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EFFECT OF WATER DEFICIT AND FOLIAR APPLICATION OF AMINO ACIDS ON GROWTH AND YIELD OF EGGPLANT IRRIGATED BY TWO DRIP SYSTEMS UNDER GREENHOUSE CONDITIONS

Basem Rahem Bader[1], Mohammed Ali Abood[1], Saad Enad Harfoush Aldulaimy[2], Shuker Mahmood Hassan Al-Mehmdy[2], Ghassan Jaafar Hamdi[3]

[1]Department of Soil Science and Water Resources, College of Agriculture, University of Diyala, Baqubah, Iraq
[2]Department of Soil Science and Water Resources, College of Agriculture, University of Anbar, Ramadi, Iraq
[3]Department of Horticulture and Landscape, College of Agriculture, University of Diyala, Baqubah, Iraq

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Vastutav autor: Corresponding author: Ghassan Jaafar Hamdi
E-mail: ghassanhamdi38@gmail.com

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ABSTRACT. Water deficit in semiarid areas limits eggplant (*Solanum melongena* L.) production and growth indicators. Suitable drip irrigation system and foliar application of amino acids may help overcome water deficit. In this work, the effects of drip irrigation system [Grand flow regulators (GR) and T-Tape], water deficit (50, 75, 100% based on field capacity) and foliar application of amino acids at 0, 100 and 200 mg L^{-1} on water relation of leaf's, yield and field water use efficiency (WUE_f) of eggplant were studied. The experiments were arranged in a split-split plot design within a completely randomized distribution each repeated three times. GR irrigation system treatment produced the highest relative water content (RWC), most yield (TY), WUE_f and the lowest of water saturation deficit (WSD) which were 74.71%, 6.50%, 5.97 t ha^{-1}, 2.11 kg m^{-3} and 23.09%, respectively. The lowest water uptake capacity (WUC) and relative membrane permeability (RMP) was obtained in T-Tape irrigation system treatment (0.43% and 59.45%, respectively). The 100% irrigation level revealed higher RWC (79.32%), WSD (7.38%), most TY (6.93 t ha^{-1}), the least of WSD (18.00%), WUC (0.28%) and RMP (39.40%). The maximum of WUE_f (2.37 kg m^{-3}) was obtained from 50% irrigation level. The foliar application of 200 mg L^{-1} Amino acids rate resulted in significantly maximum RWC (81.50%), WRC (7.19%), TY (6.75 t ha^{-1}) and WUE_f (2.51 kg m^{-3}) and least WSD (15.88%), WUC (0.33%), RMP (52.02%). GR drip irrigation system is best for water use efficiency; 200 mg L^{-1} Amino acids produced the best response for most studied traits.

Introduction

Water is a key determinant of plant productivity in agriculture in numerous world regions, particularly in dry and semi-dry regions (Tahi *et al.*, 2007). With increasing human population, urbanization and industrialization, competition for freshwater is increasing worldwide. The divergence between water availability and demand is widening. Worldwide, more than 40% of food production rely on supplementary irrigation (Ahmad, 2016). In Iraq, agriculture uses more than 93% of good quality freshwater (Aldulaimy *et al.*, 2019). There is a need to stretch freshwater resources to keep pace with the ever-increasing demand of varied users (Hsiao *et al.*, 2009, Wang *et al.*, 2010). Given the circumstance of not having much prospect of additional freshwater resources to be developed, the only choice is to control the available freshwater resources and improve management procedures (Haliński, Stepnowski, 2016). Since agriculture is the prime consumer of freshwater resources, any effort towards improving WUE_f in this sector will be worthwhile. Increasing WUE_f through upgraded irrigation technology and improving the efficiency of retaining soil productivity are complementary towards making the best use of irrigation water and conserving water for other uses. The average irrigation efficiency for surface irrigation is between 30–50% (Topcu *et al.*, 2007; Al-Shammari *et al.*, 2018a; Aldulaimy *et al.*, 2019). Poor irrigation efficiency provides an opportunity for improvement that will lead to additional water resource for agriculture or other uses; however, this should not be by negatively affecting yields.

It is proved that drought conditions damage cellular membranes, slow down water movement and nutrient absorption, reduce photosynthesis efficiency, respiration rate, enzyme activity and hormone balance, and increase reactive oxygen species production, which detrimentally production (Maloney *et al.*, 2010, Gupta, 2011). The loss of agricultural production is estimated by about 17% (Ahmad, 2016; Al-Shammari *et al.*, 2020a).

Amino acid applied to foliage or added to total soil have recently been used as a method to promote plant growth and productivity (Spann *et al.*, 2010). Amino acids have a direct function in increasing tissue protein content and enzyme activity necessary for metabolic antioxidant on-site events. Amino acids are precursors and proteins constituents which are necessary for cell growth. They contain acid and basic groups and act as buffers, which help maintain favourable pH within plant cells. Amino acids can influence physiological activities in plant growth and development (Sadak *et al.*, 2015; Al-Shammari *et al.*, 2018b).

Primarily housebroken by inhabitants of South and East Asia (Polignano *et al.*, 2010) and then transferred to Europe through Arab trade or migration around 600 CE (Daunay, 2008), eggplant is considered one of the most common vegetable crops grown in Iraq and other the world parts and its fruits are utilized as a staple food. Eggplant is only the third most important crop in consumption terms, behind potatoes and tomatoes, from the *Solanaceae* family. The varieties of eggplant show a wide range of fruit shapes and colours, ranging from oval or egg-shaped to long club-shaped; and from white, yellow, green through degrees of purple pigmentation to almost black. Eggplant fruits contain a considerable carbohydrates amount, proteins and some minerals (Raigón *et al.*, 2008, Mahmoud, 2000). Eggplant fruits are known for being low in calories and having a mineral composition useful for human health. They are also a wealthy source of potassium, magnesium, calcium and iron (Zenia, Halina, 2008). The eggplant fruit possesses antioxidant activities (Plazas *et al.*, 2013, San José *et al.*, 2013). This project was undertaken to determine effects of drip irrigation system type, irrigation levels and foliar application of Amino decanate® on leaf's Sprouts, yield and water use efficiency of eggplant under water deficit conditions.

Materials and methods

Experimental sites and description

Field experiments were conducted at a greenhouses experimental station of the College of Science, University of Diyala, Baqubah, Iraq, on 8 November 2018 to 3 April 2019. The area of the greenhouse was 450 m². The soil of the study site is classified as well-drained sandy loam. The chemical properties of the soil were: $CaCO_3$ (157.79 g kg^{-1}), $EC_{1:1}$ (13.17 dS m^{-1}), organic matter (OM) (0.91 g kg^{-1}), and nitrogen (N), phosphorous (P) and potassium (K) as 32.60, 9.70 and 160.6 mg kg^{-1}, respectively. Bulk density was 1.35 mg m^{-3}. Field capacity (F.C) was 25% (mass water content). The irrigation water EC was 0.82 dS m^{-1} (River water). Poultry litter was added at 1 kg m^{-2} during bed preparation.

Experimental design and treatments description

The experimental design was arranged in a 2 × 3 × 3 split-split plot, in a randomized complete block design, with 3 factors, replicated in 3 blocks. The first factor was the drip irrigation system type (GR and T-Tape). Surface drip irrigation GR (Grand flow regulators) diameter of the tube was 6.35 mm, plastic wall thickness is 1 mm, the distance between the emitters is 30 cm, the maximum capacity of water flow of the emitters is 4 L h^{-1} (Manufacturer: Universal for Industry of Drip Irrigation Pipes, Amman, Jordan). For surface drip irrigation T-Tape, a diameter of the tube was 6.35 mm, plastic wall thickness is 1 mm, the distance between the emitters is 11 cm, the maximum capacity of water flow of the emitters is 1 L h^{-1} (Manufacturer: Rivulis Reserve Drip Tape, USA). The second factor was the level of irrigation, 50, 75 or 100% of field capacity, each system was individual for levels irrigation, determined according to Allen (1998). The third factor was the level of Amino decanate® at 0, 100 or 200 mg L^{-1}. There were 18 treatments, totalling 54 plots. Amino decanate® was applied with a backpack sprayer 4 times at a 10-day interval beginning from flowering. Foliar treatment was applied early in the morning. The nutrients contents of the Amino decanate® are given in Table 1.

Table 1. Composition of Amino decanate®

Material	Amount (wt./vol.)	Material	Amount (wt./vol.)
L-Leucine		L-Threonine	
L-Valine	5 g	L-Phenylalanine	
L-Isoleucine		L-Tyrosine	
L-Glutamine		L-Asparagine	
L-Alanine		L-Aspartate	0.5 g
L-Arginine		L-Cysteine	
L-Histidine	0.5 g	L-Lysine	
L-Proline		L-Serine	
L-Methionine		L-Tryptophan	
L-Threonine		Glycine	

Conduction of study

Seeds of eggplant (*cv*. Barcelona) was planted in cork trays with 200 cavities on 28 September 2018 using previously saturated peat moss as the substrate in a commercial nursery. When seedlings reached the 3 true leaf stage, they were established in a greenhouse on November 8, 2018. There was 1.25 m between rows and 0.4 m between plants, with 10 plants per experimental unit and a density equivalent to 20 000 plants ha^{-1}. To demonstrate effects of drip irrigation system type, water deficit, and foliar application of Amino decanate® in growth and yield on eggplant, the 20N-20P-20K was added in four split applications throughout the growth period with a dose of 240 kg ha^{-1} with irrigation water. After spraying the insecticides Carbaryl 85® at a dose 2 g L^{-1} of water and SITA JINTA® at a dose 1 ml L^{-1} of water, weeds were controlled manually. Irrigation was applied until the end of the last harvest; schedule irrigation was based on depletion of 50% of available water and water was added to the F.C. The process of sampling was conducted to estimate moisture content before each irrigation and according to the weight method and depth of 0–30 cm to the flowering stage and depth 0–60 cm to the end of the growing season.

Traits measured

Eight plants were randomly selected from each plot to determine relative water content in the leaves (RWC). The leaves were cut with scissors, then placed in polythene bags and transported to the laboratory as quickly as possible to minimize water losses due to evaporation. RWC was determined by the following equation:

$$RWC = \frac{(Fresh\ weight - Dry\ weight)}{(Turgid\ weight - Dry\ weight)} \times 100 \quad (1)$$

The water saturation deficit (WSD) was calculated by the following formula:

$$WSD = 100 - RWC \quad (2)$$

Water retention capacity (WRC) was estimated by the following formula:

$$WRC = \frac{Turgid\ weight}{Dry\ weight} \quad (3)$$

The water uptake capacity (WUC) was measured by the following formula:

$$WUC = \frac{(Turgid\ weight - Fresh\ weight)}{Dry\ weight} \quad (4)$$

For the relative membrane permeability (RMP), leaves were cut into small equal pieces and transferred into the test tube containing 20 mL of deionized distilled water. After shaking with a stirrer for 10 s, this solution was assessed for initial electrical conductivity (EC_0). For the (EC_1), these test tubes were kept at 4 °C for 24 hours and then assayed. Then these samples were autoclaved at 121 °C for 25 minutes for the determination of (EC_2), so RMP was calculated according to the following equation:

$$RMP = \frac{(EC1 - EC0)}{(EC2 - EC0)} \times 100 \quad (5)$$

Harvesting was done 76 days after the plantation. Sixteen harvestings were done. The fruits which have ripened were cut with a pruning shear and then weighed on an electronic scale in the treatment site. The yield obtained from each treatment was recorded (kg m^{-2}).

Values of field water use efficiency (kg m^{-3}) were calculated for different treatments after harvest based on the method specified by Jensen (1983), according to the following equation:

$$WUE_f = \frac{Total\ yield}{Water\ applied}, \quad (6)$$

where WUE_f is field water use efficiency.

Data analysis

Data were subjected to analysis of variance (ANOVA) using SAS (JMP ver. 9.1, SAS Institute, Cary, NC). If interactions were significant, they were used to explain results. If interactions were not significant means were separated with the Tukey-Kramer HSD test.

Results

Results in the variance analysis (table 2) show significant differences in all measured traits. Results in Table 2 display the effects of drip irrigation systems (GR and T-Tape) on all measured traits. Comparing with T-Tape drip irrigation system, GR drip irrigation system recorded higher values of RWC (74.71%), WRC (6.50 %), TY (5.97 t ha^{-1}), WUE_f (2.11 kg m^{-3}) and betters lower value of WSD (23.09 %). In all terms, GR drip irrigation system seems to be more performant than T-Tape.

Table 2. Effect of the main factors and their interference in all studied traits

Source of variation	df	Relative water content, %	Water saturation deficit, %	Water retention capacity, %	Water uptake capacity, %	Plasma membrane osmosis, %	Total yield, kg m^{-2}	Field water use efficiency, kg m^{-3}
Block	2	27.18	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation system (S)	1	1652*	1675*	5.13*	0.01*	157*	31.69*	1.68*
Error main plot	2	0.07	0.00	0.00*	0.00	0.00	0.00	0.00
Irrigation (I)	2	1887*	2192*	22.53*	0.47*	746*	55.47*	2.79*
S×I	2	46.54*	0.37*	0.45*	0.01*	111*	4.58*	0.05*
Error split plot	8	0.01	0.00	0.00	0.00*	0.00	0.00	0.00
Amino decanate (A)	2	2859*	2845*	20.02*	0.34*	128*	46.06*	6.15*
S×A	2	65.86*	5.95*	0.93*	0.00	509*	3.81*	0.28*
I×A	4	77.08*	12.32*	0.81*	0.02*	118*	2.47*	0.05*
S×I×A	4	15.01*	14.04*	0.40*	0.10*	185*	0.92*	0.03*
Error split-split plot	24							
Corrected Total	53							

* – significant at 0.05 level, ANOVA

Table 3 also illustrates the effects of irrigation levels and amino decanate® increments on the studied parameters. Increasing irrigation level from 50 and 75 to 100% of field capacity gradually and significantly improved the percentage of RWC, WSD and WRC as well as the mass of TY: these values evolved to the best status respectively from 58.84 and 69.38 to 79.32; from 40.03 and 27.94 to 18; from 5.09 and 6.5 to 7.32; and from 3.42 and 5.26 to 6.93. Inversely, WUC, RMP and WUE_f decreased whenever irrigation level increased.

Similarly, the same trend was observed from the amino decanate® doses which are in plus significantly increased the WUE_f from lower values of 1.34 and 1.96 to the highest value of 2.51 kg m^3 at 0, 100, and 200 mg L^{-1} respectively.

Respecting in Table 3 the interaction effect of GR drip irrigation system at full irrigation level resulted in a significant increase in RWC (86.50%), WRC (7.75%), TY (8.24 t ha^{-1}) and decrease in WSD (12.27%), while these parameters represented 53.38%, 4.96%, 3.11 t ha^{-1} and 45.49 % respectively, in T-Tape drip irrigation system at 50% irrigation level. The highest WUE_f was 2.50 kg m^{-3} for GR drip irrigation system at 50% irrigation level, while the lowest WUE_f (1.36 kg m^{-3}) for T-Tape drip irrigation system at full irrigation level. For the other traits, T-Tape drip irrigation system at 100% irrigation level had the minimum values of WUC (0.27%) and RMP (37.71%). While the maximum of WUC was (47.00%) for GR drip irrigation system at 75% irrigation level and RMP was (83.86%) for GR drip irrigation system at 50% irrigation level.

Plants treated with GR drip irrigation system and foliar treatment of 200 mg L^{-1} Amino decanate® resulted in a significant increase in total RWC (88.57%), WRC (7.23%), TY (7.93 t ha^{-1}) and WUE_f (2.80 kg m^{-3}), which decreased to a minimum 52.39%, 4.63%, 3.29 t ha^{-1} and 1.29 kg m^{-3} respectively, at the controlled treatment in T-Tape drip irrigation system.

T-Tape drip irrigation system and foliar treatments of 200 mg L^{-1} Amino decanate® had the minimum of WUC (0.31%) and RMP (44.32%), while Plants treated with GR drip irrigation system and no application (control treatment) had the maximum of WUC (0.64%), RMP (67.57%) comparing to plants treated with T-Tape drip irrigation system and no application (control treatment). Minimum of WSD (10.20%) treated plant was found in by GR drip irrigation system and foliar application of 200 mg L^{-1} Amino decanate®, and a maximum was obtained 45.96% by T-Tape drip irrigation system and foliar application of 200 mg L^{-1} Amino decanate®.

Table 3. Effect of drip irrigation systems, irrigation levels and Amino decanate® on factors in eggplant traits

Factors	Relative water content, %	Water saturation deficit, %	Water retention capacity, %	Water uptake capacity, %	Plasma membrane osmosis, %	Total yield, kg m^{-2}	Field water use efficiency, kg m^{-3}
Drip irrigation systems							
GR	74.71^a	23.09^b	6.50^a	0.47^a	59.45^a	5.97^a	2.11^a
T-Tape	63.65^b	34.23^a	5.88^b	0.43^b	56.03^b	4.44^b	1.76^b
Irrigation levels, %							
50	58.84^c	40.03^a	5.09^c	0.60^a	79.65^a	3.42^c	2.37^a
75	69.38^b	27.94^b	6.15^b	0.47^b	54.17^b	5.26^b	1.84^b
100	79.32^a	18.00^c	7.32^a	0.28^c	39.40^c	6.93^a	1.60^c
Amino decanate, mg L^{-1}							
0	56.31^c	41.01^a	5.08^c	0.60^a	67.45^a	3.56^c	1.34^c
100	69.73^b	29.09^b	6.29^b	0.41^b	53.76^b	5.30^b	1.96^b
200	81.50^a	15.88^c	7.19^a	0.33^c	52.02^c	6.75^a	2.51^a

Irrigation level and foliar application of Amino decanate® rate affected leaf characters and yield (Table 4). 100% irrigation level and foliar of 200 mg L^{-1} Amino decanate® treatments produced the highest RWC (87.45%), WRC (8.65%) and TY (9.17 t ha^{-1}), and the lowest WSD (6.87%) and WUC (0.16%), compared with other treatments. The highest WUE_f (3.06 kg m^{-3}) was for the combined treatment of 50% irrigation level and 200 mg L^{-1} Amino decanate®, compared with other treatments. For the least RMP (32.77%) was for full irrigation level and foliar of 100 mg L^{-1} Amino decanate®, compared with other treatments.

Results of analysis of variance in Table 5 showed that at GR drip irrigation system plant irrigated at 100% irrigated level and treated with 200 mg L^{-1} Amino decanate® had the highest relative water content (97.19%), water retention capacity (9.08%), most yield (11.26 t ha^{-1}) and the minimum of water saturation deficit (1.46%). For the best WUE_f (3.24 kg m^{-3}) was in a GR irrigation system by 50% irrigated level plants with 200 mg L^{-1} Amino decanate®. At each T-Tape and GR irrigation system by 100% irrigated level plants with 200 mg L^{-1} Amino decanate® had a minimum of water uptake capacity and relative membrane permeability (0.17 and 0.16% respectively).

Table 4. Interaction drip irrigation systems, irrigation levels and Amino decanate® on factors in eggplant traits

Factors		Relative water content, %	Water saturation deficit, %	Water retention capacity, %	Water uptake capacity, %	Plasma membrane osmosis, %	Total yield, kg m^{-2}	Field water use efficiency, kg m^{-3}
Drip irrigation systems	Irrigation levels, %							
GR	50	64.29^{e}	43.58^{b}	5.22^{e}	0.65^{a}	83.86^{a}	3.74^{e}	2.50^{a}
	75	73.34^{b}	22.41^{e}	6.52^{c}	47.00^{c}	53.40^{d}	5.93^{b}	2.01^{c}
	100	86.50^{a}	12.27^{f}	7.75^{a}	0.29^{d}	41.09^{e}	8.24^{a}	1.83^{d}
T-Tape	50	53.38^{f}	45.49^{a}	4.96^{f}	0.56^{b}	75.45^{b}	3.11^{f}	2.24^{b}
	75	65.41^{d}	33.46^{c}	5.78^{d}	0.47^{c}	54.94^{c}	4.58^{d}	1.67^{e}
	100	72.14^{c}	23.73^{d}	6.90^{b}	0.27^{e}	37.71^{f}	5.62^{c}	1.36^{f}
Drip irrigation systems	Amino decanate®, mg L^{-1}							
GR	Control	59.70^{e}	36.06^{b}	5.54^{e}	0.64^{a}	67.34^{b}	3.83^{e}	1.38^{e}
	100	75.87^{b}	23.01^{d}	6.71^{c}	0.41^{d}	51.30^{e}	6.16^{b}	2.15^{c}
	200	88.57^{a}	10.20^{f}	7.23^{a}	0.36^{e}	59.72^{c}	7.93^{a}	2.80^{a}
T-Tape	Control	52.92^{f}	45.96^{a}	4.63^{f}	0.57^{b}	67.57^{a}	3.29^{f}	1.29^{f}
	100	63.59^{d}	35.18^{c}	5.87^{d}	0.42^{c}	56.22^{d}	4.45^{d}	1.77^{d}
	200	74.43^{c}	21.56^{e}	7.14^{b}	0.31^{f}	44.32^{f}	5.58^{c}	2.21^{b}
Irrigation levels, %	Amino decanate®, mg L^{-1}							
50	Control	46.80^{i}	52.02^{a}	4.36^{i}	0.78^{a}	91.66^{a}	2.42^{i}	1.68^{f}
	100	57.83^{g}	41.17^{b}	5.24^{g}	0.54^{c}	75.44^{b}	3.39^{h}	2.36^{b}
	200	71.89^{d}	26.93^{f}	5.67^{f}	0.50^{d}	71.88^{c}	4.46^{f}	3.06^{a}
75	Control	53.45^{h}	40.86^{c}	4.87^{h}	0.60^{b}	64.59^{d}	364^{g}	1.27^{h}
	100	69.52^{e}	29.13^{e}	6.37^{d}	0.47^{e}	53.07^{e}	5.51^{d}	1.91^{e}
	200	85.15^{b}	13.84^{h}	7.22^{c}	0.34^{g}	44.86^{g}	6.63^{c}	2.53^{c}
100	Control	68.67^{f}	30.16^{d}	6.03^{e}	0.44^{f}	46.12^{f}	4.62^{e}	1.07^{i}
	100	81.83^{c}	16.99^{g}	7.27^{b}	0.24^{h}	32.77^{i}	7.01^{b}	1.61^{g}
	200	87.45^{a}	6.87^{i}	8.65^{a}	0.16^{i}	39.33^{h}	9.17^{a}	2.11^{d}

Table 5. Means comparison the interaction effects of drip irrigation systems, irrigation levels and Amino decanate® on factors in eggplant

Factors			Relative water content, %	Water saturation deficit, %	Water retention capacity, %	Water uptake capacity, %	Plasma membrane osmosis, %	Total yield, kg m^{-2}	Field water use efficiency, kg m^{-3}
Drip irrigation systems	Irrigation levels, %	Amino decanate®, mg L^{-1}							
GR	50	Control	51.69^{l}	47.30^{b}	4.81^{f}	0.83^{a}	93.75^{a}	2.65^{h}	1.77^{c}
		100	64.27^{j}	34.73^{c}	5.58^{de}	0.57^{c}	75.55^{c}	3.72^{fg}	2.49^{b}
		200	76.93^{e}	21.72^{ef}	5.27^{e}	0.56^{c}	82.28^{b}	4.85^{ef}	3.24^{a}
	75	Control	54.81^{k}	34.82^{c}	5.22^{e}	0.65^{c}	64.60^{d}	3.83^{fg}	1.28^{e}
		100	73.63^{fg}	25.02^{d}	6.99^{cd}	0.41^{de}	51.98^{ef}	6.29^{d}	2.10^{bc}
		200	91.58^{b}	7.41^{i}	7.36^{c}	0.35^{e}	43.62^{g}	7.69^{c}	2.66^{b}
	100	control	72.59^{g}	26.07^{d}	6.61^{d}	0.46^{d}	43.66^{g}	5.01^{e}	1.11^{ef}
		100	89.71^{c}	9.28^{h}	7.58^{c}	0.26^{f}	26.37^{hi}	8.47^{b}	1.88^{c}
		200	97.19^{a}	1.46^{j}	9.08^{a}	0.17^{fg}	53.26^{e}	11.26^{a}	2.51^{b}
T-Tape	50	Control	41.91^{m}	56.74^{a}	3.91^{g}	0.73^{b}	89.56^{b}	2.19^{i}	1.60^{d}
		100	51.39^{l}	47.60^{b}	4.60^{f}	0.51^{c}	75.33^{c}	3.07^{gh}	1.73^{c}
		200	66.86^{h}	32.14^{cd}	6.08^{d}	0.44^{d}	61.48^{de}	4.08^{f}	2.89^{b}
	75	Control	52.10^{l}	46.90^{bc}	4.52^{f}	0.56^{c}	64.58^{d}	3.45^{g}	1.26^{e}
		100	65.41^{i}	33.24^{cd}	5.76^{de}	0.53^{c}	54.15^{e}	4.73^{ef}	2.24^{bc}
		200	78.73^{d}	20.26^{f}	7.08^{c}	0.34^{e}	46.09^{fg}	5.58^{de}	2.04^{c}
	100	Control	64.75^{ij}	34.24^{c}	5.46^{e}	0.42^{d}	48.58^{f}	4.24^{ef}	1.03^{f}
		100	73.96^{f}	24.69^{e}	6.97^{cd}	0.23^{f}	39.17^{h}	5.56^{de}	1.35^{de}
		200	77.72^{de}	12.27^{g}	8.27^{b}	0.16^{g}	25.39^{i}	7.08^{c}	1.72^{cd}

Discussion

The foremost objective of this research was to determine the better irrigation system (GR or T-Tape) and foliar application rate of Amino decanate®, which could mitigate the adverse effects of water deficit (50, 75 and 100% of field capacity) on leaf characters, yield and WUE_f of eggplant.

The results of Table 3 show that the GR drip irrigation system had the highest values for the RWC, WRC, TY and WUE_f. This is due to the water application efficiency of the GR drip irrigation system, which provides water supply for the growth of the plant and to carry out all the physiological and vital processes.

This could be due to the maintenance of soil moisture allowing continued nutrient uptake (Al-Shammari *et al*., 2019, Ghazouani *et al*., 2019). This was probably due to full irrigation as long as water supply to the complete root area is consistent so that drench and dry-out conditions are reduced. Most biochemical, morphological and physiological processes related to plant development are come to terms pending water deficit and can result in poor photosynthesis, respiration, and nutrient metabolism. In the GR drip irrigation system, the amount of water is low and thus stresses the root zone, which leads to produced, ABA and transport it to leaves and adjust stomata aperture, reduce transpiration rate, when drought and wetness appeared by turns in different regions of root. In this experiment, it was found that irrigation levels inducing water deficit had a conspicuous effect on plant water status (Table 2). The water status change may be ascribed to, the transpiration in plants; water is thought to come from the soil out of osmosis process, and this water goes into the transpiration stream out of apoplastic and symplastic pathways. Water deficit is responsible for changing the situation on account of restricted transpiration. The reduction of transpiration hinders water uptake from the soils on account of injury in the root systems, which at the latest reasons the water status disparity in plants. Lower water uptake is thought to be accountable for lessening RMP rate (Table 3). The cell membrane, being at the interface between the cells and its surroundings, is the first organelle that is susceptible to water deficit and the capacity of maintaining its integrity is an important process related to plant resistance against water deficit (Hamdi, 2017; Shenia, Gangshuana, 2018; Ghazouani *et al*., 2019).

T-Tape drip irrigation system irrigates only planting row. Long-term water stress in the soil in a non-irrigated row would affect soil root distribution equality, to some extent and unfavourable to soil nutrient movement and absorption in the non-irrigation zone. Water amount of T-Tape drip irrigation system was so much that planting row and the working row was usually waterish, soil character becomes bad, reducing the absorbency of the root system, and affecting soil water and nutrient absorption and utilization (Díaz-Pérez, Eaton, 2015; Saddique, Shahbaz, 2019).

Water deficit caused significant reductions in yield. Full irrigation treatment (without water deficit) resulted in the maximum fruit yield (Table 3). Yield is affected by water deficit and it is significantly decreased by intensified water deficit conditions. Water deficit can progressively decrease CO_2 assimilation rates due to stomata closing and reduced leaf area, and consequently reduce photosynthetic pigment content and activity (Al-Sahmmari *et al.,* 2019b; Ghazouani *et al*., 2019). Drought stress also induces a decrease in the content and activity of photosynthetic carbon and enzymes cycle, including its key enzyme ribulose-1, 5-bisphosphate carboxylase/ oxygenase (Díaz-Pérez, Eaton, 2015; Abood *et al.,* 2019a; Saddique, Shahbaz, 2019). In the present study, using a foliar application of Amino decanate® in the presence and absence of water deficit induced level irrigation (50%, 75 and 100%), we showed that foliar application of 200 mg L^{-1} Amino decanate® had the best effect on enhancing eggplant tolerance to water deficit. Foliar application of Amino decanate® promote eggplant tolerance to water deficit, due to the improved water status, active osmotic adjustment, and mitigation of oxidative stress through efficient ROS scavenging by the enhanced activity of antioxidant enzymes (Tani *et al.,* 2018; Saddique, Shahbaz, 2019).

The first symptom of water deficit is the seizure of growth as a mechanism to preserve carbohydrates for unrelenting metabolism, for extended energy supply, and for improved recovery after stress relief (Bozkurt Çolak *et al*., 2015; Hamdi, 2017). However, poor water relations are the key reason responsible for plant growth reduction under water deficit (Bozkurt Çolak *et al.,* 2015; Ghazouani *et al.,* 2019). Plants keep water and reduce stress loading by reducing the transpiration rate, leaf water potential, and water use as well (Abood *et al.,* 2019b).

Foliar application of Amino decanate® showed a pronounced effect on leaf characters, TY and WUE_f of eggplant plants (Table 3) that eventually increased plant growth and biomass production in plants. The positive effects of the application of Amino decanate® may be due to osmoregulatory since it is soluble in water and increase concentrations of cellular osmotic components. Amino acids work is useful in withstanding adverse environmental conditions. Amino decanate® play an important role in the regulation of a variety of physiological processes, including cell division, morphogenesis, senescence (Al-Sahmmari *et al.,* 2020b).

Notably, foliar application of Amino decanate® is a common agriculture practice in vegetable cultivation that not only increases vegetable yield but also enhances plant tolerance to water deficit in arid and semi-arid areas. Therefore, agronomic management including the use of Amino decanate® has become one of the cutting-edge research topics to improve eggplant tolerance to water stress (Pandav *et al*., 2016; Abood *et al*., 2019a).

Conclusions

GR Drip irrigation system is the best and most efficient in providing the plants with the necessary water requirements to improve the qualities of vegetative growth and yield. Foliar application of Amino decanate® played a role in alleviating the negative impact of water deficit and improved plant growth, yield and water use efficiency.

Conflict of interest

The authors declare that they have no conflict of interest.
No funds from the public or private sector were used for this research. The authors covered all expenses.
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Author contributions

MA 50%, GH 50% – study conception and design;
MA 25%, BB 25%, SH 25%, SA 25% – acquisition of data;
GH 50%, MA 50% – analysis and interpretation of data;
GH 50%, MA 50% – drafting of the manuscript.
MA 50%, GH 50% – critical revision and approve the final manuscript.

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