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Silicon Fertilization Improves the Maize (*Zea mays* L.) Performance under Limited Moisture Supply

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Field crops are subjected to numerous inconsiderate climatic hazards that negatively affect physiological processes, growth and yield. Drought is one of the major abiotic factors that limits the agricultural productivity especially in the arid and semi-arid areas of the globe. Silicon (Si) is a naturally occurring beneficial nutrient which modulates plant growth and development events and has been known to improve the crop tolerance to abiotic stresses. With the objective to investigate the role of silicon nutrition on maize hybrids under limited moisture supply, a two year field study was conducted during 2010–11 at Post Graduate Research Station (PARS), University of Agriculture Faisalabad, Pakistan. We evaluated growth of two maize hybrids P-33H25 and FH-810 under well watered (100% field capacity) and water deficit situation (60% field capacity) as affected by Si application. Silicon was added in soil @ 100 mg/kg using Calcium Silicate as source. Water deficit condition significantly reduced agro-morphological and physiological attributes of maize plants. Silicon application significantly increased the plant height, leaf area index, yield and related attributes along with improvement in photosynthetic rate, leaf water status and osmotic adjustment under limited moisture supply. It was concluded that silicon application to drought-stressed maize enhanced its growth and yield owing to improved photosynthetic rate, higher osmotic adjustment, increased water status and lowered transpiration.

Keywords: water deficit, silicon, hybrid maize, gaseous exchange, water relations, yield

Introduction

Food security is a big challenge to feed the burgeoning population of the globe. Currently, 1.02 billion people of the world suffer from hunger (FAO 2011). Meanwhile, over the next 30 to 50 years with an estimated population of 9–10 billion people, the biggest problem that arises is the food security for growing population, especially in the least developed countries (Beddington 2010). The dilemma is increased when field crops are subjected to numerous inconsiderate climatic hazards like flood, drought, extreme temperature, salinity, pollutants and heat that negatively affect physiological processes, growth and yield of crops (Boubacar 2012). Among these drought stress is one of the most dev-

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astating stressful environments for plant growth and production (Farooq et al. 2008; Peleg et al. 2011). One viable strategy of overcoming the drought-induced injurious effect on plant growth is the exogenous application of inorganic nutrients (Ashraf and Foolad 2007). By adopting this strategy, Tuna et al. (2008) have recommended the supplements of Si to plants subjected to the salt affected soils, addition of Si has been considered beneficial for improving crop tolerance to both biotic and abiotic stresses (Ahmed et al. 2011; Kojic et al. 2012). The ameliorative role of Si to adverse effects of drought has been examined in different crops e.g. sugarcane (Bokhtiar et al. 2012), rice (Chen et al. 2011), wheat (Karrou et al. 2012), tomato (Aranda et al. 2006), cowpea (Mali and Aery 2008), sorghum (Ahmed et al. 2011) and soybean (Hamayun et al. 2010). Plants deprived of Si often show poor development and reproduction, but it depends on the type of plant species. In general, plants belonging to family Gramineae accumulate much more silicon than that by other species belonging to other families. It has also been reported that most dicot plants absorb Si passively but monocots can efficiently exclude Si from their roots (Kurdali and Al-Shammaa 2010; Chen et al. 2011).

Different mechanisms are reported to induce drought tolerance in plants through silicon treatment including increased water status of plants (Kurdali et al. 2013), improved photosynthetic efficiency (Chen et al. 2011), osmoregulation or osmotic adjustment (Sacala 2009; Ahmad and Haddad 2011), maintenance of photosynthetic apparatus and pigments (Hamayun et al. 2010; Chutipaijit et al. 2012), up-regulation of plant defense system (Ahmed et al. 2013), and lowered transpiration rate (Kurdali et al. 2013).

Therefore, Si application to crops can be an efficient and viable management practice to improve production potential and to enable plants to withstand water deficit conditions. We hypothesize that exogenous application of Si under water deficit condition may substantially improve the maize water status, photosynthetic rate and yield. Keeping in view the above facts, an experiment was conducted to explore the role of Si application in order to alleviate the drought stress in maize hybrids.

Materials and Methods

The research was conducted at Postgraduate Agricultural Research Station, University of Agriculture Faisalabad, Pakistan. The station is located between longitude 73°74 East, latitude 30°31.5 North, with an elevation of 184 meters above sea level. This area is located in the Indus plain among the Indus river tributaries. The soil was taken from the field and soil samples were sent to soil testing laboratory for analysis. The experimental soil texture was sandy loam with pH 8.1, total exchangeable salts 0.29 dS m^{-1}, 0.81% of organic matter, total nitrogen 0.049%, available phosphorus 8 ppm, exchangeable potassium 110 ppm and extractable silicon 30 ppm. The design of experiment was randomized complete block (RCBD) with split-split arrangement randomizing the maize hybrids (P-33H25 and FH-810) in main plots, irrigation levels (100% and 60% field capacity) in sub plots and silicon application (0 and 100 mg/kg of soil) in sub-sub plot with three replications. The field was well prepared by ploughing and followed by planking. The ridges were made with the help of tractor mounted ridger at 75 cm apart from each other.

The crop was sown on August 5 and August 7 during the years 2010 and 2011, respectively. A fertilizer dose of 250 kg N + 125 kg P_2O_5 and 125 kg K_2O ha^{-1} was applied. All the P, K and 1/3 of N fertilizer were applied before sowing while remaining N was applied in two splits. The drought was imposed one month after germination by maintaining 60% FC after. A flume was installed at the start of field water channel to measure the quantity of water. The measured quantity of water was applied to control plot (100% field capacity) and drought stressed plots (60% field capacity) to maintain the required field capacity level with the help of cut throat flume. The crop was kept free of weeds and pests by following suitable plant protection measures. The crop was harvested at its physiological maturity. There was soil application of silicon (100 mg/kg) in the form of calcium silicate after dissolving it in KOH at 71 °C (Ali et al. 2009). Harvesting was done at physiological maturity of crop. The daily average weather data on month basis for study period is given in Table 1.

Table 1. Month wise daily average weather data for the study period

Months	Rainfall (mm)		Temperature (°C)		R. Humidity (%)		Potential ET (mm)	
	2010	2011	2010	2011	2010	2011	2010	2011
August	7.31	2.99	30.5	29.8	74.6	74.7	3.4	3.1
September	2.88	5.17	28.6	28.3	66.8	75.8	3.4	2.8
October	0	0.01	26.3	24.7	59.6	61.0	3.0	3.3
November	0	0	18.8	20.5	62.3	61.2	2.1	1.8

Determination of irrigation levels at field

Gravimetric procedure of direct soil water measurement was applied to determine the water content in the soil. Soil sampling for soil moisture measurement was carried out regularly on alternate days keeping in view the weather conditions. Composite soil samples at the depth intervals of 30 cm up to 100 cm were taken on taking into consideration of maize growth stage from randomly located sites in each plot for moisture determination, as the maximum moisture extraction depth of root zone of maize crop was taken as 100 cm (Nachabe 1998).

Depth of irrigation water

Irrigation was applied to the respective plots as soon as the desired available soil moisture depletion level reached in the soil of crop root zone. Depth of irrigation for each field capacity level was predetermined by adopting the direct measurement or field sampling method of crop water requirement as reported by Majumdar (2002) and Tariq and Usman (2009):

$$d = \frac{\left(F_c - M_b\right)\left(Bd\right) D}{100}$$

Here

- d = Depth of water to be applied in (cm)
- D = Depth of root zone (cm)
- F_c = Moisture content at field capacity as per treatment (100% or 60% field capacity) in percent by weight
- Bd = Bulk density of soil g/cm^3
- M_b = water content in soil before irrigation in percent by weight

Discharge of water applied to each treatment was determined with the help of a cut throat flume (3'×8"). The time required to supply the required depth of irrigation water to each plot was calculated according to following equation (Rafiq 2001):

$$t = \frac{d \times a}{q}$$

Where

- t = time in hours
- d = depth of water in inches
- a = area in acres
- q = discharge of irrigation water in ft^3/s.

Agronomic attributes

Following agronomic attributes were recorded in this study like plant height, leaf area index, and cob length, number of grains per cob, 100-grain weight, grain yield and biological yield per plant.

Water relation parameters

Relative water content (%)

To determine relative water content the third uppermost fully expanded youngest leaf from two plants of each treatment was taken. The leaves were quickly transferred to laboratory by sealing in plastic bags after cutting from the base of lamina. Leaf fresh weight (LFW) was obtained within one and half hour after removal of leaves from plants. After that leaves were soaked for 16–18 hours at room temperature 25±2 °C and then leaves blotted dry carefully with the help of tissue paper to determine the leaf turgid weight (LTW). The leaf dry weight (LDW) was found after drying the samples of leaves in an oven at 70 °C for 72 hours. Relative leaf water content (RLWC) was calculated from the formula proposed by Turner (1986) and then averaged.

$$\text{RLWC (\%)} = (\text{LFW} - \text{LDW})/(\text{LTW} - \text{LDW}) \times 100$$

Where
RLWC = relative leaf water content,
LFW = fresh weight of leaf,
LDW = dry weight of leaf,
LTW = turgid weight of leaf.

Leaf water potential (MPa)

From top of plants the third youngest fully expanded leaf from each treatment was excised in the morning time (6:00 a.m.–8:00 a.m.) to avoid evapotranspiration. Water potential apparatus, using the method proposed by Scholander et al. (1964) was used for determination of leaf water potential. The leaf (third fully expanded youngest leaf) was sealed in the pressure chamber in such a way that the cut surface protruding out of the hole then pressure was applied from a cylinder of compressed gas to the leaf until sap from xylem appeared at the surface of cut.

Leaf osmotic Potential (MPa)

To determine leaf osmotic potential same leaf sample as for determination of water potential was used. Sample was frozen for more than 7 days in a freezer at below –20 °C, after that leaf was thawed and then leaf sap was extracted by pressing leaf sample with the use of glass rod. The osmotic potential was determined by vapor pressure osmometer using the leaf sap directly (Nobel 1983).

Gas exchange observation

The various leaf gas exchange parameters (Photosynthetic rate (μmol/m^2/s) and Transpiration rate (mmol/m^2/s) were estimated with the help of an open system LCA-4 ADC portable infrared gas analyzer (Analytical Development Company, Hoddeson, England). Observations were made on 3^{rd} leaf from the top of plant that was fully expanded and youngest in the morning time from 8:00 a.m. to 10:00 a.m. The following adjustments were carried out to take observations: leaf chamber temperature varied from 25–28 °C, surface area of leaf 6.25 cm^2, ambient CO_2 concentration was 371 μmol mol^{-1}, ambient pressure in chamber was 97.95 kPa, Photosynthetically active radiations (PAR) at the surface of leaf were maximum up to 770 μmol/m^2/s, leaf chamber volume gas flow rate was 296 mL min^{-1} and molar gas flow rate into chamber was 400 μmol/s.

Statistical analysis

Data collected were analyzed statistically using Fisher' analysis of variance technique. Difference among the treatments means was compared using least significant difference test at 5% probability level (Steel et al. 1997) using the MSTAT C computer software.

Results

Crop growth and yield attributes

Water deficit significantly reduced the plant height in both maize hybrids during either of the study years (autumn 2010 or 2011). There was a reduction of 27.83 and 41.40% in maize cultivars P-33H25 and FH-810, respectively in first year while a decrease of 23.96 and 35.50% was observed in maize genotypes P-33H25 and FH-810, respectively during autumn 2011. However, silicon fertilization promoted the plant height under well watered and deficit condition. The results from the Table 2 showed that under water deficit longer plants were observed where silicon was applied in both maize hybrids while minimum plant height 99.94 and 118.81 cm during 2010 and 2011, respectively was observed in maize hybrid FH-810 without silicon application under water deficit situation (Table 2).

The perusal of the Table 3 showed that drought stress significantly reduced the leaf area index in both maize hybrids. Maximum reduction of 35.71 and 40.49% was observed in maize hybrid FH-810 during 2010 and 2011, respectively. However, hybrid P-33H25 showed a decrease of 27.01 and 26.55% in leaf area index during 2010 and 2011, respectively. Silicon nutrition under drought condition was found to have significant positive effect on this attribute in maize hybrids during both years of study. However, maximum leaf area index was recorded in maize hybrid P-33H25 where silicon was used under well watered condition (100% FC) during both years of study (Table 3).

Table 2. Influence of silicon on plant height (cm) of maize hybrids grown under water deficit

Hybrids	Moisture levels	2010		2011	
		Si 0 mg/kg	Si 100 mg/kg	Si 0 mg/kg	Si 10 mg/kg
P-33H25	WW	178.50b	194.68a	182.14c	206.92a
	WD	128.83d	141.79c	138.50e	164.70d
FH-810	WW	170.56b	177.32b	184.19c	196.45b
	WD	99.94e	123.59d	118.81f	157.29d

LSD (H × D × Si) = 10.20; LSD (H × D × Si) = 8.74.

Table 3. Influence of silicon on leaf area index of maize hybrids grown under water deficit in autumn season

Hybrids	Moisture levels	2010		2011	
		Si 0 mg/kg	Si 100 mg/kg	Si 0 mg/kg	Si 10 mg/kg
P-33H25	WW	3.85b	4.40a	4.67b	5.10a
	WD	2.81f	3.36d	3.43c	3.68c
FH-810	WW	3.78c	4.03bc	4.52b	4.70b
	WD	2.43g	3.10e	2.69d	3.44c

LSD (H × D × Si) = 0.18; LSD (H × D × Si) = 0.34.

Yield and related attributes of maize hybrids were also drastically affected by water deficit stress while higher cob length, cob girth, number of grains per cob, biological and grain yield was recorded for plants that were fertilized with silicon under both well watered and water deficit condition (Tables 4–8). However, more silicon based improvement in above mentioned parameters was noticed where silicon was added to plants of maize that were grown under limited moisture (60% FC) supply during both of the study years. Nonetheless, more number of grains per cob, biological and grain yield was recorded during the second year of study i.e. 2011 (Tables 6–8). There was a greater reduction in grain yield in hybrid FH-810 under drought condition (60% FC) than P-33H25

Table 4. Influence of silicon on cob length (cm) of maize hybrids grown under water deficit in autumn season

Hybrids	Moisture levels	2010		2011	
		Si 0 mg/kg	Si 100 mg/kg	Si 0 mg/kg	Si 100 mg/kg
P-33H25	WW	15.58^{NS}	16.59	16.84bc	18.60a
	WD	11.18	12.55	13.02f	15.10d
FH-810	WW	15.51	16.15	16.40c	17.33b
	WD	11.17	11.33	11.20g	13.87e

LSD (H × D × Si) = 0.59.

Table 5. Influence of silicon on cob diameter (cm) of maize hybrids grown under water deficit in autumn season

Hybrids	Moisture levels	2010		2011	
		Si 0 mg/kg	Si 100 mg/kg	Si 0 mg/kg	Si 100 mg/kg
P-33H25	WW	4.47b	5.75a	4.11^{NS}	4.55
	WD	2.74e	3.39d	3.10	3.55
FH-810	WW	3.99c	4.49b	4.09	4.38
	WD	2.56e	3.52cd	3.07	3.33

LSD (H × D × Si) = 0.47.

Table 6. Influence of silicon on number of grains per cob of maize hybrids grown under water deficit in autumn season

Hybrids	Moisture levels	2010		2011	
		Si 0 mg/kg	Si 100 mg/kg	Si 0 mg/kg	Si 100 mg/kg
P-33H25	WW	323.99b	355.04a	336.22b	389.19a
	WD	228.67d	253.55c	262.48de	285.78c
FH-810	WW	308.76b	326.34b	315.21b	336.72b
	WD	173.20e	234.87cd	240.40e	284.81cd

LSD (H × D × Si) = 23.44; LSD (H × D × Si) = 22.48.

Table 7. Influence of silicon on biological yield per ha-1 (t) of maize hybrids grown under water deficit in autumn season

Hybrids	Moisture levels	2010		2011	
		Si 0 mg/kg	Si 100 mg/kg	Si 0 mg/kg	Si 100 mg/kg
P-33H25	WW	12.01c	13.19a	14.19b	15.32a
	WD	9.91e	10.91d	11.42c	12.16c
FH-810	WW	12.11bc	12.68ab	13.97b	14.43b
	WD	8.74f	10.48de	9.84d	11.92c

LSD (H × D × Si) = 0.60; LSD (H × D × Si) = 0.76.

Table 8. Influence of silicon on grain yield per ha-1 (t) of maize hybrids grown under water deficit in autumn season

Hybrids	Moisture levels	2010		2011	
		Si 0 mg/kg	Si 100 mg/kg	Si 0 mg/kg	Si 100 mg/kg
P-33H25	WW	4.55c	5.42a	5.61bc	6.40a
	WD	3.23f	3.98d	4.09f	4.90d
FH-810	WW	4.53c	4.92b	5.50c	5.87b
	WD	2.69g	3.63e	3.54g	4.51e

LSD (H × D × Si) = 0.18; LSD (H × D × Si) = 0.26.

Means not sharing the same letter differ significantly from one another at 5% probability level; Si = silicon, WW = well-watered, WD = water-deficit.

during both years of study (autumn 2010 and 2011). However, silicon application proved to be beneficial for both maize hybrids (P-33H25 and FH-810) under either of the moisture regime (100% FC or 60% FC) during both years of study. Maximum grain yield was recorded in hybrid P-33H25 with silicon addition under well watered condition while lower was exhibited by hybrid FH-810 under water deficit (60% FC) without silicon nutrition during first year of study and similar trend was observed in second year of experimentation (Tables 4–8).

Gas exchange parameters

Silicon nutrition proved to be advantageous for improving photosynthetic rate under water deficit (60% FC) for maize cultivars P-33H25 and FH-810. Silicon fertilized plants of hybrid P-33H25 also responded well under well watered condition (100% FC) during both years (autumn 2010 or 2011). Hybrid FH-810 also showed significant increase in photosynthetic rate during the course of study. Silicon fed plants of both hybrids under water deficit condition (60% FC) showed more photosynthetic rate as compared to plants that were grown without silicon application during both years of study. Water deficit condition significantly reduced the transpiration rate in both maize hybrids during 2010 and 2011. Higher transpiration rate was recorded where silicon was not added to plants of both maize hybrids under well watered condition or drought condition. However, more transpiration rate was observed in plants that were grown with optimal moisture without silicon application (Fig. 2).

Water relation parameters

The results given in Fig. 1 illustrated that relative water content decreased when maize cultivars P-33H25 and FH-810 were exposed to water deficit condition. However, silicon fed plants of both maize hybrids showed greater relative water content under well watered or drought stressed condition. However, well watered silicon fed plants of maize hybrid P-33H25, possessed more relative water content over FH-810 under similar environment during both years (autumn 2010 and 2011). However, maximum relative water content

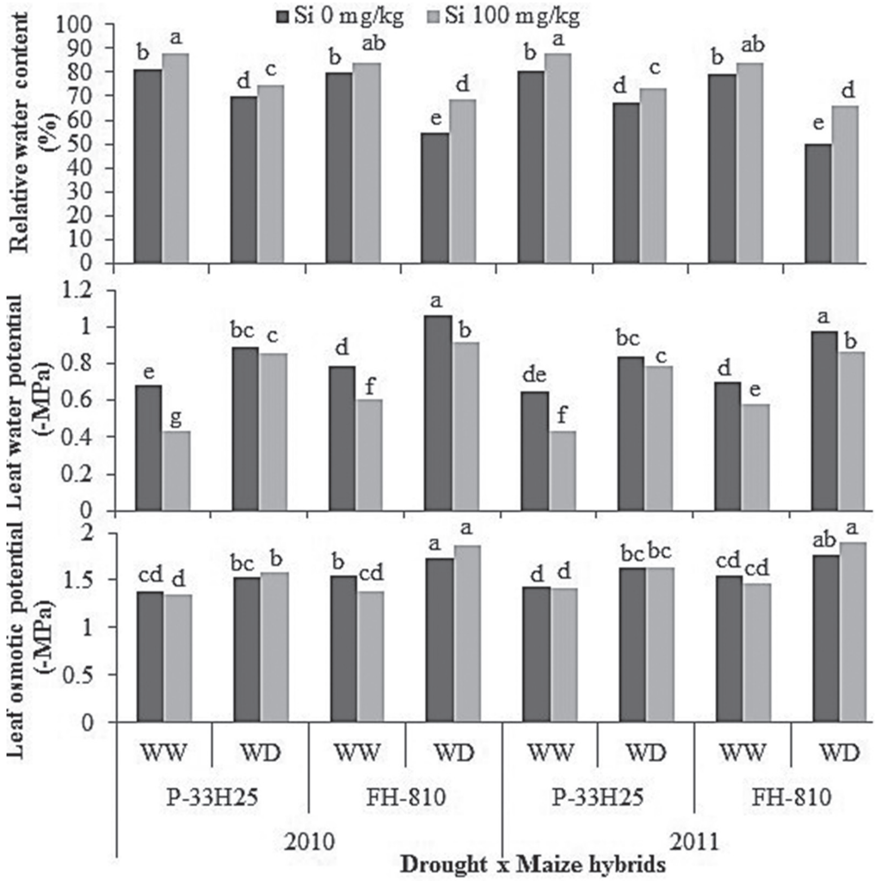

Figure 1. Effect of silicon on the water relation of maize hybrids grown under water deficit conditions. Si = silicon; WW = well watered; WD = water deficit

was maintained by silicon fertilized plants of hybrid P-33H25 under well watered condition (100% FC). Nonetheless, the minimum relative water content was exhibited by drought stressed plants (without silicon) of maize cultivar FH-810 during both years of experimentation (autumn 2010 or 2011), throughout the growing period. Water deficit condition (60% field capacity) caused a significant reduction (more negative) in leaf water potential of both maize hybrids (Fig. 1). There was more reduction in leaf water potential of hybrid FH-810 over P-33H25 under drought condition (60% FC) during both years (autumn 2010 and 2011). Silicon fed plants of both maize hybrids had more (less negative) leaf water potential under either of the moisture regime (100% or 60% FC) during both years. However, more leaf water potential was recorded in silicon-mediated plants of hybrid P-33H25 under well watered situation (100% FC) during both years. The minimum leaf water potential was recorded in drought stressed plants of maize genotype FH-810 where silicon was not applied during both years. Drought had an influence on the osmotic potential (more negative) in both maize cultivars under study during the course of study i.e. autumn 2010 and 2011 (Fig. 1). Silicon fed water-stressed plants of maize cultivars lowered their osmotic potential while silicon-treated well watered plants improved their osmotic potential.

Discussion

The present research study was aimed to improve the performance of hybrid maize by silicon fertilization under limited moisture supply in field condition. Normally, the deleterious effect of drought is eliminated through silicon nutrition by inducing several physiological changes e.g. osmotic adjustment (Ahmad and Haddad 2011), improved photosynthetic rate (Ahmed et al. 2011; Kurdali et al. 2013), maintenance of photosynthetic pigments and apparatus (Chutipaijit et al., 2012), increased water status of plants (Ahmed et al. 2013), decrease decomposition of chlorophyll (Kurdali et al. 2013), lowered transpiration rate (Ahmed et al. 2013), improved nutrient use efficiency (Miao et al. 2010) and up-regulation of plant defense system (Sacala 2009; Milne et al., 2012) and finally increased yield (Hakim et al. 2012) in plants facing water deficit. A significant improvement in shoot length, and leaf area index with silicon fertilization reveals that it was beneficial to enhance the growth of maize hybrids under drought stress (Tables 3 and 4). Likewise, Hamayun et al. (2010) reported that adverse effects of NaCl and PEG on plant growth were alleviated by adding 100 mg/kg and 200 mg/kg Si to salt and drought stressed plants of soybean. They observed 14.18%, 15.25% and 13.09% increase in shoot length, shoot dry weight and chlorophyll content, respectively of silicon fed drought-stressed plants of soybean than drought-stressed plants that were grown without silicon addition. Silicon-mediated increase in growth of water deficit stressed plants may be due to the important role of silicon in the promotion of water status of stressed plants (Ahmed et al. 2013) that might be the reason of lowered transpiration (Gao et al. 2006). Nonetheless, increase in the photosynthetic rate in silicon-fertilized drought-stressed plants may improve the growth (Ahmed et al. 2013).

Water deficit significantly affected the leaf water potential and osmotic potential in maize genotypes during the study period (Fig. 1). Nonetheless, silicon nutrition maintained higher water potential, lowered osmotic potential and improved relative water content that showed improved drought tolerance in Si-treated maize compared to plants that were grown without silicon under limited moisture supply. Improved performance of drought-stressed plants may be contributed to Si nutrition that causes osmotic adjustment through maintaining the turgor pressure at low water potential (Sonobe et al. 2011; Ahmed et al. 2013). Exogenous silicon application considerably improved the relative water content (Fig. 1) under both well watered and water deficit condition. Silicon fertilized drought stressed plants of soybean maintained 29.53% higher relative water content than deprived drought stressed seedlings (Shen et al. 2010). The enhanced ability of drought stressed silicon treated plants might be related to decrease in transpiration rate because of silicon deposition beneath the cutical (Sacala 2009; Kurdali et al. 2013).

It is generally known that the reduced rate of photosynthesis resulted in reduced plant growth in most plants. In this study, the imposition of drought significantly reduced the efficiency of photosynthesis with a concomitant decrease in transpiration. However, exogenously applied Si significantly enhanced photosynthetic rate while lowered the transpiration rate during both years (Fig. 2). Shen et al. (2010) investigated that Si addition under well-watered condition resulted in an increase of 5.97% photosynthetic rate while Si mediated drought stressed (–0.5 MPa, simulated with 20% polyethylene glycol) plants maintained 20.99% higher photosynthetic rate than Si deprived water stressed plants. The

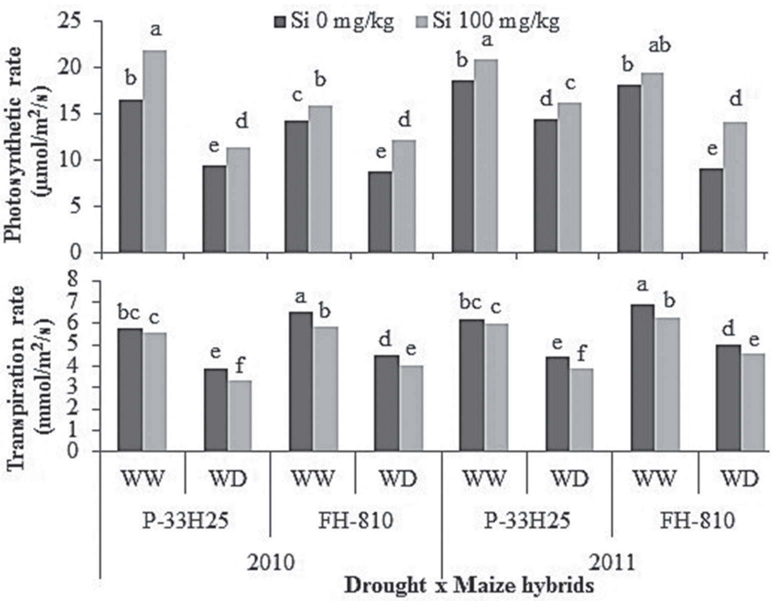

Figure 2. Effect of silicon on the photosynthetic rate and transpiration rate of maize hybrids grown under water deficit conditions. Si = silicon; WW = well watered; WD = water deficit

improvement in photosynthesis might be related to ameliorative effect of silicon on plants under water stress that deposited as colloidal silica gel (SiO_2) in the xylem vessels and cell walls of leaves. So, decreases the bypass flow of transpired water that crosses the root cells towards the xylem vessels and provides a barrier to cuticular transpiration (Savvas et al. 2009). Such effects of Si increase the relative water content of plant tissues so hold leaves erect and strengthening the stem to prevent lodging that results in improved accommodation of light in plant community thus improving photosynthesis (Abdalla 2009). The silicon based increase in the photosynthesis of drought stressed plants under drought might also be associated with the increase in activities of photosynthetic enzymes.

Silicon nutrition seemed to be effective for improving cob length, cob diameter, number of grains per cob, biological and grain yield under water stress conditions (Tables 4–8). Drought stress condition significantly reduced the growth and development but Si supplement maintained the increase in yield and related attributes in maize. Ali et al. (2012) reported that silicon application of 150 mg/kg to salinity induced (12 dS/m) plants of wheat variety SARC-5 significantly improved several plant characteristics like plant height (9.19%), spike length (24.28%), number of grains per spike (20.75%), 100-grain weight (10.24%), biological yield (22.94%) and grain yield (30.96%), and harvest index (7.69%). In fact, negative effects of drought stress on maize plants are minimized by Si nutrition through its positive role in maintaining water status of plants (Chen et al. 2011), photosynthetic efficiency (Zuccarini 2008), photosynthetic apparatus and pigments (Chutipaijit et al. 2012), ultra-structure of leaf organelles (Shu and Liu 2001), osmotic adjustment (Ahmad and Haddad 2011), plant defense system (Milne et al. 2012) and lowering transpiration (Zou et al. 2005).

In conclusion, silicon nutrition significantly improved the growth and yield of hybrid maize and was also useful in minimizing the negative effects of water deficit stress by improving the photosynthetic rate, lowering the transpiration rate and maintaining the leaf water status.

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