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Evaluation of the yield and photosynthetic parameters of corn by some amendatory materials under deficit irrigation conditions

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ABSTRACT

Irrigation is essential for corn plants. Because this plant is a summer crop, irrigation is critical to its production, and an absence of moisture is a significant constraint on its development. This study aimed to investigate the impacts of hydrophilic polymer (HP) and fulvic acid (Fu-A) as amendatory materials on yield, yield component, and photosynthetic parameters of corn plants under the deficit irrigation (DI) situation. The treatments were performed by mixing two water provision groups, including complete irrigation (CI) and DI, two soil improvements, including the application of without HP or with HP, and two foliar amendments, including spraying without Fu-A or with Fu-A, with four replications. According to the results, under DI and CI situations, the co-treatment of two amendatory materials, Fu-A and HP, enhanced corn yield significantly. These enhancements were higher than enhancements attained by using them alone. Besides, the moisture and leaf proline available for the plant during DI circumstances were increased by utilizing both amendatory materials. Under DI treatment, using Fu-A and HP amendatory materials together may thus be more significant and beneficial for increasing production and boosting photosynthetic mechanisms.

Key words: corn plant, fulvic acid, hydrophilic polymer, photosynthesis, yield

HIGHLIGHTS

- The co-treatment of two amendatory materials enhanced corn yield significantly.
- The moisture and leaf proline were increased by utilizing both amendatory materials.
- Using both amendatory materials together may thus be more beneficial for increasing production and boosting photosynthetic mechanisms.

ABBREVIATIONS

CI	complete irrigation
CF	chlorophyll fluorescence
CP	control plot
DI	deficit irrigation
DW	distilled water
DRR	dark respiration rate
Fu-A	fulvic acid
Fl-v	variable fluorescence
Fl-m	maximum fluorescence
HP	hydrophilic polymer
IQY	intrinsic quantum yield
LP	leaf proline
LOP	leaf osmotic potential
LCP	light compensation point
LSP	light saturation point
NPR	net photosynthetic rate

PFD photosynthetic photon flux density
LRWC leaf relative water content
TCC total chlorophyll content

INTRODUCTION

Agricultural output in arid and semi-arid areas is severely restricted by a lack of available water, which is the most significant constraint on agricultural productivity. Iran's vast majority comprises arid and semi-arid areas with inadequate water supplies; thus, failure to meet the plant's minimal water requirements would result in drought stress and permanent crop damage (Fazeli Rostampour *et al.* 2010). Dry season could be a normal danger caused by a diminishment in precipitation underneath the normal (Faye 2022). It is possible to maximize the use of water resources while conserving them by using superabsorbent polymers. These materials not only improve product quality and performance but also enhance water use efficiency. In arid and semi-arid areas, these compounds may decrease the consequences of dehydration on plants and improve yield (Fazeli Rostampour *et al.* 2010). Superabsorbent polymers can capture and hold water many times their original weight. Water in the polymer progressively drains as the surrounding dries, keeping the soil wet without the requirement for re-irrigation. To combat dehydration and minimize the damaging impacts of drought stress on plants, this characteristic is critical (Wu *et al.* 2008; Haghighi *et al.* 2014). The use of superabsorbent polymers increases soil water conservation and reduces irrigation frequency by as much as half (Nazarli *et al.* 2010). Corn is a vital crop that plays a critical role in human nutrition, livestock, poultry, and industry. Corn makes up 20–25% of the human diet, 60–75% of animal and poultry feed, and 5% of industrial raw materials (Imam 2007). Because this plant is a summer crop, irrigation is critical to its production, and an absence of moisture is a significant constraint on its development (Khadem *et al.* 2011). An antiperspirant-like molecule, fulvic acid, is a multifunctional growth regulator. Many nations, including China, utilize it in agriculture, horticulture, and a wide range of trees. Due to its ability to decrease the quantity of leaf stomatal transpiration and therefore increase plant drought tolerance and water use efficiency, fulvic acid may be sprinkled on plants. Fulvic acid has been shown to enhance water absorption in wheat by increasing the hydraulic conductance of roots, the permeation of root cell membranes, and the plant's capacity to adjust to soil water shortage situations (Delfine *et al.* 2005). In the irrigation cycle once every 7 days, the investigators found that the most significant average of corn grain yield equal to 21.2 tons per hectare was achieved using superabsorbent hydrogel, showing a 46.21% increase relative to the control intervention (Shamci Gooshki *et al.* 2015). Jabal *et al.* (2022) reported an increasing trend in crop production as a result of the frequent use of surface water and groundwater sources along with the application of greenhouse cultivation. For single cross-cultivar 703, the use of superabsorbent reduced irrigation demand by 13.4% during growth. Using superabsorbents has been successful in improving water use efficiency (Aghayari *et al.* 2016). A 75 kg/ha application rate of superabsorbent polymer compensated for stress deterioration, according to the study's findings under moderate circumstances (Mojaddam *et al.* 2017). According to the study's conclusions, using superabsorbent polymer improved grain yield, grain yield components, chlorophyll a and b concentrations, and reduced proline percentage (Lotfi-Agha *et al.* 2017). Eucalyptus trees were more resistant to dehydration and salinity using superabsorbent polymers (Khodadadi Dehkordi 2017). Khodadadi Dehkordi (2018) reported that the introduction of superabsorbent polymer to sandy soil improved soil water retention potential and plant germination frequency when plants were subjected to desiccation. Using a combination of superabsorbent polymer and fulvic acid, this study aimed to determine the effects on corn yield, yield constituents, and photosynthetic parameters under water stress situations.

MATERIALS AND METHODS

Materials and experimental details

This study was performed at 31°48′30″ N and 48°46′15″ E with the elevation of 11 m from sea level in Hamidiyeh, Khuzestan province, Iran. The climate of this region is hot and relatively arid. It has a hot summer and a Mediterranean winter. The mean annual rainfall is about 210 mL, and the mean temperature is almost 5 °C in the winter and over 50 °C in the summer. Table 1 indicates the physical and chemical characteristics of the tested soil, and Table 2 indicates the chemical characteristics of the irrigation water. The hydrophilic polymer (HP) Super-AB-A-300 was applied in this study (Table 3). This polymer is a granular type manufactured by Rahab Resin Co. with product license holding of Iran Polymer and Petrochemical Institute (Rahab Resin Co. 2016). This HP is a tripolymer of acrylamide, acrylic acid, and acrylate potassium. The price of this polymer is lower, and preparing it is easier than other types of HPs in Iran. Fulvic acid (Fu-A) was obtained from the SOUTH GREEN company, England. The vessels with 35 cm height and 35 cm diameter were filled with 25 kg of dry soil

Table 1 | The physical and chemical characteristics of the soil

Soluble potassium (mg kg^{-1})	Soluble phosphorus (mg kg^{-1})	Bulk density (g cm^{-3})	pH	Total nitrogen (g kg^{-1})	Soil organic matter (g kg^{-1})	EC (dS m^{-1})	Soil texture	Size of the soil particles (%)		
								Sand	Silt	Clay
353	50.6	1.59	7.4	3.3	45.7	6.85	Loam	34	44	22

Table 2 | The chemical characteristics of the irrigation water

EC (dS m^{-1})	Na (meq l^{-1})	Ca (meq l^{-1})	Mg (meq l^{-1})	SAR
1.1	5.5	4.4	2.5	2.96

Table 3 | The characteristics of Super-AB-A-300 polymer (Rahan Resin Co, 2016)

Characteristics	Super-AB-A-300 polymer
Shape	Granular
Density	1.4–1.5 g cm^{-3}
Size of particles	30–100 μm
Maximum stability in soil	5 years
Practical capacity of water uptake	600 g g^{-1}

(gathered from the above 25-cm depth in the farm). Before cultivation, each vessel was irrigated with 5 L water. The bottom of each vessel was permeable. Then, vessels were placed into the soil, whereas the tops were leveled with the ground. Vessels were divided into the two categories of without HP and with HP. For the HP category, 1.2 g kg^{-1} HP was added to the upper 4 cm of the soil surface. Three corn (*Zea mays* L.) seeds (SCKaroun701) were cultivated in each vessel at a 4 cm depth. This variety is a new corn variety that is tolerant to drought stress and suitable for cultivation in tropical regions that was introduced by the Agricultural Research Center of Safi-Abad Dezful, Khuzestan, Iran. When the corns reached the four-leaf stage, two plants were cut out. A plastic tent was used to cover the vessels from the rain. This study had eight treatments. The treatments were performed by mixing two water provision groups, including complete irrigation (CI) and deficit irrigation (DI), two soil improvements, including the application of without HP or with HP, and two foliar amendments, including spraying without Fu-A or with Fu-A, with four replications. This test was conducted with a completely randomized block design. Without applying the mixed Fu-A and HP amendatory materials, the CI category was designated as the control treatment (CT). Before starting irrigation treatments, the entire vessels were orderly watered until heading. Corns without HP and with HP categories from the heading phase (1 August) to the grain fill phase (9 September) for two years (2019–2020) were grown under DI (60% FC) or CI (100% FC) situations. The value of water supplied was evaluated according to the variance in vessel weight; vessels were weighed every 3 days at 19:00 h. After performing water treatments, the whole corns were under CI until harvest. For achieving the suitable concentration of Fu-A (2 g L^{-1}), it was dissolved in distilled water (DW) as reported by the authors (Celik *et al.* 2010; Suh *et al.* 2016; Zhang *et al.* 2016; Yang *et al.* 2019b). One of 8 days after performing the water treatments, Fu-A liquid was spattered on corn leaves (110 mL per plant). The treatment without the Fu-A utilization was spattered with an equal value of DW.

Evaluation of photosynthetic parameters

In each treatment, four leaves were separated from corns to achieve a light response curve after the end of each test stage. The net photosynthetic rate (NPR) was assessed at 2,100, 1,700, 1,400, 1,100, 800, 500, 200, 100, 70, 40, 10, and 0 μmol m^{-2} s^{-1} photosynthetic photon flux density (PFD) by applying in a photosynthesis test apparatus (CI-340 Handheld Photosynthesis System, USA) with ±5 μmol accuracy and 0–2,500 μmol m^{-2} s^{-1} measuring range. The NPR to PFD response curve was calculated by the following equation (Ye *et al.* 2013; Yang *et al.* 2019b):

$$\mathrm{NPR(PFD)} = \alpha \frac{1 - \beta(\mathrm{PFD})}{1 + \gamma\,(\mathrm{PFD})}(\mathrm{PFD} - \mathrm{LCP})$$

where the coefficients including α, β, and γ are not correlated with PFD. LCP is the light compensation point. Intrinsic quantum yield (IQY), dark respiration rate (DRR), light saturation point (LSP), and maximum net photosynthetic rate ($NPR_{(max)}$) were evaluated by fitting the curve.

Chlorophyll fluorescence (CF)

The first and second samplings were gathered 15 and 22 days after performing the water treatment. In each treatment, the corn plants were separated to assess the fluorescence parameters and chlorophyll amount. Total chlorophyll content (TCC) from the plant, along with the leaves of upper, middle, and bottom of four corn plants, was assessed with a chlorophyll amount meter (CCM-200 plus, Opti-Sciences, USA). CF was also measured with a chlorophyll fluorometer (OS1p, Opti-Sciences, USA). A fresh leaf was used to measure the ratio of variable fluorescence (Fl-v) to maximum fluorescence (Fl-m), which had been dark-acclimated for 30 min. The light source was applied to prepare a red LED (light-emitting diode) source.

Leaf proline (LP) and leaf water

Based on the code explained by del Amor *et al.* (2010), the samples separated for measuring leaf relative water content (LRWC) were finally applied to determine leaf osmotic potential (LOP). LRWC was assessed using fresh leaves. For achieving the saturation weight (M2), almost 2 g of fresh leaves (M1) were put in DW and desiccated at 85 °C for 1 day to achieve dry mass (M3). The following equation was used for determining the LRWC as LRWC (%) = [(M1 − M3)/(M2 − M3)] × 100. About 1 g of leaf sample was used for the assessment of soluble proline extraction based on Bates *et al.*'s (1973) recommendation.

Yield and yield components

For determining yield components, yield, and aboveground dry biomass, corn plants from each treatment were selected and gathered. For achieving dry tissues, the aboveground samples were placed in the oven at 85 °C for 3 days. For assessing moisture content of the grain, 120 g of kernel was placed in the oven at 110 °C for 1 day.

Statistical analysis

The analysis of data was carried out using SPSS 22.0 software. Variance analysis was applied to evaluate the differences among the treatments. A value of $P < 0.05$ was recognized statistically significant.

RESULTS

Light reply characteristics

Figures 1 and 2 indicate the equation of regression that contributed a suitable simulation of the correlation among NPR and PFD treated with Fu-A and HP amendatory materials under two irrigation treatments ($R^2 = 0.97$–0.97). Thus, the photosynthesis-related parameters could be assessed by the mentioned equation by fitting the curve. Table 4 indicates that soil water, HP, and Fu-A had significant effects on $NPR_{(max)}$, LSP, DRR, and IQY. However, reciprocal effects of Fu-A and HP on photosynthetic parameters under CI or DI situations were non-significant. Under both irrigation treatments, $NPR_{(max)}$, DRR, and IQY indicated a rising trend generally; LSP indicated a declining trend while providing optimal LCP (Table 4). When analyzing the control plots (CPs) under the DI situation, $NPR_{(max)}$ in plots treated with Fu-A or HP improved by 13.2 and 11.5%, respectively, and in plots treated with both amendatory materials improved by 19.8%. Analyzing CT under the CI situation showed that $NPR_{(max)}$ was almost constant, while soil HP or Fu-A was contributed as an amendatory material. The IQY amounts were amended by 11.7 and 10.2% in plots treated with Fu-A or HP, respectively, when compared with the CPs under the DI situation. Besides, the mixed use of both amendatory materials significantly amended $NPR_{(max)}$ by 19.8% and IQY by 18.5% when compared with the CPs under the DI situation. The mixed influence of these two amendatory materials on photosynthesis was also higher than the influences when used alone. Applying both Fu-A and HP significantly amended DRR by 26.7% under the CI situation and 12.8% under the DI situation. Under the DI situation, LSP amounts

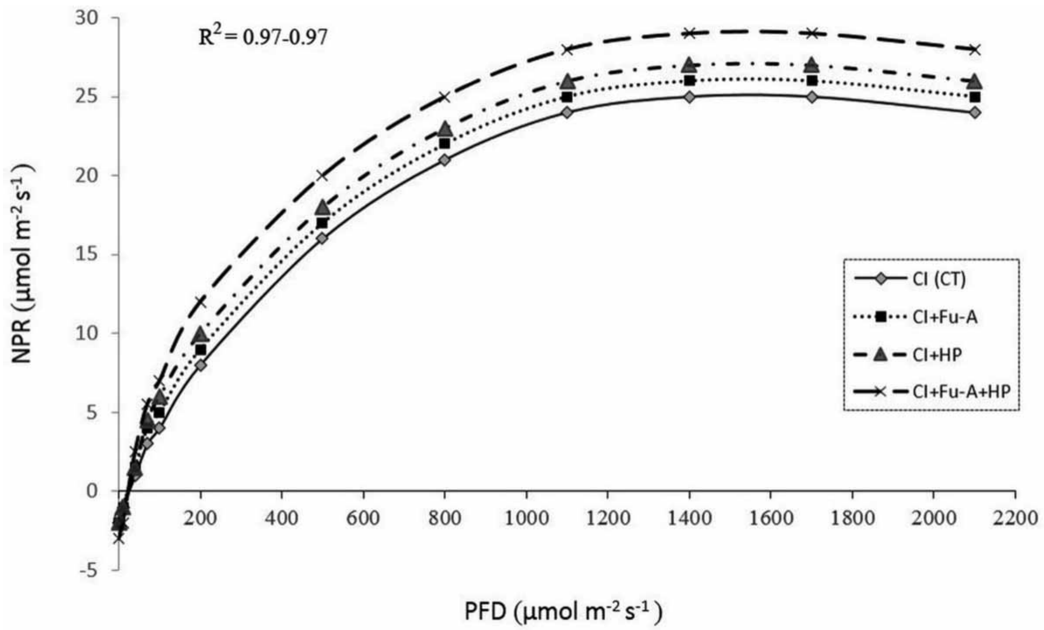

Figure 1 | NPR response to PFD in corn plants treated with Fu-A and HP under CI conditions.

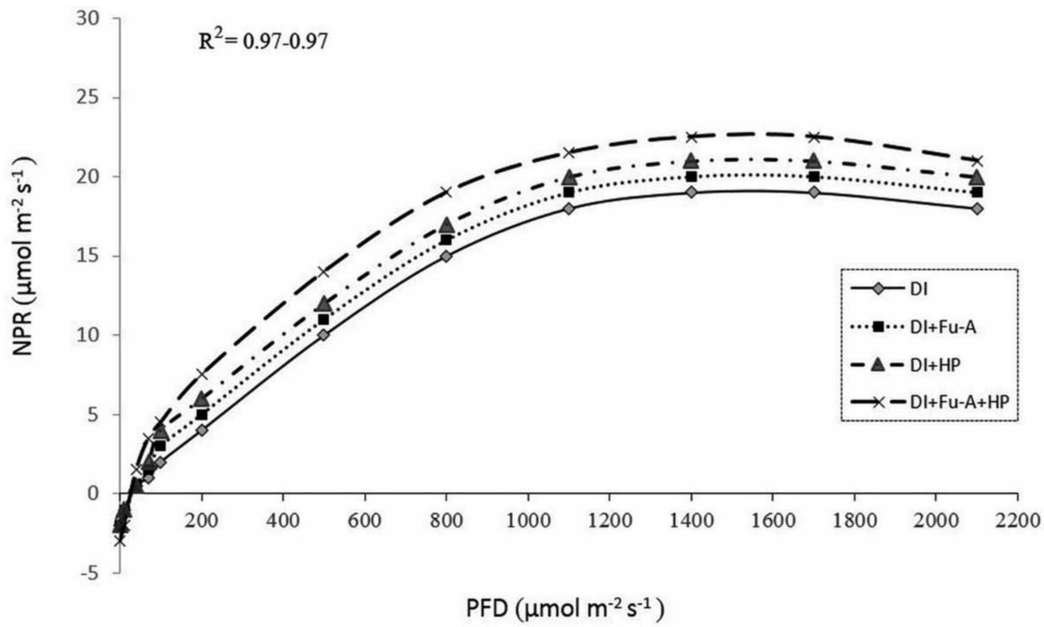

Figure 2 | NPR response to PFD in corn plants treated with Fu-A and HP under DI conditions.

declined by 10.5 and 18.1% in the Fu-A and HP treatments, respectively, compared with the CPs. However, LSP in the Fu-A, HP, and combined treatments was non-significant under CI conditions.

Chlorophyll fluorescence

After 15 and 22 days of water treatment, TCC and Fl-v/Fl-m amounts were lesser in the DI category than in the CI category (Figures 3–6). Fu-A and HP individuals did not influence on TCC and Fl-v/Fl-m after 15 days of DI treatment. Although, after

Table 4 | $NPR_{(max)}$, LSP, LCP, DRR, and IQY in corn plants treated with Fu-A and HP under CI and DI situations

Treatment	$NPR_{(max)}$ (μmol (CO_2) $m^{-2}s^{-1}$)	LSP (μmol (CO_2) $m^{-2}s^{-1}$)	LCP (μmol (CO_2) $m^{-2}s^{-1}$)	DRR (μmol (CO_2) $m^{-2}s^{-1}$)	IQY (μmol (quantum) $m^{-2}s^{-1}$)
CI (CT)	20.6bc	1682b	40.2a	1.54b	0.070bc
CI + Fu-A	22.4b	1642bc	42.7a	1.61b	0.077b
CI + HP	22.2b	1589c	41.8a	1.49b	0.075b
CI + Fu-A + HP	25.6a	1663bc	44.2a	2.1a	0.086a
DI	13.8d	1851a	40.3a	1.09d	0.053e
DI + Fu-A	15.9cd	1656bc	41.9a	1.27c	0.060d
DI + HP	15.6cd	1516d	43.1a	1.17cd	0.059d
DI + Fu-A + HP	17.2c	1534d	42.3a	1.25c	0.065c

Different letters within each column indicate significant difference between treatments at $P < 0.05$.

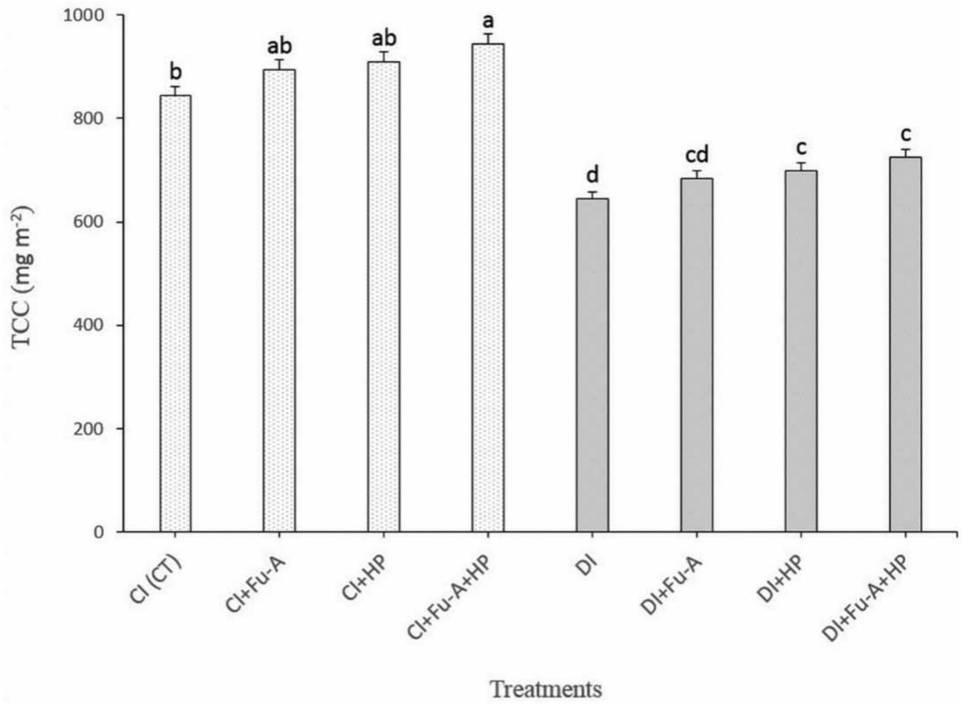

Figure 3 | TCC in corn plants treated with Fu-A and HP under CI and DI conditions for 15 days.

15 days of DI treatment, both mixed amendatory materials, as compared with CPs, significantly amended TCC by 11.1% and Fl-v/Fl-m by 10.1%. Besides, at 15 days after performing the CI situation, TCC and Fl-v/Fl-m amounts were non-significantly variant in applying Fu-A and HP alone, so that they significantly rose by 10.6 and 8.1% under applying the mixed amendatory materials, respectively. While irrigation treatments were performed until day 22, applying the mixed amendatory materials significantly amended the TCC by 13.6 and 10.1% under DI and CI situations, respectively.

Leaf water and LP

Table 5 shows that soil water and HP indicated significant individual and reciprocal influences ($P < 0.05$) among these parameters. Fu-A amendatory material and soil water had significant influences on LOP and LRWC; soil water and HP

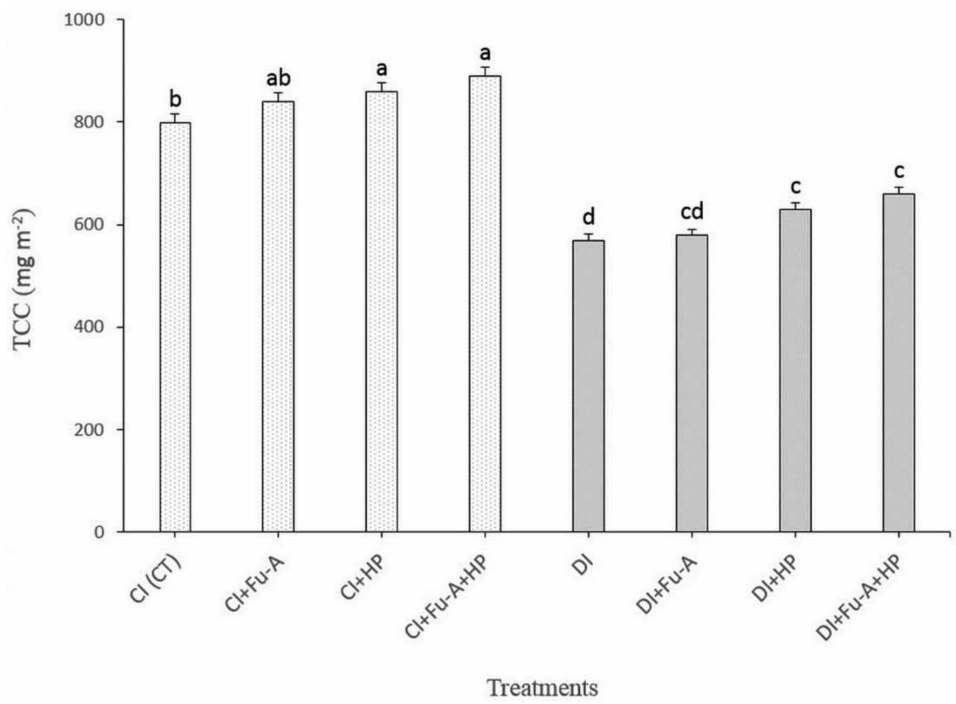

Figure 4 | TCC in corn plants treated with Fu-A and HP under CI and DI conditions for 22 days.

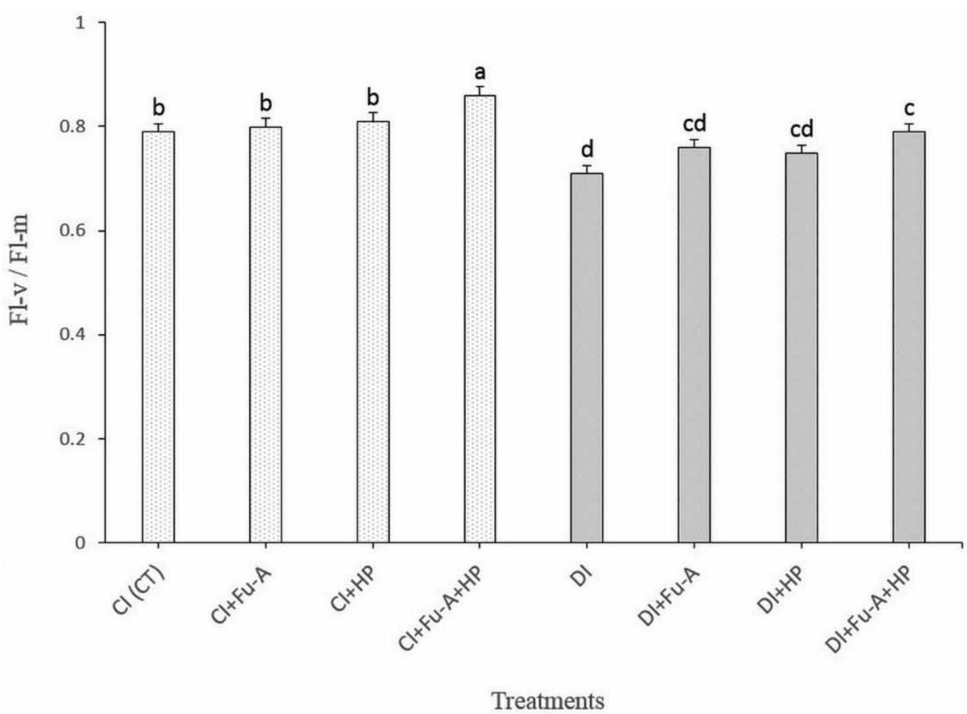

Figure 5 | Fl-v/Fl-m in corn plants treated with Fu-A and HP under CI and DI conditions for 15 days.

with Fu-A indicated significant reciprocal effects on LOP and LRWC. Without adding these two amendatory materials, and compared with the CI category (CT), LOP and LRWC significantly declined by 20.6 and 15.4%, respectively (15 days after starting the DI), and by 19.8 and 12.8%, respectively (22 days after starting the DI). Fu-A and HP individuals or mixed did

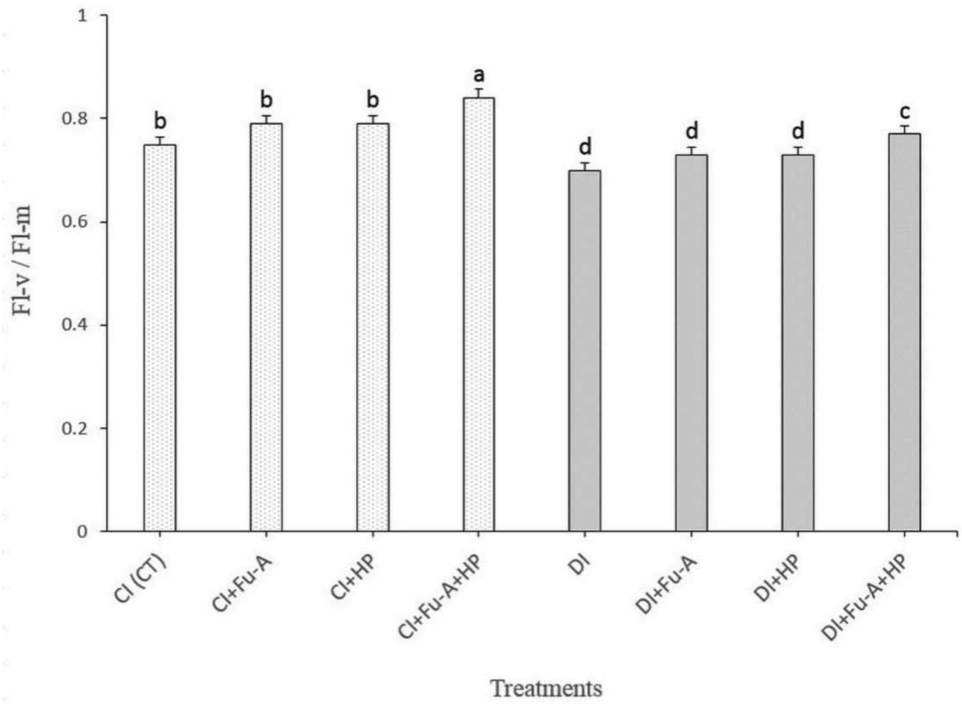

Figure 6 | Fl-v/Fl-m in corn plants treated with Fu-A and HP under CI and DI conditions for 22 days.

Table 5 | LOP, LRWC, and LP for corn plants treated with Fu-A and HP under CI and DI conditions for 15 and 22 days

	LOP (MPa)		LRWC (%)		LP (μmol g^{-1})	
Treatment	**15 days**	**22 days**	**15 days**	**22 days**	**15 days**	**22 days**
CI (CT)	−1.23a	−1.38ab	103.83a	91.45bc	23.25e	31.52de
CI + Fu-A	−1.27a	−1.35ab	101.90a	94.63ab	28.25de	35.53d
CI + HP	−1.23a	−1.45bc	109.51a	92.89bc	28.10de	27.24e
CI + Fu-A + HP	−1.19a	−1.30a	105.13a	97.88a	30.89d	34.19d
DI	−1.55bc	−1.72e	87.89c	79.76d	43.61c	61.39c
DI + Fu-A	−1.51b	−1.62de	88.46bc	78.12d	52.65a	81.88a
DI + HP	−1.68c	−1.60d	90.22c	80.11d	45.31bc	66.62c
DI + Fu-A + HP	−1.45b	−1.53cd	97.41b	89.42c	48.23ab	73.50b

Different letters within each column indicate significant difference between treatments at $P < 0.05$.

not influence on LOP and LRWC after 15 and 22 days of CI. When DI was performed until day 15 or 22, the LRWC amounts significantly amended by 9.8 and 10.8% after applying the mixed amendatory materials, respectively, contrasted with the CPs; these rises were greater improvements than when each amendatory material was applied individually. After passing 15 or 22 days of DI beginning, and without applying HP and Fu-A amendatory materials, LP amounts rose by 46.7 and 48.7%, respectively, compared with the CI category (CT). After passing 15 or 22 days of DI beginning and compared with CPs, LP rose by 17.2 and 25.0% with the Fu-A utilization individual, 3.8 and 7.9% when using HP individual, and 9.6 and 16.5%, respectively, when using both amendatory materials. After 15 days of starting the DI and compared with the CPs, LP amounts rose significantly by 17.2% in the Fu-A alone and 9.6% in the mixed Fu-A and HP treatments. For a lengthened period and under the DI situation (22 days), the mixed use of both amendatory materials significantly rose LP by 9.24% compared with the individual HP treatment and declined by 10.2% compared with the Fu-A treatment individual. Besides, after 15 or 22 days under the CI situation, LP amounts were not significantly variant among Fu-A and HP treatments individual or mixed. For both 15 and 22 days moisture management, Fl-v/Fl-m was significantly related with LRWC and LOP ($P < 0.05$, $R^2 = 0.82$ and 0.77, respectively), between LOP and LP ($R^2 = 0.61$), and between LRWC and LOP ($R^2 = 0.87$) under DI conditions with Fu-A and HP alone or combined (Figure 7).

Yield and yield components

Without applying the two amendatory materials, the yield was 35.7% lesser in the DI category than in the CI category (CT) (Figure 8). Compared with CT, yield under the DI situation treated with Fu-A or HP individual declined by 27 and 29.4%, respectively. Yield declined by 19% under the DI situation when treated with mixed Fu-A and HP and compared with CT. Individual application of Fu-A led to a 9.3% shoot biomass enhancement under CI situation and 17.8% enhancement under the DI situation. Under the CI situation, applying Fu-A and HP individuals showed no influence on yield components and yield under the CI situation; the mixed utilization rose 10.6% for yield and 11.6% for grain weight. Besides, both amendatory materials mixed rose yield (20.6%) and the number of grains (12.8%) under the DI situation. Under the DI situation, yield in the mixed treatment was 12.7 and 9.8% greater than with HP and Fu-A individuals.

DISCUSSION

The use of Fu-A or HP as amendatory materials can significantly boost $NPR_{(max)}$ and IQY alone under two distinct irrigation regimes. This observation is in line with others from the same field of study. Table 4 shows that the simultaneous application of both amendatory materials in two distinct irrigation regimes improved IQY and $NPR_{(max)}$ significantly. The use of Fu-A and HP in vessels improved IQY by increasing light absorption of the plant. Nevertheless, under the DI situation, the compensating effects of the mixed Fu-A and HP treatments on $NPR_{(max)}$ and IQY were larger than under the CI situation. The usage of Fu-A and HP as amendatory materials during drought stress situations is thus beneficial and efficient. This study indicated that when the two amendatory materials are used in combination, the effects of soil water deficit on the plant may be mitigated more effectively than when they are employed independently. The simultaneous application of Fu-A and HP efficiently sustains high NPR rates and lowers leaf stomatal transpiration during drought stress situations, according to a study

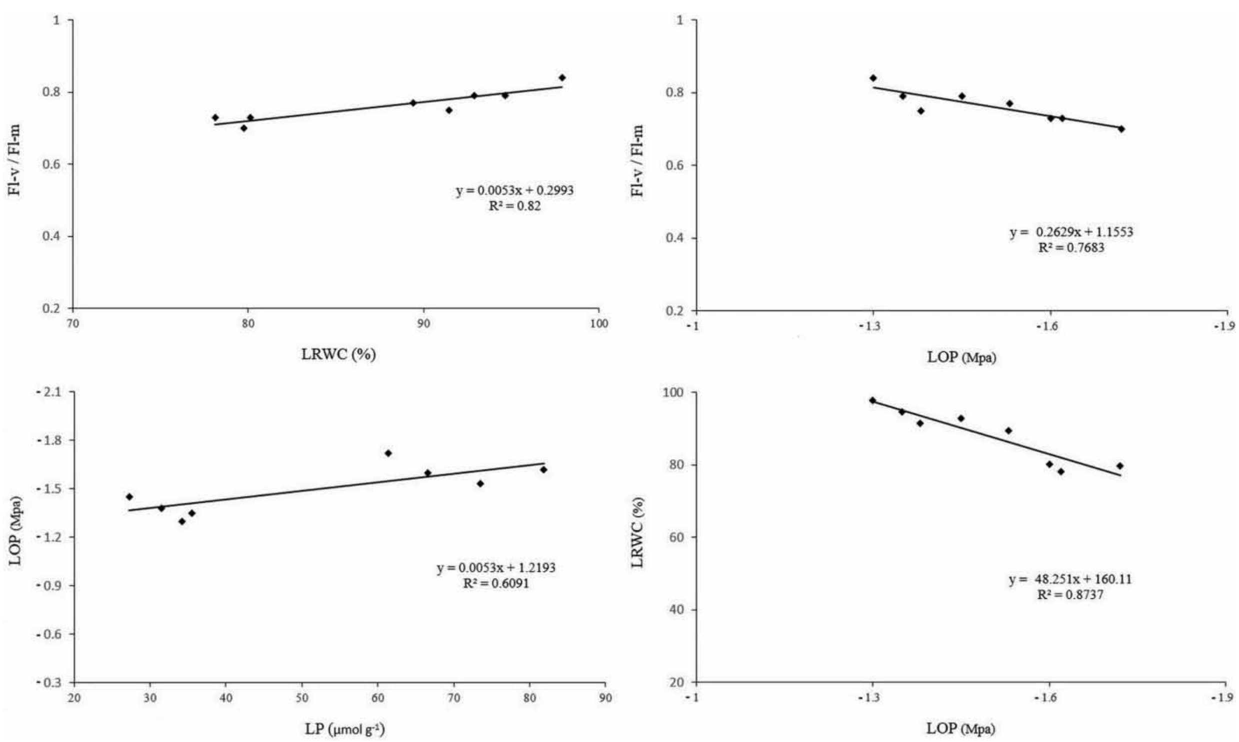

Figure 7 | Linear regression relationships between the Fl-v/Fl-m, LRWC, and LP in corn plants treated with Fu-A and HP under water deficit conditions.

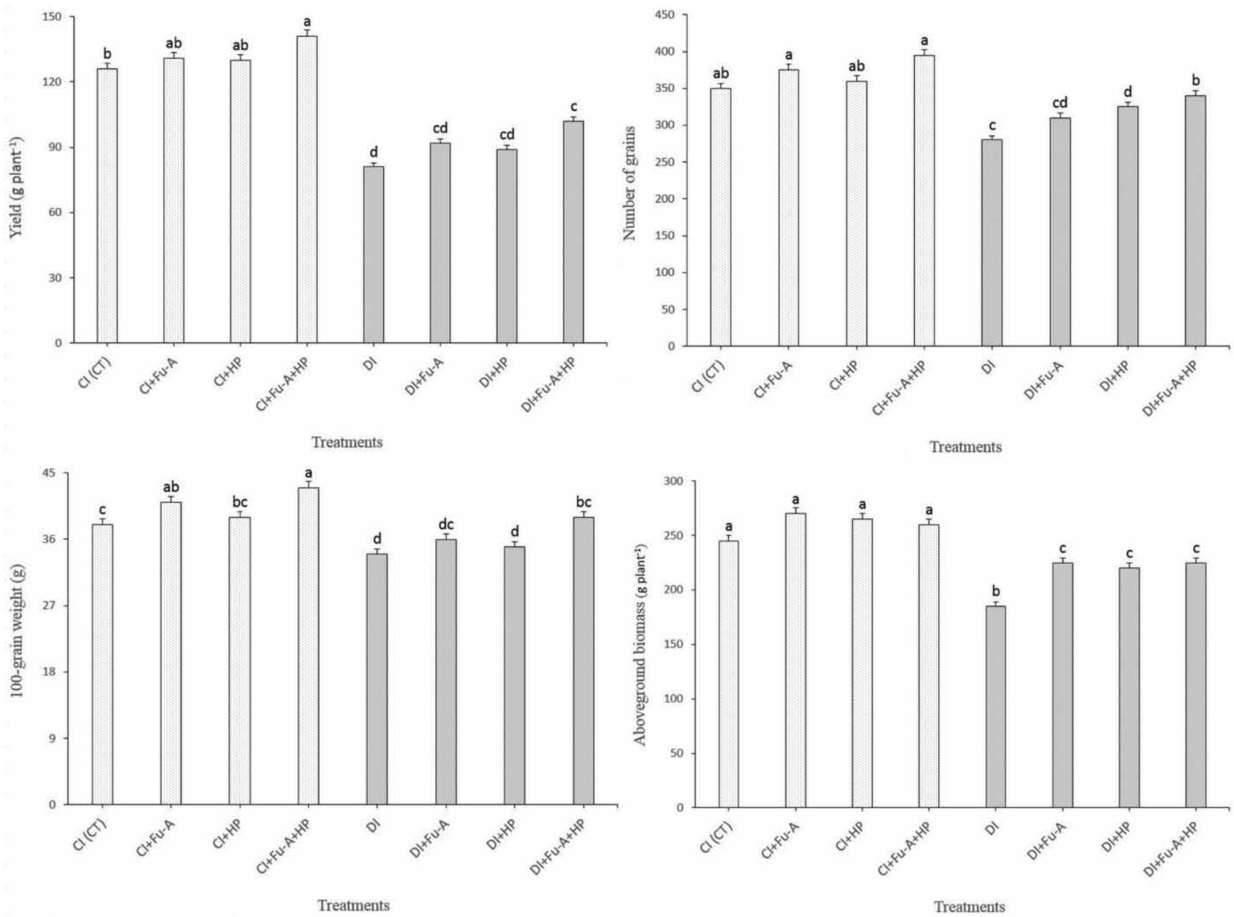

Figure 8 | Yield components and yield for corn plants with applying Fu-A and HP under CI and DI conditions.

conducted by Yang *et al.* (2017, 2019a) on corn grown in the vessel. HP as the first amendatory material could amend the soil water retention capacity under water deficit situations and enhance the circumstances for water to reach the plant roots when the soil is dehydrated. Moreover, it aids in the roots absorbing water and nutritious minerals and then passing them to the leaves (Celik *et al.* 2010; Islam *et al.* 2011). Under low rainfall, the root water intake by corn was greatly enhanced by both amendatory materials. Fu-A as the second amendatory material could amend the diphosphate ribulose carboxylase and photochemical reaction oxygenation levels. As a result of these circumstances, photosynthesis and grain yield were improved (Calvo *et al.* 2014; Canellas *et al.* 2015; Liao *et al.* 2018; Yang *et al.* 2019b). Zhang *et al.* (2016) found that the use of Fu-A as an amendatory material had a greater impact on plant development and NPR amendment when applied with the appropriate amount of moisture. Photosystem II's photochemical conversion performance may be measured using the Fl-v/Fl-m ratio. According to Singh & Reddy (2014), when the Fl-v/Fl-m ratio decreases, the extent of photosynthetic efficiency restriction tends to increase. The application of Fu-A amended the Fl-v/Fl-m ratio under both irrigation treatments (Figures 5 and 6). The findings of this study are in line with those of Lotfi *et al.* (2018) and Yang *et al.* (2019b), who found that applying Fu-A as an amendatory material amended the Fl-v/Fl-m proportion and the grain ripeness index of the plant under DI and CI conditions. It also elevates photosynthesis as a result of this property. Whenever Fu-A was used alone on TCC, there was no significant difference between irrigation procedures (Figures 3 and 4). The use of the Fu-A amendatory material has minimal impact on TCC according to a few prior investigations (Goreta *et al.* 2007; Celik *et al.* 2010; Yang *et al.* 2019a). On the other hand, Anjum *et al.* (2011) found that using the Fu-A as an amendatory material significantly amended TCC in corn whether irrigation was deficient or complete. The timing of application and the concentration of the Fu-A may be accountable for these differences. TCC may be improved significantly by incorporating HP into the soil during both irrigation regimens. This study's findings align with earlier ones (Koupai *et al.* 2008; Celik *et al.* 2010; Calvo *et al.* 2014; Yang *et al.* 2019b). When comparing the mixed treatment of Fu-A and HP amendatory materials to their separate application under both distinct irrigation regimens, the Fl-v/Fl-m ratio, and TCC exhibited a rising tendency. Under dehydration circumstances, the combination of Fu-A and HP amendatory materials was more constructive at safeguarding the chloroplast construction and the chain of electron transport. Calvo *et al.* (2014) and Khadem *et al.* (2010) reported that the addition of HP to soil amended soil hydration during drought stress situations, whereas the application of Fu-A improved plant TCC. This phenomenon is ascribed to corn's nitrogen (N) uptake. Liao *et al.* (2018) and Farooq *et al.* (2009) reported with the application of Fu-A and HP amendatory materials and observed an enhancement in nitrogen levels of corn roots following drought stress situation. Besides, LP improvement occurs because of osmotic modulation in plant cells' cytoplasm and chloroplasts. Mahajan & Tuteja (2005), Campos *et al.* (2004), and del Amor *et al.* (2010) reported that when this active reactive mechanism is applied, plant tissue water is improved, damage induced by biochemical and physiological dehydration of the plants is reduced, and plants are more likely to survive under drought stress situations. Nevertheless, this phenomenon happens when the plant's leaves swell to an extreme degree. It was discovered by Good & Zaplachinski (1994) that LP concentrations rose only when plant tissue dehydrated from roughly 70 to 75% of LRWC. While LRWC was less than 80% after 22 days of DI treatment performance, Fu-A induced significant improvements in LP and LOP (Table 5). This result differed from the other studies (related to vessel investigations). Anjum *et al.* (2011) and Goreta *et al.* (2007) reported that the application of Fu-A amendatory material increased LRWC and LP concentrations largely when applied to corn under drought stress situation, but that just 60% of the LRWC was enough for LP aggregation. Besides, the LP aggregation amount in plants exposed to the Fu-A amendatory material probably relies on the kind of plant and the intensity of drought stress. Under both DI and CI conditions, applying HP amendatory material to the soil seemed not to influence LP (Table 5). According to Aggag *et al.* (2015), LRWC and LP in tomato plants did not react to Fu-A amendatory material under small drought stress situations; however, they rose significantly under more severe drought stress situations. During a pepper vessel investigation, del Amor *et al.* (2010) found that using amendatory materials of leaf antiperspirant showed no impact on LRWC or LP under extreme drought stress situations, but both increased under moderate drought stress situations. Using the HP amendatory material, Cao *et al.* (2017) and Najafinezhad *et al.* (2015) found that corn may demonstrate improved adaptability to soil water scarcity when higher soil moisture and leaf water potential are supplied. Under the long-term DI situation, applying both Fu-A and HP amendatory materials resulted in higher levels of LRWC and LP than applying them independently. Photosystem II's photosynthetic performance was also improved as a result of these circumstances. This is because the plant was highly dehydrated when leaf moisture and LP measurements were recorded. Good & Zaplachinski (1994) and Islam *et al.* (2011) reported that severe dehydration and tissue withering impair plant development when water is scarce. Thus, due to the quick decline in LRWC and LOP, these circumstances will not be conducive to LP aggregation whenever the LRWC falls below 80%. Besides, the addition of HP in soil boosts LRWC and leaf water potential in drought-stressed plants while significantly increasing plant water consumption. Yang *et al.* (2017) demonstrated that the application of Fu-A amendatory material reduces water loss in corn-cultivated soils under drought stress situations by lowering leaf stomatal transpiration. Reduced plant dehydration was achieved by following this ideal guideline, which increased soil moisture and maintained suitable LRWC (Figure 7). It also can raise LP and, as a result, enhance plant viability. Figure 8 shows that when Fu-A and HP were applied simultaneously, the increased corn yield was significantly reliant on the increased number of grains. In addition, it might be linked to pollen survival. For example, according to Weerasinghe *et al.* (2016), drought stress promotes pollen survival and grain production in plants when antiperspirant amendatory materials are applied to the leaves during the reproductive phase. When using Fu-A or HP amendatory materials plus CI, the improvement in corn yield is mostly attributable to the improvement in grain weight. Figures 1–7 show that under CI circumstances, corn grew and had a physiological yield that was satisfactory. Because of this, corn yields may be greater under these circumstances (Figure 7). The products may reach high photosynthetic effectiveness and high chlorophyll amount by employing two amendatory materials, Fu-A and HP, and the CI situation (Figures 3–6). Of course, grain filling qualities were favorably demonstrated in increased product yield. The use of Fu-A amendatory material improved the wheat grain filling mechanism and enhanced grain weight under CI circumstances, according to Zhang *et al.* (2016). Fu-A and HP amendatory materials have been shown to boost plant yield through two different processes when used in soils with varying moisture levels. Under CI, crop yield decreased when two amendatory materials, Fu-A and HP, were used compared to DI. When Fu-A and HP were used, NPR and photosynthetic efficiency of the Photosystem II under DI circumstances were greater than the CI situation (Table 4). Under the DI situation, using Fu-A and HP amendatory materials together may thus be more significant and beneficial for increasing production and boosting photosynthetic mechanisms.

CONCLUSION

Under DI and CI situations, the co-treatment of two amendatory materials, Fu-A and HP, enhanced corn yield significantly. These enhancements were higher than enhancements attained by using them alone. The increased corn yield was attributable to the employment of two amendatory materials, including Fu-A and HP, under the DI situation and, to a larger extent, the corn grains number's enhancement. When applied together, Fu-A and HP enhanced NPR and plant chlorophyll levels and photosynthetic efficiency of Photosystem II in this study even though irrigation treatments were different. The moisture and LP available for the plant during DI circumstances were increased by utilizing both amendatory materials, Fu-A and HP. It is recommended that the two amendatory materials, Fu-A and HP, can be used alone or in conjunction in studying the growth of corn and other crops under various irrigation programs. Thus, larger LP values and improved photosynthetic efficiency may be attained in this manner, allowing for higher yields to be obtained, particularly under the DI situation.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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