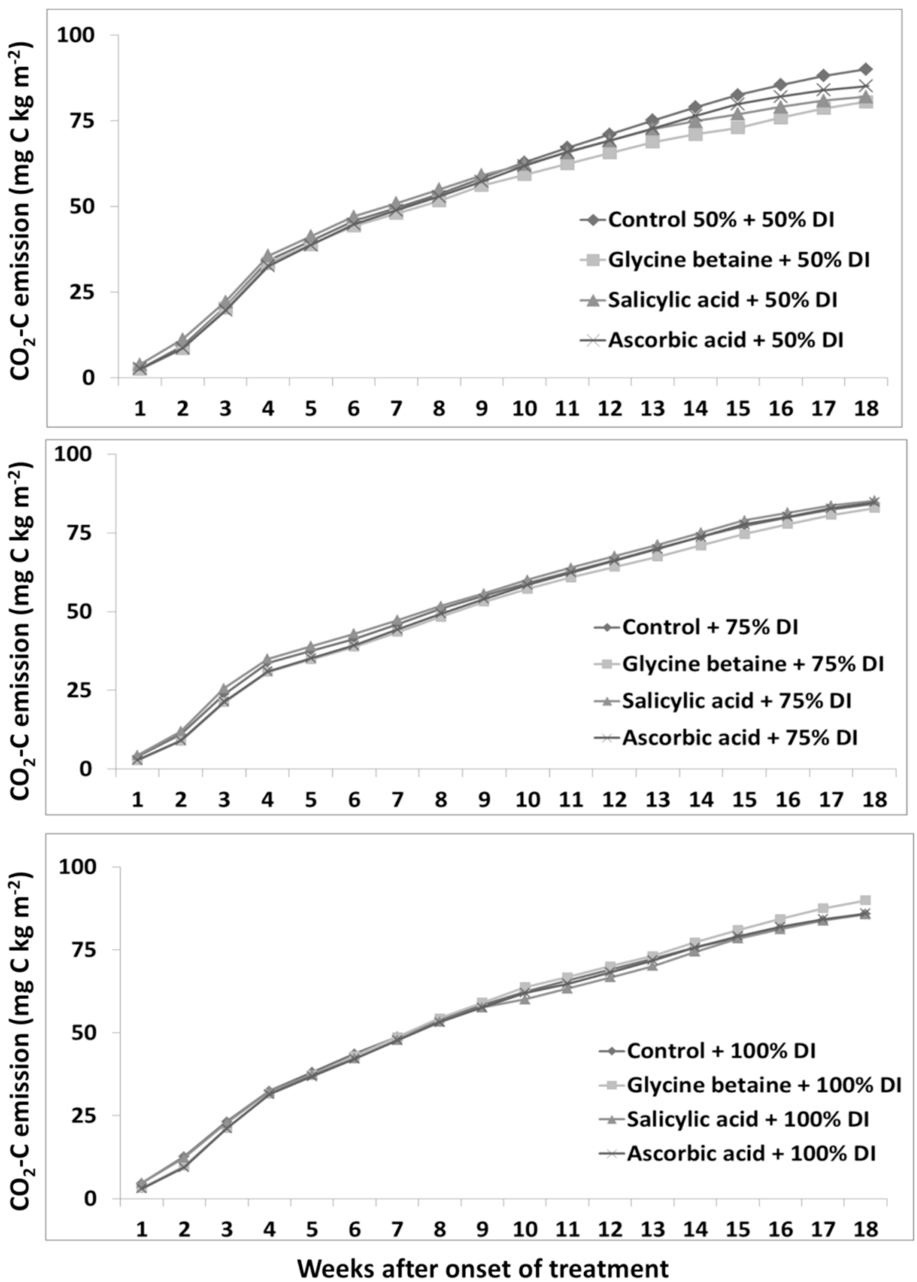

Fig. 2. Relationship between osmolytes application with CO_2-C emission under different irrigation.

glycine betaine application caused a 4.8 % increase in CO_2-C emissions compared to control. The CO_2-C emission in all I_{100} × osmolytes' interactions except salicylic acid application increased compared to the control (Fig. 3).

3.3. Effect of deficit irrigation and osmolytes application on cotton yield

Seed cotton yield was significantly ($p < 0.01$) affected by the individual and interactive effects of different irrigation levels and osmolytes. The I_{50} and I_{100} irrigation treatments resulted in the lowest (3800 kg ha^{-1}), and the highest (4746 kg ha^{-1}) seed cotton yields, respectively. Similarly, no application of osmolytes and glycine betaine application resulted in the lowest (4097 kg ha^{-1}) and the highest (4545 kg ha^{-1}) seed cotton yield, respectively. Regarding interactions, I50 × control and I100 × glycine betaine resulted in the lowest (3530 kg ha^{-1}) and the highest (5050 kg ha^{-1}) seed cotton yield, respectively (Fig. 4).

3.4. Effects of deficit irrigation and osmolytes application on emission factor (EFs)

The EFs provides a standard methodology for estimating direct or indirect emissions from agricultural soils. The lowest and the highest EFs value was recorded for glycine betaine and ascorbic acid application, respectively. Similarly, I_{75} × glycine betaine and I_{50} × ascorbic acid resulted in the lowest and the highest EFs value, respectively (Table 3).

3.5. Effects of deficit irrigation and osmolytes application on economic returns

The sole and combined impacts of various irrigation treatments and the application of osmolytes had a substantial impact on the economic returns of cotton. The interaction between I_{100} and glycine betaine yielded the highest net income and benefit-to-cost ratio, while the interaction between I_{50} and the control yielded the lowest values in this regard. The utilization of osmolytes resulted in considerably enhanced economic gains compared to the control treatment across all irrigation levels examined in the present investigation (Table 4).

4. Discussion

The CO_2 emissions from cotton planted in a semi-arid region were investigated in the current study. The lowest and the highest carbon emission was noted for I_{50} and I_{100} irrigation treatments, respectively. The CO_2-C emission from the soil is closely related to the soil properties (microorganism, C, N, etc.), topography, environmental conditions (irrigation, fertilization), and plant root respiration. Insufficient water in soils causes significant disruptions in the carbon and nutrient cycles. Water constraint is the main factor affecting the physiological properties of soil microorganisms. Therefore, the amount of CO_2-C emission increased with the increase in the amount of irrigation water. The application of irrigation water increased the C emission from the soil. The CO_2-C emission rate increased at the beginning of cotton growth period and then decreased. Microorganism activity in soils is higher under drip irrigation conditions. The increase in carbon mineralization increases microbial activity and respiration, thus increasing CO_2-C emission from the soil. The emission of greenhouse gases is significantly influenced by irrigation techniques (Sapkota et al., 2020). Increased release of these gases may lead to a reduction in accessible water resources due to the effects of global warming. Various irrigation systems differ significantly in their greenhouse gas emissions (Wu et al., 2014). It is well-established that deficit irrigation reduces the emission of these gases (Gultekin et al., 2023). The higher irrigation rates (I_{100} and I_{75}) increase activities of the soil microorganisms, as well as the breakdown of organic matter and CO_2 release (Kumar et al., 2016) The results of the current study are in agreement with the findings of Scheer et al. (2013) who studied the effects of deficit irrigation on CO_2-C emissions. The lower water application decreased the CO_2-C emission. Kumar et al. (2016) reported less CO_2-C emission in the low irrigation level in eastern

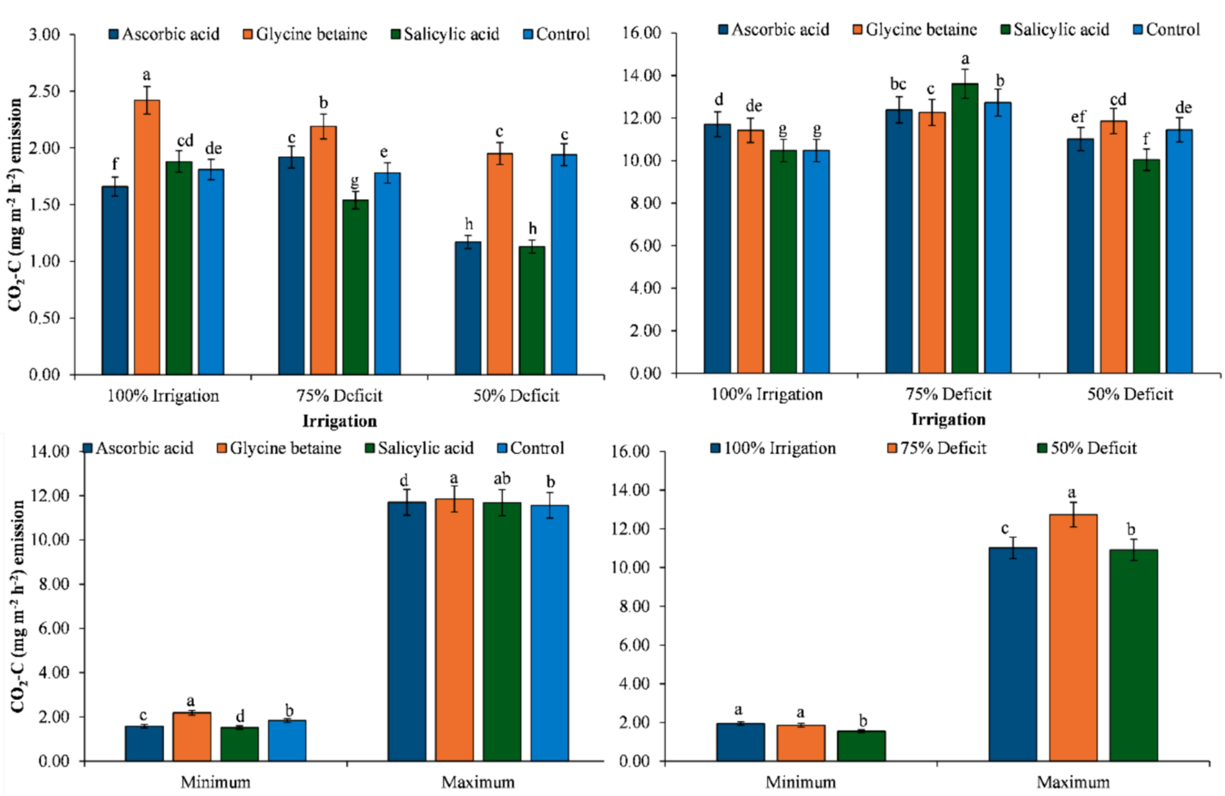

Fig. 3. The CO_2-C (mg m^{-2} h^{-2}) emission from the cotton-cultivated soil under different osmolyte applications and deficit irrigation treatments.

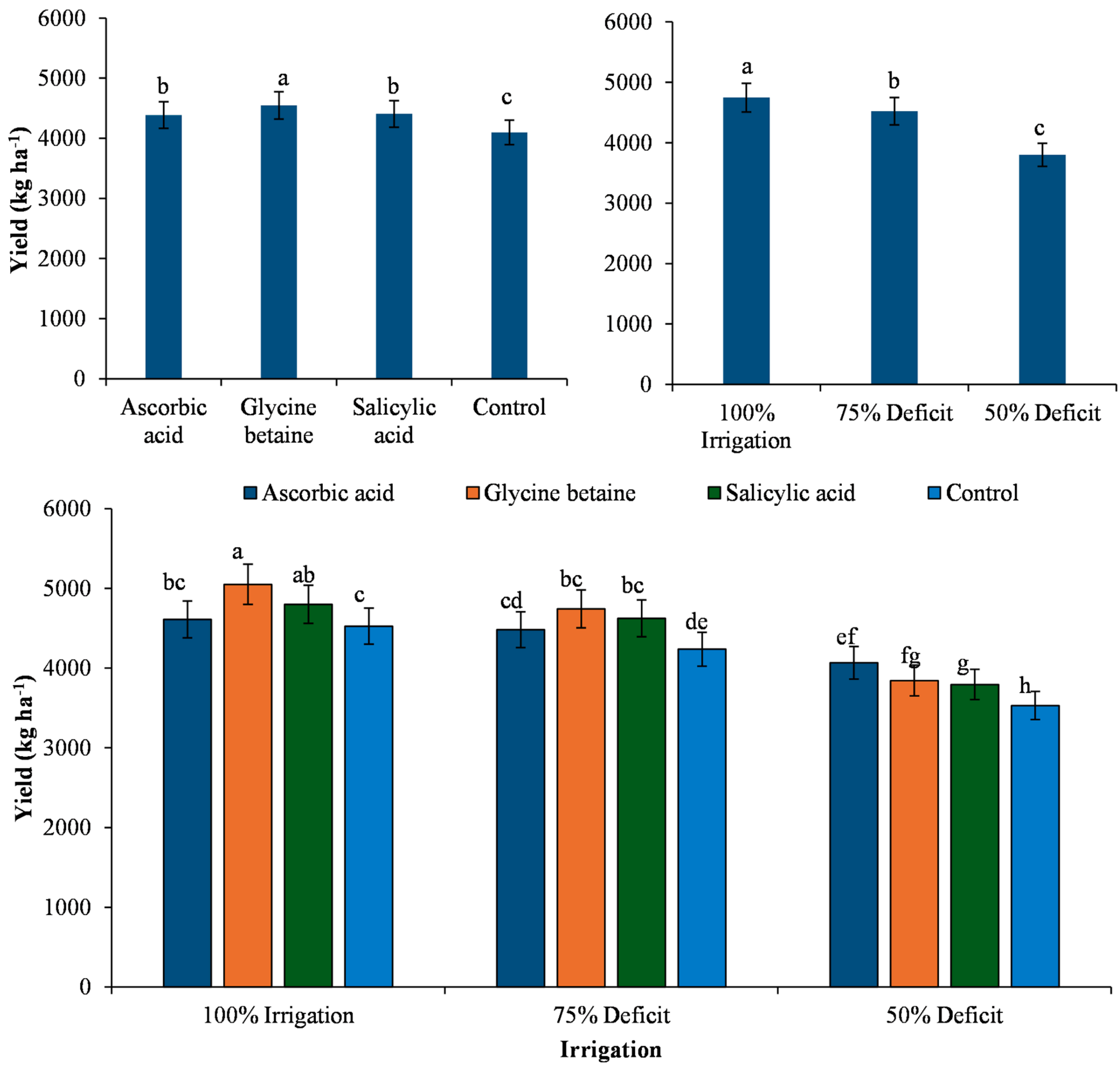

Fig. 4. The effect of osmolytes application on cotton yield (kg ha^{-1}) under different deficit irrigation treatments.

Table 3
The impact of different osmolytes application on EFs (kg CO_2 kg^{-1}) of cotton grown under different irrigation treatments.

Irrigation treatments	Osmolyte Treatments			
	Ascorbicacid	Glycinebetaine	Salicylicacid	Control
100 % Irrigation	0.000186 bc (0.0186 %)	0.000178 a (0.0178 %)	0.000179 ab (0.0179 %)	0.00019c (0.019 %)
75 % Deficit	0.000189 cd (0.0189 %)	0.000175 bc (0.0175 %)	0.000184 bc (0.0184 %)	0.000189 de (0.0189 %)
%50 Deficit	0.000209 ef (0.029 %)	0.00021 fg (0.021 %)	0.000216 g (0.0216 %)	0.000255 h (0.0255 %)

CV(%):1.95 Tukey (Deficit irrigation):** Tukey (Osmolyte):** Tukey (Deficit irrigation × Osmolyte):** Means followed by different letters are statistically different from each other ($p < 0.05$).

Table 4
Economic analysis of growing cotton under different irrigation treatments and osmolyte application.

Treatments	Total Cost	Gross Income	Net Income	BCR
	USD ha^{-1}			
$I_1 \times O_1$	2370	3425 bc	1055 bc	1.45
$I_1 \times O_2$	2370	3752 a	1382 a	1.58
$I_1 \times O_3$	2370	3567 ab	1197 ab	1.50
$I_1 \times O_4$	2333	3363 c	1031 c	1.44
$I_2 \times O_1$	2354	3331 cd	977 cd	1.41
$I_2 \times O_2$	2354	3524 bc	1170 ab	1.50
$I_2 \times O_3$	2354	3435 bc	1081 bc	1.46
$I_2 \times O_4$	2333	3148 de	815 de	1.35
$I_3 \times O_1$	2339	3022 ef	683 ef	1.29
$I_3 \times O_2$	2339	2856 fg	517 fg	1.22
$I_3 \times O_3$	2339	2819 g	480 g	1.21
$I_3 \times O_4$	2333	2623 h	290 h	1.12

I_1 = 100 % irrigation, I_2 = 75 % irrigation, I_3 = 50 % irrigation, O_1 = Ascorbic acid, O_2 = Glycine betaine, O_3 = Salicylic acid, O_4 = no osmolyte application (control). Means followed by different letters are statistically different from each other ($p < 0.05$).

India than in the higher irrigation level. The root respiration is largely dependent on the photosynthetic rate transported from the above-ground part of the plant; therefore, soil CO_2-C emission may be significantly correlated with plant production (Kakumanu et al., 2019).

The lowest mean carbon emission was noted for salicylic acid and the highest was recorded for glycine betaine application. The lowest carbon emission in irrigation × osmolyte application was recorded for I_{50} × salicylic acid, whereas the highest emission was recorded I_{100} × salicylic acid application. The high CO_2-C emission in glycine betaine applications may be associated with the high plant activity since glycine betaine is a simple and flexible amino acid readily used by the plants (Hernandez-Leon and Valenzuela-Soto, 2023). However, the uptake of salicylic acid is difficult because it has a crystalline structure and is less soluble in water (Kawashima et al., 2011). Therefore, the utilization rate of salicylic acid by the plants is low, and thus, its activity on the plants is low. Low plant root activity and low respiration can result in low CO_2 production. Photosynthesis rate decreases as the CO_2 concentration in the leaves decreases with the closure of the stomata (Lawlor, 2002). The decrease in photosynthesis rate with the closure of stomata (Farrant, 2000) and lowered use of atmospheric CO_2 by the plants is a disadvantage for global warming. The plants constrain CO_2 fixation under insufficient soil water by closing its stomata to prevent water loss (Flexas, 2002).

The production of crops remains unaffected when the amount of irrigation is reduced to a certain degree (Martínez-Nicolás et al., 2019). Nonetheless, the use of deficit irrigation combined with osmolytes has the potential to achieve a yield similar to that of full irrigation(Ünlü et al., 2011). In addition, deficit irrigation has been found to substantially decrease the release of greenhouse gases(Hou et al., 2019). Thus, the utilization of deficit irrigation and osmolytes may present a feasible option to maintain cotton productivity. The CO_2 needed in photosynthesis increases the emission of greenhouse gases that cause an increase in atmospheric temperature. Therefore, different osmolytes were applied to help cotton plants perform their normal life functions under deficit irrigation. The application of all osmolytes improved cotton yield under deficit irrigation. Ascorbic acid proved the most effective in improving cotton yield even under severe deficit. Ascorbic acid can improve cotton output under water deficit conditions by minimizing oxidative injury, conserving photosynthetic ability, and stimulating growth and yield factors (Mekki et al., 2015). Hence the improvement in seed cotton yield by the application of ascorbic acid is owed to these mechanisms.

The C, CO_2 and soluble mineral substances increase rapidly in dry soil compared to moist soil. Therefore, deficit irrigation causes more CO_2-C emissions in wetting and drying soils (Kakumanu et al., 2019). The application of osmolytes causes an increase or decrease in CO_2-C, when a dry soil is wetted (Warren, 2016). Similar results were obtained in the present study. The response of emission factor to osmolyte + deficit irrigation applications was positive. The EFs values were lower than the default values stated in the IPCC. The results can be attributed to the low organic carbon content of the experimental site (Wang et al., 2016). Cayuela et al. (2017) reported the EFs value as 0.005 (0.5 %) in a study on fertilizer management, crop management and water management in warm climate zone and stated that this was far below the default value. In another study using mineral fertilizer applications, the EF values were calculated as 0.0107 and 0.006 (1.07 % and 0.6 %), which were different from the default values (Mazzetto et al., 2020). In the near future, the products can only be exported or imported considering the amount of water (green, blue, gray) used in the production and CO_2 emission values (emission value per product).

5. Conclusion

It is concluded that application of glycine betaine can be used to improve seed cotton yield and economic returns under I_{100} and I_{75} irrigation treatments. Nevertheless, ascorbic acid proved most effective in improving yield and economic returns under I_{50} irrigation treatment. The carbon emission was higher under full irrigation compared to deficit irrigation and glycine betaine proved helpful in reducing CO_2-C emission under deficit irrigation compared to normal irrigation. Therefore, glycine betaine can be used to improve yield and economic returns of cotton and lower CO_2-C emission under deficit irrigation.

CRediT authorship contribution statement

Emrah Ramazanoglu: Writing – review & editing, Writing – original draft, Visualization, Software, Investigation, Formal analysis, Data curation. **Nimet Kılınçoğlu:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation. **Vedat Beyyavas:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Cevher İlhan Cevheri:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Erdal Sakin:** Writing – review & editing, Validation, Methodology, Conceptualization. **Ahmet Çelik:** Writing – review & editing, Validation, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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