

Research Article

# Super Absorbent Polymers and Soil Texture Affects on *Zea mays* L. Physiological Response, under Drought Stress Condition

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## Abstract

**Background:** Super absorbent polymers (SAP) have been studied as soil amendments in arid and semiarid environments, but little is known about potential use for drought stress mitigation in different soil textures.

**Objectives:** The objective of this survey was to evaluate the role of SAP under drought stress condition on antioxidant enzymes and Corn crop production.

**Methods:** Current research arranged in splitsplit plot experiment based on completely randomized block design with three replications. The primary plots included different types of soil, including sandy and clayloam. The subplots were categorized into three levels of drought stress, 80, 100 and 120 mm of evaporation from the pan which is named severe drought stress, mild drought stress and well-watered conditions, respectively. Five value of SAP including 0, 10, 20, 40, and 80 kg.ha<sup>-1</sup> were applied as the subs subsidiary factor.

**Result:** The results illustrated that drought caused a significant decrease in net photosynthesis rate, leaf stomatal conductance, chlorophyll (Chl.) a+b, relative water content (RWC), plant height, and grain yield of Maize. Catalase (CAT), Super oxide dismutase (SOD), Ascorbate peroxidase (APX), Relative electrolyte conductivity (REC), and proline were significantly elevated with increase in drought stress level. Relative to the control treatment, the moderate and severe drought conditions increased water use efficiency (WUE) on average by 5.8 and 11.7%, respectively. The maximum value of grain yield (491.8 g) was recorded for clayloam soil texture. Applying SAP under drought condition enhanced the leaf gas exchange parameters, total chlorophyll, RWC, plant height, and grain yield, while it decreased REC, proline content, CAT, SOD, and APX activity. The highest and lowest Net photosynthesis rate, leaf stomatal conductance and Chl. a+b contents were related to amounts of 80 and 10 kg.ha<sup>-1</sup> SAP respectively. A significant increase in leaf relative water content was observed with application of 40 and 80 kg.ha<sup>-1</sup> SAP whilst the lower amounts (10 and 20 kg.ha<sup>-1</sup> SAP) had no significant impact on the parameter in compared with control (0 kg.ha<sup>-1</sup> SAP).

**Conclusion:** Finally recommend using SAP at a dose of 80 kg.ha<sup>-1</sup> for dealing with drought conditions in the sandy and clayloam soils.

**Keywords:** Antioxidant enzyme, Ascorbate peroxidase, Catalase, Chlorophyll, Proline, stomatal conductance.

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## 1. Background

Maize is a crucial crop in maintaining global food security, but due to water scarcity worldwide, its yield potential has decreased by up to 40% between 1980 and 2015. (Cairns et al., 2013; Daryanto et al., 2016). The efficient use of water for crop irrigation is important in semiarid and arid regions, as well as in tropical climates where drought is frequent (Saha et al., 2020). One reason for soil amendment is to help the soil hold more water for a longer time (Montesano et al., 2015; Galeş et al., 2016). SAP can be used on farms to help the soil hold more water and make plants grow better (Yang et al., 2013; Chen et al., 2014). Super absorbent polymers are special types of materials that can hold a lot of water within them. They are made of linked molecules and have the ability to soak up and store water effectively. SAP can soak up and hold lots of water and solute molecules when it swells up. This happens because it has hydrophilic groups like carboxyl, amino, and hydroxyl groups in its structure (Feng et al., 2014). So far, many researchers have evaluated various parameters under drought stress conditions. Each of the morphological, physiological and biochemical parameters has somehow expressed the effects of stress on the plant. Photosynthesis is one of the main plant processes that is affected by drought stress. The susceptibility of photosynthesis related processes to drought stress is primarily due to stomatal closure, resulting in reduced CO<sub>2</sub> intake. This reduction directly affects the rate of photosynthesis, ultimately impacting plant growth and yield. Thus, the maintenance of photosynthetic rates during drought stress is crucial for plants to develop drought tolerance (Yang et al., 2021 and Waititu et al., 2021). Plant cells create a defense system to protect themselves from getting damaged by harmful substances that can affect their structures. The cellular antioxidant system has been proven to help protect against various environmental stresses. (Gill et al., 2011). SOD, CAT, and APX are important chemicals that help plants protect themselves from harm caused by their environment, specifically when it is harsh or unfavourable. The extra antioxidant enzyme activity may help protect the cells from harm caused by stress (Ahmad et al., 2014). Osmotic regulation is an important way that plants respond to lack of water (Iqbal et al., 2018). Proline is a substance that plants need to keep their cells working properly when there is not enough water (Dutta et al., 2019). The RWC can show how a crop is growing and developing, and it can also tell us if the leaves are conserving water (Junttila et al., 2018; El-Hendawy et al., 2019). Measuring these characteristics will help us understand how plants' physiology and biochemistry change when they are under stress, particularly during

drought. Many studies have looked at how plants and crops like Maize respond to drought. They have studied the physical and biological changes in these plants and how it affects their yield (Cai et al., 2020; Song et al., 2018), while very little conclusive researches have been reported for the effects of SAP and soil texture on the physiological and biochemical changes in Maize under drought stress.

## 2. Objectives

The present study was aimed to evaluate (i) if antioxidant activity, leaf gas exchange parameters, osmotic adjustment substances, photosynthetic pigments, RWC, electrolyte leakage and grain yield of Maize was influenced with SAP, soil texture, drought stress, and their interactions (ii) which measured parameters had greatest impact on grain yield of Maize plant under moderate and severe stress conditions.

## 3. Materials and methods

### 3.1. Field and Treatments Information

The study was done via split-split plot arrangement, based on completely randomized block design with three replicates. The experiment was carried out on agricultural land that was leased from local farmers in the Kerman region. The primary plots in the study were the implementation of different types of soil, including sandy and clayloam. The subplots were categorized into three levels of drought stress, 80, 100 and 120 mm of evaporation from the pan which is named severe drought stress, mild drought stress and well-watered conditions, respectively. An evaporation pan (Class A) placed 15 cm above the soil surface of the farm was used to regulate the irrigation amount and schedule. In addition, five values of SAP including 0, 10, 20, 40, and 80 kg.ha<sup>-1</sup> were applied as the subsidiary factor. The measurement of the application of the irrigation regime was conducted using the weight method.

### 3.2. Farm Management

A soil sampling device, specifically a cylinder, was utilized to extract a sample from the targeted depth of the soil. A dry weight was determined for the wet soil sample through an oven-drying procedure involving a temperature of 110 °C for 48 hours (Brendan, 2005). The following equation was used to calculate the moisture content of soil under FC conditions: Equ.1. Soil moisture content = Soil dry weight minus soil fresh weight / Soil dry weight (Brendan, 2005). The time intervals, numbers, and total amounts of irrigation for different levels of drought, soil type and SAP are shown in table 1. Depending on the water stress level and the type of soil and SAP, the volume of irrigation water has changed during the plant growth period. After four weeks of

**Table 1.** The time intervals, numbers, and total amounts of irrigation for different levels of drought, soil texture and SAP

Soil texture	Drought condition	Evaporation level (mm)	Time Interval (d)	Number of irrigations	SAP values (kg.ha <sup>-1</sup> )	Total irrigation amount (L.plot <sup>-1</sup> )
Sandy	No drought	80	8	12	0	2714
					10	2721
					20	2706
					40	2564
					80	2411
	Moderate drought	100	12	8	0	2201
					10	2198
					20	2205
					40	2011
					80	1903
	Severe drought	120	16	6	0	1695
					10	1681
20					1684	
40					1453	
80					1346	
Clay-loam	No drought	80	8	12	0	2453
					10	2439
					20	2445
					40	2216
					80	2134
	Moderate drought	100	12	8	0	1948
					10	1946
					20	1941
					40	1726
					80	1634
	Severe drought	120	16	6	0	1424
					10	1419
20					1421	
40					1216	
80					1135	

treatment application, the plant materials were collected and stored at a very low temperature of -80 °C to measure the presence of photosynthetic pigments, proline content, and antioxidant activity.

### 3.3. Measured Traits

#### 3.3.1. Gas exchange measurement

To measure the amount of photosynthesis and the level of leaf permeability, a device called Handheld Photosynthesis System (CI-340, CID Bio-Science, USA) was used between 11:00 am and 14:00 pm, one week prior

to plant flowering stage. Leaves with the same shape (fully grown young leaves) were selected for this purpose.

#### 3.3.2. Relative water content (RWC) and electrolyte leakage

RWC was measured using the equation described by Farahbakhsh et al. (2017).

$$\text{Equ.2. RWC} = \frac{[(\text{Fresh weight} - \text{dry weight}) \div (\text{Turgor weight} - \text{dry weight})] \times 100}{100}$$

To determine electrolyte leakage, fresh leaf discs measuring 0.25 cm<sup>2</sup> were used, as described by Compos et al. (2003). The results were reported as REC.

### 3.3.3. Proline content

To measure proline concentration, a fresh leaf sample weighing 50 mg was extracted using a pestle and mortar with 4.5 ml of 3% 5-sulfosalicylic acid and then filtered using filter paper. Two ml of the filtrate was mixed with 2 ml of acid-ninhydrin and 2 ml of glacial acetic acid in a test tube. The mixture was then heated for 1 hour at 100 °C, and the reaction was terminated in an ice bath. Proline concentration was determined spectrophotometric ally at 520 nm, as described by [Bates \(1973\)](#).

### 3.3.4. Chlorophyll content

fresh leaves (about 100 mg) and crushed them in acetone (80% acetone). Then, centrifuge at a high speed (11000 g) for 10 minutes at a low temperature (4 °C). The acetone extracts were tested at two different colours, 663 nm and 645 nm, to measure how much they absorbed. ([Lichtenthaler, 1987](#)).

### 3.3.5. Preparation of enzyme extract

To prepare the samples for enzyme activity assay, fresh leaf organs weighing 100 mg were frozen in liquid nitrogen and then homogenized using a prechilled mortar and pestle under ice cold conditions. The homogenization was performed in 4 ml of 50 mM potassium phosphate buffer with a pH of 7.0 and containing 1 mM EDTA. The resulting homogenate was centrifuged at 25,000 g for 20 minutes at 4°C, as described by [Mishra et al. \(1993\)](#). The supernatant was collected and stored at -20 °C until further use.

### 3.3.6. Preparation of enzyme extract

The [Dhindsa et al. \(1981\)](#) method was used to measure catalase activity by tracking the consumption of H<sub>2</sub>O<sub>2</sub>. The reaction mixture included enzyme extract, 15 mM H<sub>2</sub>O<sub>2</sub>, and a 50 mM potassium phosphate buffer with a pH of 7.0. The decrease in H<sub>2</sub>O<sub>2</sub> was monitored using spectrophotometry at 240 nm.

### 3.3.7. Superoxide dismutase activity

Superoxide dismutase (SOD, EC 1.15.1.1) activity was determined by measuring the inhibition of photochemical reduction of NBT ([Giannopolitis and Ries, 1977](#)). The colour was developed by adding the following reagents: 2.4 ml of 50 mM Potassium Phosphate buffer solution (pH 7.8), 0.2 mL of 195Mm methionine, 0.1m L of 0.3 mM EDTA, 50µL enzyme extract, 0.2 ml of 1.125 mM NBT and 0.2 ml of 60µM riboflavin. Reaction mixtures were illuminated for 15 min at light intensity of 5000 Lux. The absorbance of solution was measured at 560 nm. One unit of SOD was defined as the amount of enzyme causing halfmaximal inhibition of the NBT reduction under the assay condition.

### 3.3.8. Ascorbate peroxidase activity

To measure ascorbate peroxidase activity, a reactive solution containing 50 mM sodium phosphate buffer with a pH of 7.0, 0.5 mM ascorbate, 0.1 mM H<sub>2</sub>O<sub>2</sub>, and 10 µl of enzyme extracts was used. Then the absorbance intensity at 290 nm was read ([Nakano and Asada, 1981](#)).

## 3.4. Statistical Analysis

Analysis of variance (ANOVA) and correlation between traits were done via SAS software (Ver. 9.2). The LSD test was used to means comparison at 5% probability level.

## 4. Result and discussion

### 4.1. Photosynthetic pigments

The chlorophyll (Chl.) a+b contents were significantly affected by both drought and SAP treatments ([Table 2](#)). The maximum value of Chl. a+b was observed at no stress condition while increasing drought stress led to a sizable reduction in the trait ([Table 2](#)). There was no significant difference between soil textures for Chl. a+b ([Table 2](#)). The highest and lowest Chl. a+b contents were related to amounts of 80 and 10 kg.ha<sup>-1</sup> SAP respectively ([Table 2](#)). The chlorophyll content serves as a measure of the plant's ability to utilize light ([Zhang et al., 2016](#)). Water deficit caused a decline in Chl. a+b. Chl. content have been suggested as one of the parameters of drought tolerance in plants and decrease in Chl. content due to drought stress has previously been reported ([Esteban et al., 2015](#); [Buezo et al., 2019](#)). Based on the theory of [Schutz and Fangmir \(2001\)](#), the reduction of chlorophyll due to drought stress is related to the increase of free oxygen radicals in the cell. These free radicals cause peroxidation and disintegration and by reduction of chlorophyll, considerable changes are produced in the plants. In this study, a protecting effect of SAP against the damage induced by drought stress was found. Results indicated that 80 kg.ha<sup>-1</sup> SAP was more effective compared to other values. This amount of SAP enhanced the Chl. a+b which can lead to an improvement in the leaf gas exchange parameters and in turn optimum growth of Maize plants under drought stress. These results were in agreement with the findings of [Nazarli et al \(2010\)](#), [Khadem et al. \(2010\)](#) and [Sayyari and Ghanbari \(2012\)](#). An increase in chlorophyll concentration with polymer amendment was reported by [Khadem et al. \(2010\)](#) and [Mao et al. \(2011\)](#) for Maize in drought stress conditions.

### 4.2. Leaf gas exchange parameters

Drought and SAP treatments affected net photosynthesis value and leaf stomatal conductance significantly (P<0.01) ([Table 2](#)). Net photosynthesis rate and leaf stomatal conductance decreased with decreasing the

relative water content of the soil (Table 2). The highest and lowest of mentioned parameters were obtained from SAP levels of 80 and 10 kg.ha<sup>-1</sup>, respectively (Table 2). Drought stress × SAP indicated that 80 kg.ha<sup>-1</sup> SAP lead to improving the leaf gas exchange parameters under drought stress conditions (Evaporation levels of 100 and 120 mm) (Fig. 1 and 2). Decreased photosynthetic capacity of Maize under drought stress might excessively reduce the photosynthetic electron transport chain.

This condition facilitates electron flow to molecular oxygen (O<sub>2</sub>), causing superoxide radical production by the Mehler reaction (Silva et al., 2010). Foliar applying SAP increased the photosynthesis rate of Maize plants. Photosynthesis rate may be increased by SAP application because of increasing chlorophyll content (Heidari, 2012).

### 4.3. Leaf relative water content

Relative water content was significantly affected by both drought stress and SAP application (Table 2). Leaf relative water content was declined by increasing drought levels so that the lowest value was gained at Evaporation

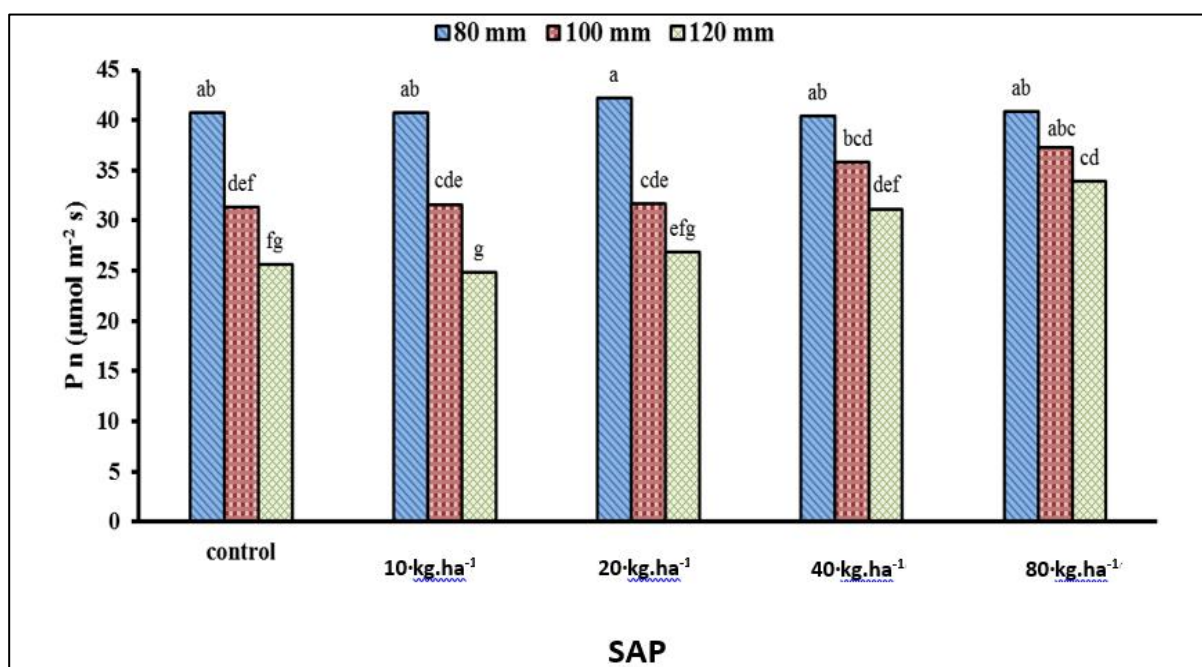
levels of 120 mm (Table 2). A significant increase in RWC was observed with application of 40 and 80 kg.ha<sup>-1</sup> SAP whilst the lower amounts (10 and 20 kg.ha<sup>-1</sup> SAP) had no significant impact on the parameter in compared with control (0 kg.ha<sup>-1</sup> SAP) (Table 2). Leaves RWC is considered as an alternative index of plant water status, which reflects the plant tissues metabolic activity (Flower and Ludlow, 1986). The results showed that RWC was meaningfully decreased by drought stress comparing the control treatment. The decrease in RWC under drought stress has been reported previously (Mazloom et al., 2020). This issue could be related to root systems, which are not able to compensate the water loss by transpiration through a reduction of the absorbing surface (Sreenivasulu et al., 2000). In this study, SAP treatments mitigated the deleterious impacts of drought on Maize plant. SAP treatment caused the RWC increase under drought stress (Table 2). This confirms that SAP was useful in water supplying for Maize grown under drought stress conditions as reported by Abobatta (2018) and Mazloom et al. (2020).

**Table 2.** Mean Comparisons of measured traits in Maize in response to SAP, soil texture and drought stress

Treatments	levels	Chl. a+b (mg g <sup>-1</sup> FW)	P <sub>n</sub> (μmol m <sup>-2</sup> s)	C <sub>leaf</sub> (mmol m <sup>-2</sup> s)	RWC (%)	REC (%)	Proline (μmol.g <sup>-1</sup> FW)	CAT (unit.mg <sup>-1</sup> protein)	SOD (unit mg <sup>-1</sup> protein)	APX (μmol min <sup>-1</sup> mg <sup>-1</sup> protein)	Plant height (cm)	Grain yield (g.m <sup>-2</sup> )
Drought (Evaporation level)	80 mm	1.893a <sup>■</sup>	41.03a	0.373a	84.66a	44.86c	0.175c	0.113c	83.23c	0.642c	171.4a	567.45a
	100 mm	1.677b	33.60b	0.316b	78.09b	57.10b	1.163b	0.188b	162.89b	1.471b	157.6b	494.3b
	120 mm	1.319c	28.51c	0.271c	63.45c	71.31a	2.702a	0.296a	201.90a	2.038a	121.6c	403c
L.S.	-	**	**	**	**	**	**	**	**	**	**	**
Soil texture	Sandy	1.630	34.78	0.324	75.74	57.06b	1.319	0.195b	147.70	1.370	152.0	484.7b
	Clay-loam	1.630	33.98	0.316	75.05	58.46a	1.374	0.203a	150.97	1.397	148.4	491.8a
L.S.	-	ns	ns	ns	ns	*	ns	*	ns	ns	ns	*
SAP (kg ha <sup>-1</sup> )	0	1.576b	32.59c	0.303cd	73.80b	59.65a	1.924a	0.231a	165.10a	1.597a	144.5b	479.7b
	10	1.574b	32.44c	0.294d	73.33b	59.70a	1.847a	0.228a	164.23a	1.589a	144.5b	479b
	20	1.578b	33.62bc	0.313c	73.91b	59.56a	1.348b	0.207b	161.23a	1.518b	146.8b	483.7b
	40	1.691a	35.86ab	0.335b	77.13a	56.13b	0.961c	0.181c	137.93b	1.213c	155.8a	497.2a
	80	1.729a	37.40a	0.355a	78.81a	53.75c	0.653d	0.149d	118.20c	1.003d	159.3a	501.5a
L.S.	-	**	**	**	**	**	**	**	**	**	**	**

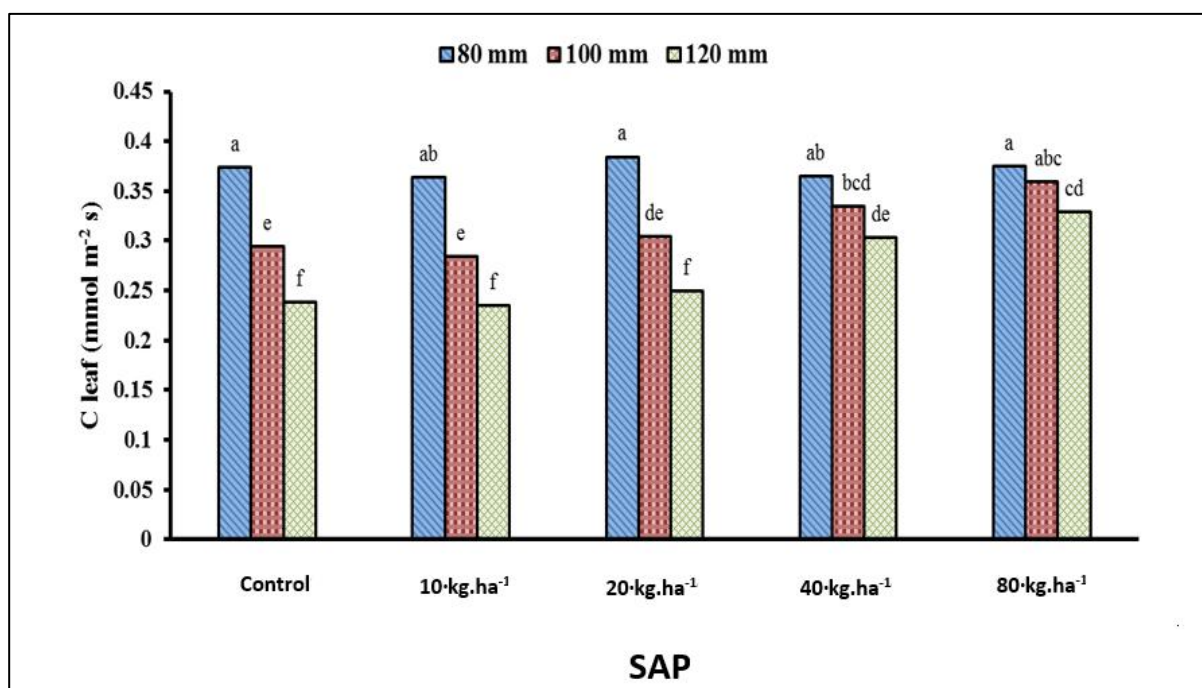
<sup>■</sup>In a column, means with different letter denoted statistically difference between treatment groups according to LSD's test (P < 0.05).

L.S.: level of significance, \* P < 0.05, \*\* P < 0.01, ns: non-significant, Chl. a+b: chlorophyll a+b, P<sub>n</sub>: net photosynthesis rate, C<sub>leaf</sub>: leaf stomatal conductance, RWC: relative water content, REC: relative electrolyte conductivity, CAT: catalase, SOD: super oxide dismutase, APX: ascorbate peroxidase.



**Figure 1.** The combined effects of different levels of drought and SAP on the net photosynthesis of Maize. Similar letters indicate non-significant differences at 5% probability level by LSD test.

P<sub>n</sub>: net photosynthesis rate, SAP: Super absorbent polymers.



**Figure 2.** The combined effects of different levels of drought and SAP on the leaf stomatal conductance of Maize. Similar letters indicate non-significant differences at 5% probability level by LSD test.

C<sub>leaf</sub>: leaf stomatal conductance, SAP: Super absorbent polymers.

#### 4.4. Relative electrolyte conductivity

This trait was significantly affected by drought, soil texture, SAP, and drought  $\times$  SAP interaction (Tables 2 and 3). The highest and lowest amounts of REC were assigned to evaporation levels of 120 and 80 mm, respectively (Table 2). In fact, increment in drought stress resulted in increased electrolyte leakage. Maximum value of this trait

(58.46%) was recorded for clay-loam soil texture (Table 2). The effect of SAP treatment on relative electrolyte conductivity was significant at 1% probability level (Table 2). Minimum value of the trait was belonged to amount of 80 kg ha<sup>-1</sup> SAP while the maximum value of REC was obtained from SAP level of 10 kg ha<sup>-1</sup> (Table 2). The response of this trait varied at different levels of drought with different amounts of SAP (Table 3). The

amount of 80 kg.ha<sup>-1</sup> of SAP had the lowest REC value under stress condition (Evaporation levels of 100 and 120 mm). Cell membranes are sensitive to environmental stressors, including drought stress, and this can be assessed by measuring cell membrane integrity (Bajji et al., 2002). Elevated REC by increasing drought stress illustrates that an increase in membrane permeability or loss of membrane stability may lead to solute leakage enhancing. A hypothesis for the electrolytes release is that

the release is mainly due to dead cells. Leaving the cell electrolytes can be occurred when the plasma membrane has lost selective permeability activity. This probably does not happen unless the cell is dead and this phenomenon occurs usually in stress condition. In the present experiment, SAP application decreased REC. These results were in agreement with the findings of Mazloom et al. (2020).

**Table 3.** Mean Comparisons of measured traits in Maize in response to drought × SAP

Drought (Evaporation level)	SAP (g kg <sup>-1</sup> soil)	Chl. a+b (mg g <sup>-1</sup> FW)	RWC (%)	REC (%)	Proline (μmol g <sup>-1</sup> FW)	CAT (mmol min <sup>-1</sup> mg <sup>-1</sup> protein)	SOD (unit mg <sup>-1</sup> protein)	APX (μmol min <sup>-1</sup> mg <sup>-1</sup> protein)
80 mm	0	1.920	84.90	44.75g <sup>■</sup>	0.228h	0.112f	83.90e	0.648g
	10	1.894	84.84	44.89g	0.197h	0.112f	82.90e	0.642g
	20	1.885	83.70	44.90g	0.171h	0.113f	83.20e	0.635g
	40	1.894	85.34	44.80g	0.149h	0.114f	83.40e	0.639g
	80	1.875	84.50	44.95g	0.130h	0.113f	82.74e	0.646g
100 mm	0	1.600	75.65	59.80de	1.638cd	0.220d	183.84b	1.830c
	10	1.614	75.00	60.84d	1.537d	0.220d	183.20b	1.785c
	20	1.614	76.05	60.05d	1.223e	0.215d	177.50b	1.720c
	40	1.745	79.94	54.84ef	0.881f	0.159e	149.90c	1.180e
	80	1.814	83.80	49.99f	0.538g	0.127f	120.00d	0.843f
120 mm	0	1.210	60.85	74.40a	3.907a	0.360a	227.55a	2.315ab
	10	1.215	60.15	73.35ab	3.808a	0.352a	226.60a	2.339a
	20	1.235	62.00	73.75ab	2.651b	0.293b	223.00a	2.200b
	40	1.435	66.10	68.75bc	1.854c	0.269c	180.50b	1.820c
	80	1.500	68.15	66.30c	1.291e	0.206d	151.85c	1.520d
L.S.	-	ns	ns	**	**	**	**	**

■ In a column, means with different letter denoted statistically difference between treatment groups according to LSD's test (P < 0.05).

L.S.: level of significance, \* P < 0.05, \*\* P < 0.01, ns: non-significant.

Chl a+b: chlorophyll a+b, P<sub>n</sub>: net photosynthesis rate, C<sub>leaf</sub>: leaf stomatal conductance, RWC: relative water content, REC: relative electrolyte conductivity, CAT: catalase, SOD: super oxide dismutase, APX: ascorbate peroxidase.

#### 4.5. Proline content

The proline content was significantly affected by drought stress levels (Table 2). Minimum value of proline ( $0.175 \mu\text{mol.g}^{-1}$  FW) was recorded for no stress condition (Evaporation levels of 80 mm) while decrease in the relative water content of soil caused to a remarkable increase in this trait (Table 2). Considering the SAP treatments, the highest and lowest value of proline assigned to amounts of 0 and  $80 \text{ kg.ha}^{-1}$  SAP, respectively (Table 2). Combined effects of drought and SAP on proline content was significant ( $P < 0.01$ ) (Table 3). Under no drought stress condition, applying  $80 \text{ kg.ha}^{-1}$  SAP had no significant effect on this trait while application of this value of SAP under drought stress condition (Evaporation levels of 100 and 120 mm) caused to decrease in proline content (Table 3). Proline is an amino acid which maintains turgor, buffers against ROS and maintains redox homeostasis to prevent dehydration of plant cells (Ashraf and Foolad, 2007). It has been reported that under drought stress condition, proline accumulation in plants more than unstressed condition (Sharma and Verslues, 2010; Abo Gamar et al., 2019; Mazloom et al., 2020). Obtained results confirm that drought stress damaged cell membranes, releasing more proline and electrolytes, and reducing the relative water content of Maize leaves (Table 2). In general, Maize grown in SAP-treated soil had less cell membrane injury (based on proline concentration and electrolyte leakage) than those in the no SAP-treated soil ( $0 \text{ kg.ha}^{-1}$ ). This suggests that there was less water limitation for Maize in the SAP-treated soil than in the other treatments, and is consistent with the Maize growth (plant height and grain yield production) in the presence of SAP. These results were in agreement with the findings of Nazari et al. (2010) and Mazloom et al. (2020).

#### 4.6. Antioxidant activity

Increasing drought stress levels caused a remarkable increase in CAT, SOD, and APX activity. The highest and lowest of CAT, SOD, and APX activity was recorded for evaporation levels of 120 and 80 mm, respectively (Table 2). SAP had a significant effect on these antioxidant enzymes of Maize (Table 2). The amount of  $80 \text{ kg.ha}^{-1}$  SAP caused a reduction in these traits compared to control (Table 2). The interaction of drought and SAP showed that the treatment of Maize with SAP led to a decrease in CAT, SOD, and APX activity. Such that, plants treated with  $80 \text{ kg.ha}^{-1}$  SAP had the lowest activity of CAT, SOD, and APX under stress conditions (Table 3). The balance of ROS in plant will be broken under drought stress condition. The antioxidant defence mechanism will be activated to prevent oxidative damage (Farooq et al., 2019). Under drought stress, Maize plants maintained

high levels of CAT, SOD and APX activity to remove ROS, which agrees with the results of Eneji et al. (2013) and Dong et al. (2019). The result showed that under normal water supply, the CAT, SOD, and APX activity did not differ between SAP levels (Table 3). This is likely because under normal water level, the balance between ROS production and its removal was maintained (Kapoor et al., 2019). Under drought conditions, SAP significantly decreased the antioxidant enzyme system (CAT, SOD, and APX activities). This showed that there was less water limitation for Maize in the SAP-treated soil than in the other treatments. Eneji et al. (2013) reported that, the super absorbent polymer decreased the activity and expression of these enzymes as an indication of stress alleviation, since the SAP conserves water in itself, thereby increasing the soil's capacity for water storage and preservation and preventing water deficiency for enhanced growth.

#### 4.7. Plant height

Soil texture had no significant effect on plant height (Table 2). The main effect of drought stress and SAP and their interaction was significant for this trait (Table 2 and figure 3). Plant height decreased with increasing drought stress levels while application of highest amount of SAP significantly improved the plant height of Maize compared with control (Fig. 3). Greater plant height at SAP level of  $80 \text{ kg.ha}^{-1}$  attributed to higher grain yield. Maize grew taller in soils treated with SAP than the no-SAP treatment. Plant height was less affected by lower levels of SAP, although the 10 and  $20 \text{ kg.ha}^{-1}$  SAP treatments produced more plant height than the no-SAP in the severe drought stress condition (Fig. 3). In a related study, Parvathy et al. (2014) observed superior plant growth in soils treated with a superabsorbent hydrogel, compared with the no-hydrogel treatment. Moreover, Islam et al. (2011) reported that application of super absorbent hydrogel increased Maize height by 11.3% in comparison with control.

#### 4.8. Grain yield

Grain yield was significantly affected by drought stress, soil texture, SAP and the interaction of drought stress and SAP (Table 2 and Fig. 4). Maximum value of this trait ( $491.8 \text{ g}$ ) was recorded for clay-loam soil texture (Table 2). Reduced grain yield caused by drought stress was improved by applying SAP treatments (Fig. 4). The highest value of grain yield under drought stress condition (evaporation levels of 100 and 120 mm) obtained when plants treated with  $80 \text{ kg.ha}^{-1}$  SAP (Fig. 4). Due to drought stress, plant height and grain yield of the plant were reduced as the total criteria of growth. The first sign of drought stress in the plants was the reduction of turgor pressure leading into the reduction of growth of cells.

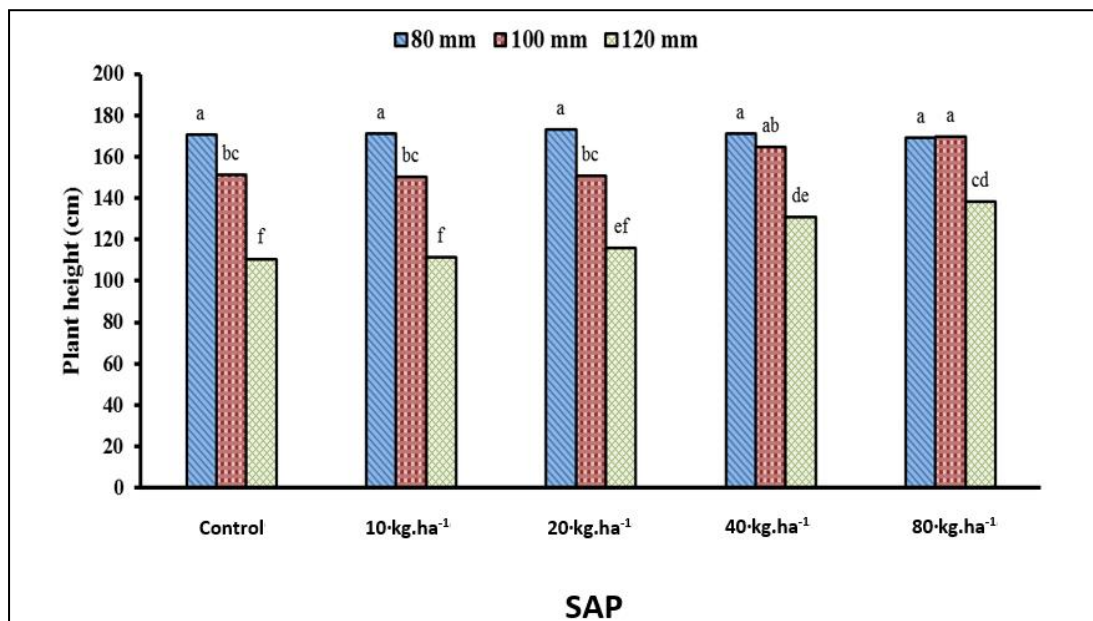


Figure 3. The combined effects of different levels of drought and SAP on the plant height of Maize. Similar letters indicate non-significant differences at 5% probability level by LSD test. SAP: Super absorbent polymers.

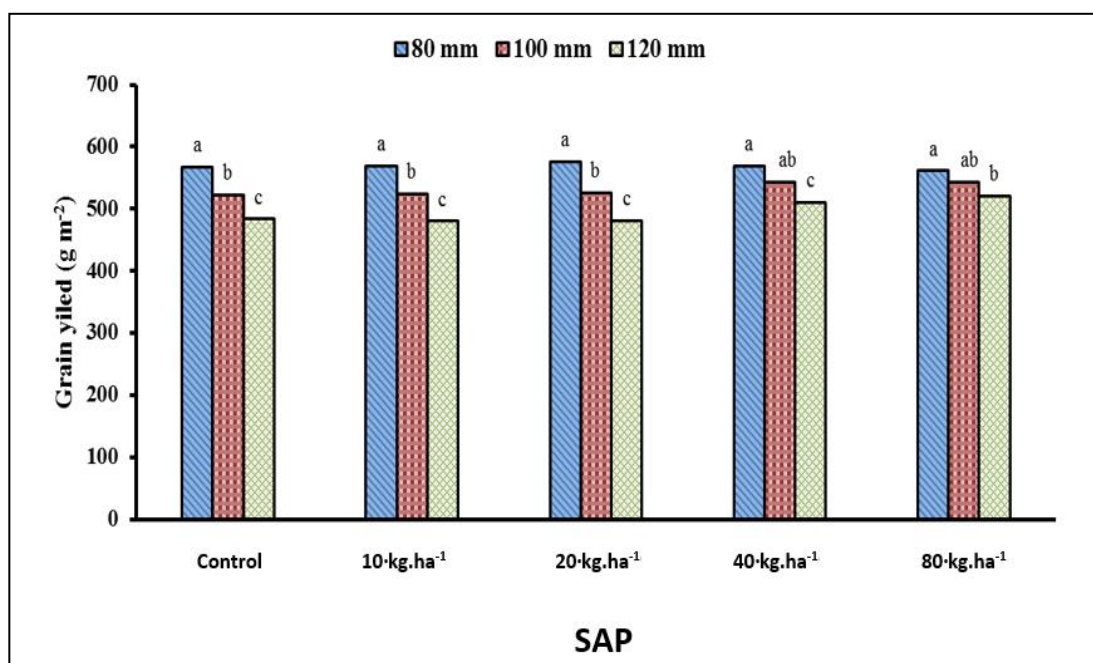


Figure 4. The combined effects of different levels of drought and SAP on the grain yield of Maize. Similar letters indicate non-significant differences at 5% probability level by LSD test. SAP: Super absorbent polymers.

The reduction of cell growth leads to the reduction of plant height and reduction of grain yield production. Thus, there was a significant relation between the reduction of cell size and reduction of water in plant tissues. By cell growth reduction the growth of leaves are reduced. By reducing leaf area, sun light absorption and photosynthesis level of the plant is reduced and it leads to the reduction in dry matter production (Hong-Bo et al., 2008). Biomass accumulation was limited by drought stress, but the SAP

treatment alleviated this effect. Under drought stress condition the highest value of plant height and grain yield was achieved when plants treated with 80 kg/ha<sup>-1</sup> SAP. The positive effect of SAP in increasing yield in the sunflower (Nazarli et al., 2010) cotton (Liang et al., 2019) and Maize (Moslemi et al., 2011; Eneji et al., 2013; Mazloom et al., 2020) was reported. It is obvious that by continuing plant growth and reduction of drought stress effects on the plant, its production is increased.

#### 4.9. Water use efficiency

The highest WUE was found in severe water stress and the lowest in full irrigation (Fig. 5). Relative to the control treatment, the moderate and severe drought conditions increased WUE on average by 5.8 and 11.7%, respectively. There is probably a physio-morphological adaptation associated with the plants need of limiting transpiration (Caparotta et al., 2019), which is assumed

to enhance the WUE. In this context, Ramezanifar et al. (2022a) reported that water stress caused a morphological adaptation in plant by reducing leaf area, so that the ratio of yield per unit of water consumption (WUE) became larger (Ramezanifar et al., 2022b). The results showed that application of highest amount of SAP under moderate (Evaporation level of 100 mm) and severe (Evaporation level of 120 mm) drought stress condition significantly improved the WUE compared with control (Fig. 5).

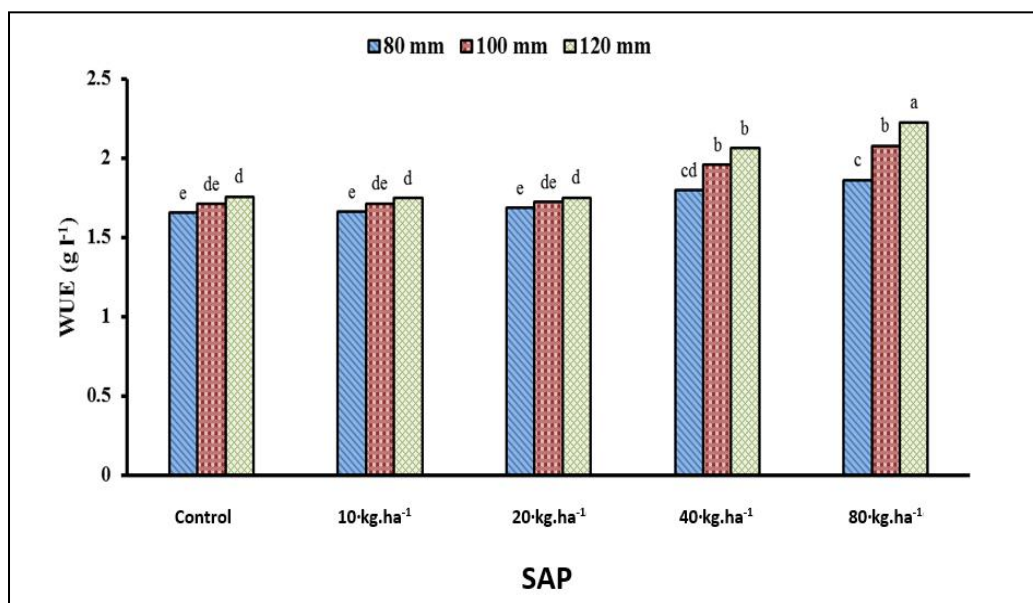


Figure 5. The combined effects of different levels of drought and SAP on the water use efficiency of Maize.

Similar letters indicate non-significant differences at 5% probability level by LSD test.

SAP: Super absorbent polymers.

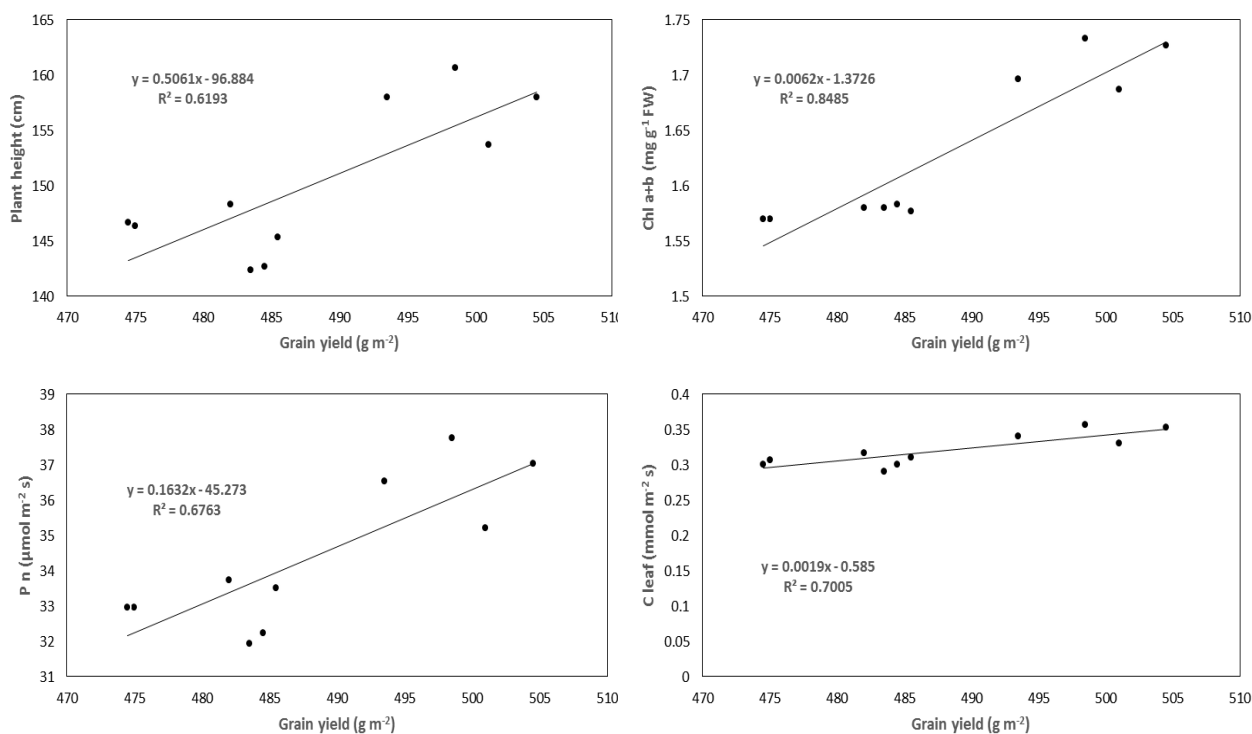
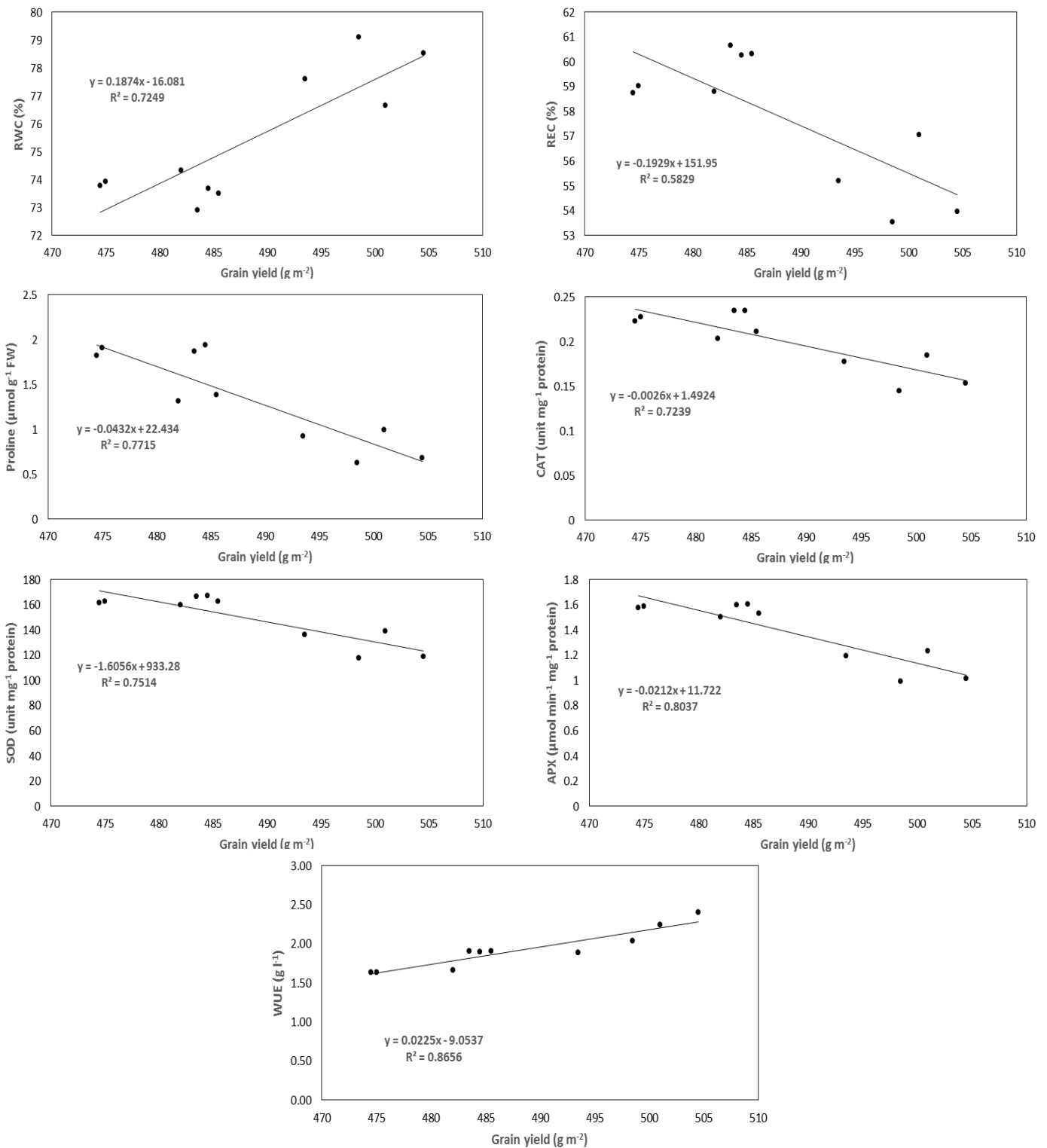


Figure 6. The linear relationships between the maize grain yield and different traits including plant height, water use efficiency (WUE), total chlorophyll content (Chl. a+b), net photosynthesis (P<sub>n</sub>), leaf stomatal conductance (C<sub>leaf</sub>), relative water content (RWC), relative electrolyte conductivity (REC), catalase (CAT), super oxide dismutase (SOD), ascorbate peroxidase (APX) and proline



**Figure 6.** The linear relationships between the maize grain yield and different traits including plant height, water use efficiency (WUE), total chlorophyll content (Chl. a+b), net photosynthesis (P<sub>n</sub>), leaf stomatal conductance (C<sub>leaf</sub>), relative water content (RWC), relative electrolyte conductivity (REC), catalase (CAT), super oxide dismutase (SOD), ascorbate peroxidase (APX) and proline.(continued)

#### 4.10. Plant traits in relation to grain yield

Fig. 6. illustrates the linear relationships between the Maize grain yield and plant traits (i.e. plant height, photosynthetic pigments, leaf gas exchange parameters, relative water content, electrolyte leakage, proline,

catalase, super oxide dismutase, and ascorbate peroxidase activity and water use efficiency). The Maize grain yield exhibited positive significant relationships with plant height, photosynthetic pigments, leaf gas exchange parameters, relative water content and water use efficiency. While the relationships between the Maize

grain yield and electrolyte leakage, proline, catalase, superoxide dismutase, and ascorbate peroxidase activity were opposite. The opposite behaviour of proline has been supported by previous studies that proline increased in response to water deficiency (Sun et al., 2014; Salek Mearaji et al., 2020). All these changes are probably physio-morphological adaptations in the plant to limit transpiration, so that WUE can be enhanced.

## 5. Conclusion

The general results of this study showed that drought caused to a significant decrease in net photosynthesis rate, leaf stomatal conductance, chlorophyll a+b, RWC, plant height, and grain yield of Maize. The moderate and severe drought conditions increased WUE on average by 5.8 and 11.7%, respectively. The maximum value of grain yield (491.8 g) was recorded for clay-loam soil texture. Applying SAP under drought condition enhanced the leaf gas exchange parameters, total chlorophyll, RWC, plant height, and grain yield. The highest and lowest Net photosynthesis rate, leaf stomatal conductance and Chl. a+b contents were related to amounts of 80 and 10 kg ha<sup>-1</sup> SAP respectively. A significant increase in leaf relative water content was observed with application of 40 and 80 kg.ha<sup>-1</sup> SAP whilst the lower amounts (10 and 20 kg.ha<sup>-1</sup> SAP) had no significant impact on the parameter in compared with control (0 kg.ha<sup>-1</sup> SAP). While initial costs may be higher, longterm benefits like reduced water consumption and improved crop yields can outweigh initial investment. Therefore, these results recommend using SAP at a dose of 80 kg.ha<sup>-1</sup> for dealing with drought conditions in the sandy and clay-loam soils.

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### Authors Contribution

All authors are equally involved.

### Conflict of interests

Authors declared no conflict of interest.

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