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SILICON INDUCED IMPROVEMENT IN MORPHO-PHYSIOLOGICAL TRAITS OF MAIZE (*Zea Mays* L.) UNDER WATER DEFICIT

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Current water scarcity is an emerging issue in semi-arid regions like Pakistan and cause of deterioration in productivity of crops to reduce crop yield all over the world. Silicon is known to be better against the deleterious effects of drought on plant growth and development. A pot study was conducted to evaluate the effect of Si nutrition (0, 50, 100 and 150 mg/kg) on the growth of a relatively drought tolerant (P-33H25) and sensitive (FH-810) maize hybrids. Two levels of soil water content were used viz. 100 and 60% of field capacity. Water deficit condition in soil significantly reduced morphological and physiological attributes of maize plants. Silicon application significantly improved the plant height, leaf area per plant, primary root length, dry matter of shoot and roots and plant dry matter, water relation and gas exchange characteristics of both maize cultivars under water deficit condition. Poor growth of drought stressed plants was significantly improved with Si application. The silicon fertilized (100 mg/kg) drought stressed plants of hybrid P-33H25 produced maximum (21.68% more) plant dry matter as compared to plants that were not provided with silicon nutrition. Nonetheless, silicon application (150 mg/kg) resulted in maximum increase (26.03%) in plant dry weight of hybrid FH-810 plants that were grown under limited moisture supply i.e., 60% FC. In conclusion silicon application to drought stressed maize plants was better to improve the growth and dry matter could be attributed to improved osmotic adjustment, photosynthetic rate and lowered transpiration.
Keywords: Drought, silicon, maize hybrids, water relation, gas exchange

INTRODUCTION

Water scarcity is the first and foremost challenging issue because of the absolute water shortage in several regions of the world (Fitter, 2012), like Pakistan (Kugelman and Hathaway, 2009; New York: Asia Society, 2009). So, to cope with this situation it is the dire need of the day to conserve water and use various strategies that can improve drought tolerance in crops under water deficit or rain fed circumstances (Zwart and Bastiaanssen, 2004; Farre and Faci, 2006).

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) recommended the use of Si for plants grown under salt affected soils, addition of Si has been considered beneficial for improving crop tolerance to abiotic stresses including water deficit (Epstein, 2009; Kojic *et al*., 2012). The ameliorative role of Si to adverse effects of drought has been examined in different crops e.g., rice (Hakim *et al*., 2012), sugarcane (Bokhtiar *et al*., 2012), wheat (Tahir *et al*., 2006), tomato (Romero-Aranda *et al*., 2006), sorghum (Ahmed *et al*., 2011) and soybean (Shen *et al*., 2010).

Different mechanisms are reported to induce drought tolerance in plants through silicon treatment (Liang *et al*., 2007) including increased water status of plants (Romero-Aranda *et al*., 2006), improved photosynthetic efficiency (Yong, 2007; Zuccarini, 2008), osmotic adjustment (Sonobe *et al*., 2010; Ahmad and Haddad, 2011), maintenance of photosynthetic apparatus and pigments (Kaya *et al*., 2006; Chutipaijit *et al*., 2012), changes in ultra-structure of leaf organelles (Shu and Liu, 2001), up-regulation of plant defense system (Al-Aghabary *et al*., 2004; Zhu *et al*., 2004; Milne *et al*., 2012), lowered transpiration rate (Zou *et al*., 2005) and enhanced K^+ uptake (Kaya *et al*., 2006). Maize growth is affected by intercropping (Shave *et al*., 2012), microbial (Zahir *et al*., 2012) and fertilizer application (Iqbal *et al*., 2012).

Certain cereal crops especially from the Poaceae and Cyperaceae families accumulate large amount of Si (Mitani and Ma, 2005), and its application to these crops ensured better growth. Being a member of Poaceae family, maize is also considered as Si accumulator. The hypothesis was whether the increased drought resistance by Si is mediated via the improved osmotic adjustment, photosynthetic rate and lowered transpiration in drought-stressed maize plants. Hence the purpose of this study was to provide additional information on exogenous application of Si and its ability to counteract drought inhibitory effects in maize at seedling stage.

MATERIALS AND METHODS

A pot experiment was conducted from mid-February to mid-March 2010 using two maize hybrids drought tolerant and sensitive i.e. P-33H25 and FH-810, respectively (Farhad *et al*., 2011) at Post Graduate Research Station (PARS), University of Agriculture Faisalabad, Pakistan. The completely randomized design (CRD) with factorial arrangement with three replications was used in the current study. Earthen pots (21 cm diameter and 25 cm depth) containing 10 kg of sandy clay loam soil were used. At 100% field capacity there were 21.50% moisture contents while at 60% FC there were 12.90% and after 30% depletion in 60% FC there were 9% moisture contents where plants continued their growth. The physico-chemical properties of soil used in the experiment are given in Table 1. Six seeds were initially planted in a pot but later thinned to keep two vigorous seedlings in a pot and plants were then grown for further two and half week under net house conditions at day/night average temperatures of $25^oC/15^oC$, maximum/minimum temperature of $30^oC/10^oC$, and an ambient sun light. In each pot recommended fertilizer dose @ 1.25g N + 0.625 g P_2O_5 and 0.625 g K_2O/pot was applied. All the P, K and 1/3 of N fertilizer were added before sowing while remaining N was applied in two splits i.e., five and ten days after germination. There were four silicon levels (0, 50, 100 and 150 mg/kg). Silicon was applied in the soil before sowing. Calcium Silicate was used as source of silicon.

Table 1. Physico-chemical properties of soil used in the experiment

S.No.	Soil characteristics	Unit	Value
1	Soil Textural Class	-----	Sandy clay loam
I	Sand	(%)	57
Ii	Silt	(%)	20
Iii	Clay	(%)	23
2	Field capacity	(%)	21.50%
3	pH	------	8.11
4	EC	(dSm^{-1})	0.73
5	O.M	(%)	0.93
6	$CaCO_3$	(%)	2.11
7	P(available)	(ppm)	7.82
8	K(extractable)	(ppm)	174.60
9	Si(extractable)	(ppm)	30

Maize seedlings were irrigated fully (field capacity) for a week to develop root growth before imposing the water deficit. There were two levels of moisture regimes, viz. D_1- well watered throughout the growing period in which plants were watered according to moisture contents at 100% FC (Field capacity) and D_2- water deficit (60% of field capacity). After 10 days of sowing, field capacity of each pot was maintained as per treatments. Soil moisture percentage of each pot was measured on daily basis with the help of soil moisture meter (Delta-T device, Cambridge, UK). Each time pots were irrigated to maintain field capacity with 30% decline in moisture contents of each moisture level. The water deficit was imposed for 14 days (10- 24 DAS). The plants were harvested at 24 DAS.

***Determination of field capacity*:** The field capacity was determined on gravimetric basis (Nachabe, 1998). For determination of field capacity three samples of 200 gm each of the soil used in the experiments were taken at the time of filling the earthen pots (24.6 cm diameter and 28 cm deep). These samples were then incubated at 105 ^0C for 24 hours and oven dried samples were weighed and averaged for determination of total moisture content of the soil at the time of seed sowing. Then the saturation percentage of three samples of 100 gm each of this oven dried soil was approximated by measuring and then averaging the distilled water used in making completely saturated paste of three samples. The field capacity was determined by using the following formula:

Field capacity **=** Saturation percentage/2

For pot experiments field capacity of each pot was maintained as per treatment. Soil moisture percentage of each pot was measured on daily basis with the help of soil moisture meter. Each time pots were irrigated to maintain field capacity level. This procedure was carried out up to assessment of seedlings.

***Morphological observations*:** Observations on morphological attributes like plant height, leaf area per plant, primary root length, dry matter of shoot and roots, and plant dry matter were recorded.

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^oC 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^oC for 72 hours. Relative leaf water content (RLWC) was calculated from the formula proposed by Turner (1986) and then averaged.

RLWC (%) = (LFW-LDW)/ (LTW-LDW) x100

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. to 8:00 a.m.) to avoid evapotraspiration. 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^oC, 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 vapour pressure osmometer using the leaf sap directly (Nobel, 1983).

Leaf turgor potential (MPa)**:** The leaf turgor potential (Ψp) was calculated by subtracting osmotic potential (ψs) from water potential (ψw), (Kramer, 1983):-

$$\Psi p = \Psi w - \Psi s$$

Gas exchange attributes**:** The various leaf gas exchange parameters i.e. transpiration rate (mmol/m^2/s) and photosynthetic rate (µmol/m^2 /s) were estimated with the help of an infrared gas analyzer (Analytical Development Company, Hoddesdon, England) from top of 3rd leaf of each plant. This kind of measurements were done from 8.00 a.m. to 10.30a.m. with the following type of adjustments such as; leaf surface area 11.35 cm^2, ambient CO_2 concentration 342.12 micromole mol^{-1}, leaf chamber temperature varies from 36.2 to 42.9 ^oC, gas flow rate of leaf chamber volume 396 mL min^{-1}, molar gas flow rate of leaf chamber 251 µmole s^{-1}, ambient pressure 99.95 KPa, molar flow of air per unit of area of leaf 221.06 mol m^{-2} s^{-1}, PAR on the leaf surface was highest up to 1030 micromole m^{-2} s^{-1}.

Statistical analysis**:** Data collected were analyzed statistically using Fisher' analysis of variance techniques. Difference among the treatments mean was compared by employing Least Significant Difference (LSD) test at probability level of 5% (Steel *et al.*, 1997).

RESULTS

Growth attributes**:** The data (Table 2) represented that drought stress (60% FC) significantly reduced the growth attributes like plant height, leaf area per plant, primary root length, dry matter of root and shoot and plant dry weight due to drought-induced inhibition in growth as compared to control conditions (100% FC) in both hybrids P-33H25 (drought tolerant) and FH-810 (drought sensitive). Extent of reduction in these attributes due to moisture deficit was more in hybrid FH-810 as compared to P-33H25. There was a reduction of 23.48% and 26.70% in plant height, 21.27% and 26.33% in leaf area, 27.19% and 36. 42% in primary root length, 28.90% and 30.58% in shoot dry weight, 16.04% and 26.29% in root dry weight, 25.80% and 29.56% in plant dry weight of P-33H25 and FH-810, respectively. Exogenous application of silicon significantly boosted the growth characteristics in both hybrids under normal as well

Table 2. Effect of various silicon levels on morphological characteristics of maize hybrids under water deficit .

Hybrids	Moisture	Si (mg/kg)	PH (cm)	LA /P (cm^2)	PRL (cm)	SDW (g)	RDW (g)	PDW (g)
P-33H25	100% FC	0	44.60bc	572.36ef	23.57bc	4.04e	1.25de	5.29e
		50	46.20b	601.72d	23.79b	4.66b	1.31c	5.97b
		100	49.70a	646.86b	26.21a	4.94a	1.44a	6.38a
		150	50.43a	675.67a	26.65a	4.88a	1.43a	6.31a
	60% FC	0	34.13h	450.63k	17.16f	2.87i	1.05i	3.92j
		50	35.80g	485.71j	18.14ef	3.11h	1.06i	4.17i
		100	38.97e	547.69gh	19.96d	3.58f	1.19fg	4.77g
		150	38.03ef	546.05gh	19.46de	3.52fg	1.19fg	4.71g
FH-810	100% FC	0	42.47d	564.61fg	22.02c	3.95e	1.23ef	5.18f
		50	44.07cd	586.65de	22.96bc	4.30d	1.28cd	5.58d
		100	45.70bc	625.28c	24.07	4.47c	1.36b	5.83c
		150	45.57bc	628.11bc	23.93	4.43c	1.37b	5.80c
	60% FC	0	31.13i	415.92l	14.00h	2.74j	0.91k	3.65k
		50	33.20h	480.14j	15.58g	2.86i	0.98j	3.84j
		100	36.47fg	517.26i	18.54d-f	3.45g	1.13h	4.58h
		150	36.73fg	528.82hi	18.70d-f	3.44g	1.15gh	4.59h
LSD (5%)			1.65	19.28	1.57	0.10	0.05	0.10

Figures sharing the same letter in a column do not differ statistically at $P \leq 0.05$, FC = Field capacity, LSD = Least significant difference, PH = plant height, LA/P = leaf area per plant, PRL = primary root length, SDW = shoot dry weight, RDW = root dry weight, PDW = plant dry weight.

as water deficit situation (60% FC). However, the application of silicon @ 50, 100 and 150 mg/kg brought an improvement of 4.89%, 14.18% and 11.43%, respectively, in the height of drought affected plants of hybrid P-33H25 while FH-810 showed an increase of 6.65%, 17.15% and 17.99% in height under similar conditions of silicon nutrition and water deficit. The maize cultivar P-33H25 plants that were grown under water deficit showed maximum increase in leaf area (21.54%) with the application of 100 mg/kg of silicon while under similar growth environment there was an improvement of 24.37% (maximum) in leaf area of maize hybrid FH-810. Nonetheless, the maximum primary root length increase (16.32%) in drought induced hybrid P-33H25 was observed in those plants that were fertilized with 100 mg/kg of silicon whereas the drought affected FH-810 plants had maximum root length (33.57% increase) where silicon was applied @ 150 mg/kg. Likewise, the silicon application @ 50, 100 and 150 mg/kg showed an increase of 8.36%, 24.74% and 22.65%, respectively, in the shoot dry weight of drought affected maize genotype P-33H25 but the hybrid FH-810 showed an improvement 4.38%, 25.91% and 25.55% for 50, 100 and 150 mg/kg of silicon application, respectively, when the plants were grown under limited moisture supply (60% FC). The maximum increase (26.37%) in root dry weight of hybrid FH-810 under 60% FC was observed in silicon mediated (150 mg/kg) plants while P-33H25 showed an equal increase (13.33%) when its water deficit stressed plants were fertilized with 100 or 150 mg/kg of silicon. However, the silicon mediated (100 mg/kg) drought stressed plants of hybrid P-33H25 produced 21.68% more plant dry matter as compared to plants that were not provided with silicon nutrition. Likewise, silicon application (150 mg/kg) resulted in maximum increase (26.03%) in plant dry weight of hybrid FH-810 plants that were grown under limited moisture supply i.e. 60% FC.

***Water relation attributes*:** Leaf water potential was significantly influenced due to water deficit condition as compared to well watered situation in both maize genotypes (Fig. 1). Magnitude of reduction in leaf water potential under drought stress was more obvious in drought sensitive maize hybrid FH-810 than drought tolerant maize genotype P-33H25. However, silicon application significantly modified the leaf water potential in both maize hybrids under control (100% FC) and water deficit environment (60% FC). Significantly higher leaf water potential was observed with the silicon application (@100 and 150 mg/kg) over other Si levels (0 and 50 mg/kg) in both maize cultivars under either of the moisture regimes. The well watered plants of both the hybrids attained higher leaf water potential with silicon

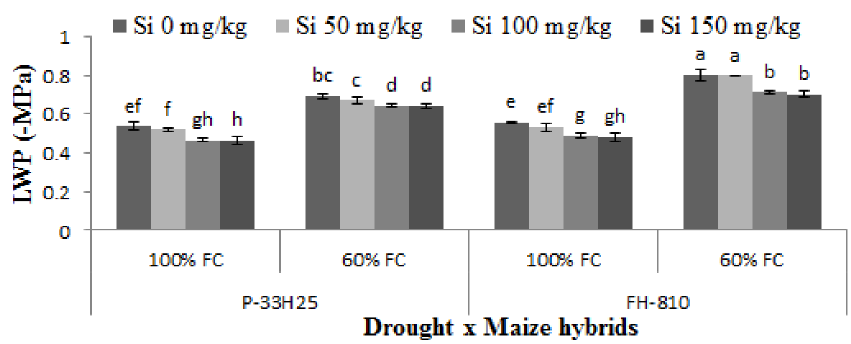

Figure 1. Interactive effect of maize hybrids, drought and silicon (Si) application on leaf water potential (LWP) (p ≤ 0.05).

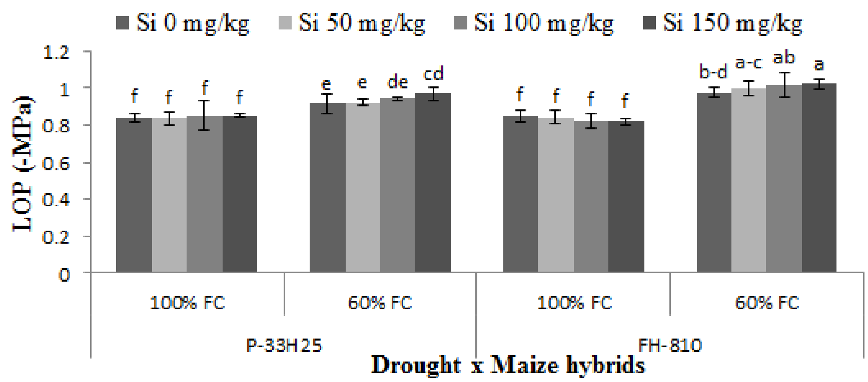

Figure 2. Interactive effect of maize hybrids, drought and silicon (Si) application on leaf osmotic potential (LOP) (p ≤ 0.05).

addition. The higher silicon levels (100 or 150 mg/kg) mostly were equally effective with respect to maintain the leaf water potential in both maize cultivars.

Leaf osmotic potential of both maize hybrids with and without silicon application under two moisture regimes is presented in Fig. 2. Water deficit significantly lowered the osmotic potential of leaves in both tested maize hybrids but reduction was more obvious in hybrid FH-810 as compared to P-33H25. Application of silicon modified the osmotic potential (more negative) of leaves in both maize genotypes under water deficit condition while remained ineffective under well watered condition.

The significant reduction in Leaf turgor was recorded in both hybrids because of water stress as compared to well watered condition (Fig. 3). Silicon nutrition significantly improved the leaf turgor potential in both hybrids under control as well as moisture deficit situation when compared with silicon deprived treatment. Maximum turgor potential was recorded in hybrid P-33H25 under control condition (100% FC) supplied with higher dose of silicon (100 or 150 mg/kg) while lower turgor potential was observed in silicon abridged drought-stressed plants of maize cultivar FH-810.

Both maize hybrids possessed a significant difference with respect to leaf relative water content under either of the water regime (Fig. 4). Hybrid P-33H25 attained significantly higher relative water content as compared to FH-810 under normal and drought stressed condition. Water deficit severely affected this attribute in both the hybrids. Nonetheless, exogenous application of silicon significantly enhanced the relative water content at its all levels under both normal and deficit water supply. The higher silicon levels (100 and 150 mg/kg) were mostly equally effective under well watered condition in both maize hybrids. Hybrid P-33H25 maintained higher water status at 100 and 150 mg/kg of applied silicon under 100% field capacity, while during water deficit 100 mg/kg silicon level was most effective. Over all higher relative water content were retained in hybrid P-33H25 than FH-810 under well watered and water deficit situation either the silicon was applied or not.

Gas exchange attributes**:** The data (Fig. 5) showed that photosynthetic rate was drastically reduced in both hybrids under water deficit condition. It is evident from the Fig. that hybrid P-33H25 maintained higher photosynthetic rate as

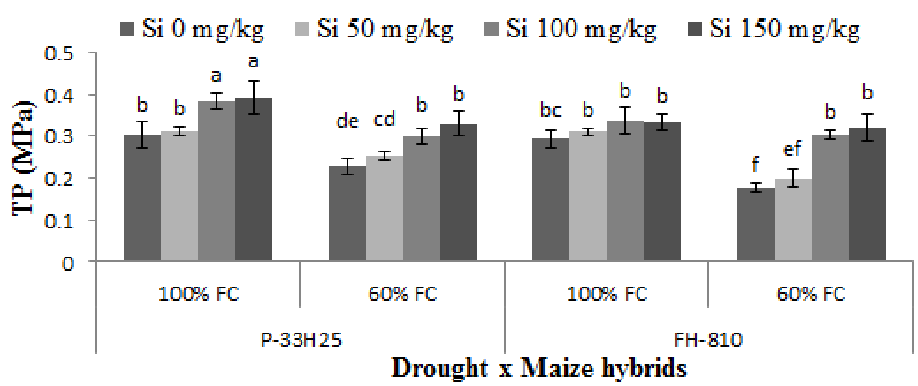

Figure 3. Interactive effect of maize hybrids, drought and silicon (Si) application on leaf turgor potential (TP) ($p \leq 0.05$).

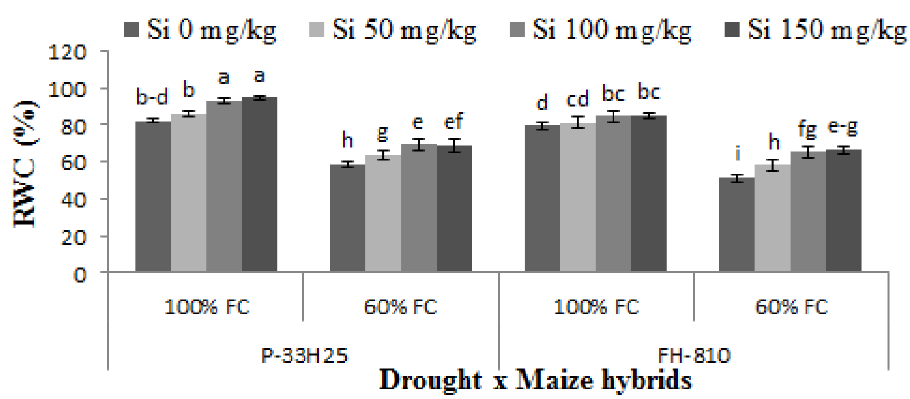

Figure 4. Interactive effect of maize hybrids, drought and silicon (Si) application on relative water content (RWC) ($p \leq 0.05$).

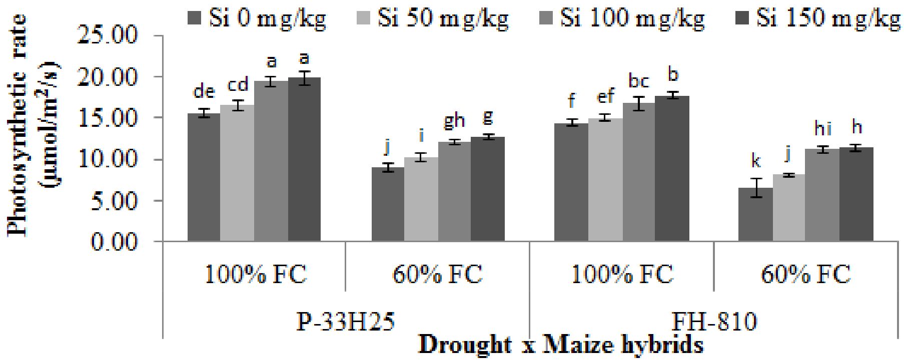

Figure 5. Interactive effect of maize hybrids, drought and silicon (Si) application on Photosynthetic rate ($p \leq 0.05$).

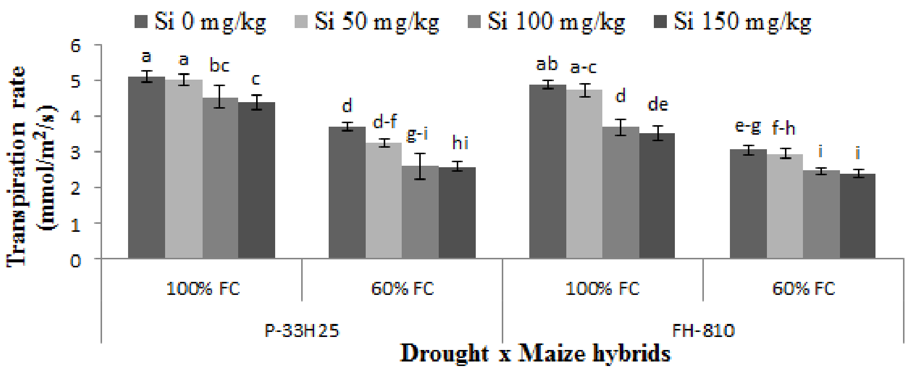

Figure 6. Interactive effect of maize hybrids, drought and silicon (Si) application on transpiration rate ($p \leq 0.05$).

compared to FH-810 under normal and water stress condition. Application of silicon enhanced this attribute appreciably at all its levels under normal (100% FC) and limited water supply (60% FC) in both hybrids. In hybrid P-33H25, maximum photosynthetic rate was recorded where higher dose of silicon was applied (100 or 150 mg/kg) under well watered condition and lower photosynthetic rate was possessed by drought-stressed plants that were grown without silicon fertilization. The drought sensitive hybrid, FH-810 showed an improvement in photosynthetic rate with every higher dose of silicon under either of the moisture regime.

The trend in transpiration rate of maize genotypes as affected by drought levels and silicon application is depicted in Fig. 6. The Fig. showed that drought stress (60% FC) significantly decreased the transpiration rate as compared to control conditions (100% FC) in both hybrids P-33H25 (drought tolerant) and FH-810 (drought sensitive). Exogenous application of silicon also significantly lowered the transpiration rate in both of the hybrids under normal as well as water deficit situation (60% FC). Maximum transpiration rate was observed in plants grown under well watered environment (100% FC) and without silicon fertilization in hybrid P-33H25. Silicon application suppressed transpiration rate at lower and higher levels under normal and water stressed condition. Minimum transpiration rate in both maize genotypes was observed under water deficit condition with 100 and 150 mg/kg of silicon.

DISCUSSION

It is evident from the current study that the plant height, leaf area per plant, primary root length, dry matter of shoot, roots and plant and different water relation and gas exchange attributes of maize hybrids were significantly influenced when grown in water deficit condition (60% FC) (Table 1). Water stress significantly reduced several plant characteristics like plant height (29.59%), leaf area (6.58%), fresh weights of shoot (29.20%) and root (5.34%), dry weights of shoot (39.82%) and root (4.66%), and osmotic potential (14.83%) of maize hybrid seedlings grown at 50% field capacity (Ali *et al*., 2011). The reduced seedling growth under limited moisture stress might be because of introverted cell division and extension (Ashraf and Mehmood, 1990). Changes in morphological parameters are the eventual determinants of stress effects on plants (Jaleel *et al*., 2009) while, response to moisture stress differs distinctly among various crop cultivars due to their intrinsic diversity in drought tolerance (Anjum *et al*., 2011). In the present investigation, exogenously applied different concentrations of Si significantly increased the growth and morphological attributes (plant height, leaf area per plant, primary root length, dry matter of root and shoot and plant dry weight) of both maize cultivars (Table 1). The silicon based growth improvement takes place under both normal (Hossain *et al*., 2002; Nolla *et al*., 2012) and abridged water supply (Ma, 2004). This effect of Si on plant growth is dose and crop specific (Ali *et al*., 2009). Silicon induced improvement in plant growth under stress may have been due to the significant role of Si in the upgrading water status of stressed plants (Romero-Aranda *et al*., 2006). Such beneficial effects of Si on plant biomass or dry matter percent increase under water abridged condition were also reported by several researchers in a number of plant species such as sugarcane 26-70% (Bokhtiar *et al*., 2012), Sorghum 25% (Hattori *et al*., 2005), soyabean 26% (Shen *et al*., 2010) and maize 23.7-40.5% (Fang *et al*., 2007), indicating the positive effect of Si application in mitigating drought induced inhibitory effects on growth of crop seedlings.

Silicon improves plant growth under stressed conditions by affecting a variety of metabolic processes including the improved water status of plant (Romero-Aranda *et al*., 2006), regulation of plant defense system (Zhu *et al*., 2004), changes in leaf organelles ultra-structure (Shu and Liu, 2001) and alleviation of specific ion effect (Tahir *et al*., 2006).

Silicon application significantly modified the leaf water potential (Fig. 1) in both maize hybrids under control (100% FC) and water deficit environment. Significantly higher leaf water potential was observed with the silicon application @ 100 and 150 mg/kg over other Si levels (0 and 50 mg/kg). There was an increase of 14.77% in leaf water potential when 2.11 mmol, sodium silicate was added to drought stressed plants of wheat (Gong *et al*., 2005). This might be due to more uptake of water by plants with addition of silicon (Hattori *et al*., 2005). It also sustains water potential of leaves in plants under water stress at the similar level as that of the well watered plants of wheat (Pei *et al*., 2010). The beneficial impact of silicon on water potential of plants leaves is also linked with decrease in transpiration that results in increase of leaf water potential under water deficit (Pei *et al*., 2010). Reduction in transpiration could be due to the deposition of silicate crystals in epidermal tissues that form an obstacle to water loss through the cuticles (Romero-Aranda *et al*., 2006).

Application of silicon did not affect the osmotic potential of leaves in both maize genotypes under control (well watered) condition while lowered under drought stress (Fig. 2). The osmotic adjustment is a chief physiological mechanism accountable for adaptation of plants to drought stress. Silicon application decreases the osmotic potential that shows an active osmotic adjustment (Sonobe *et al*., 2011). It leads to water potential gradient between the roots and the culture solution so serves as a driving force for water uptake by plants (Hsiao and Xu, 2000). Osmotic adjustment generally takes place as a result of an increase in osmolytes such as soluble sugars, minerals and amino acids under stressed condition (Kaya *et al*., 2006; Sonobe *et al*., 2011). Moreover, silicon complexes (high-molecular weight) may be transported into the vacuoles by endocytosis under water deficit condition (Romero-Aranda *et al*., 2006). Our findings showed that drought stressed silicon fertilized plants had more negative osmotic potential than the drought stressed plants not treated with silicon. The more negative osmotic potential means higher osmotic adjustment, and ultimately more capacity of plants to retain tissue water content. More degree of negative osmotic potential of silicon treated plants could be due to the deposition of silicon and its higher molecular weight complex in the cytoplasm and vacuoles (Neuman and De-Figueiredo, 2002). Thus Si application might enhance the ability of water stressed maize plants to retain tissue water content and ultimately the leaf turgor potential and water status is improved under drought condition.

The significant reduction in leaf turgor was recorded in both hybrids because of water stress as compared to well watered condition (Fig. 3). However, silicon nutrition significantly increased the leaf turgor potential in both hybrids under control as well as moisture deficit situation when compared with silicon deprived treatment. Under water deficiency stress plants lower their osmotic potential through accumulation of organic solutes so water moves into the cell from surroundings, eventually plants retain their turgor and carry on their metabolic activities (Subbarao *et al*., 2000).

The relative water content is an alternate measure of water status of plants and reflecting the metabolic activities in plant tissues (Mali and Aery, 2008). Exogenous application of silicon significantly enhanced the relative water content (Fig. 4) at its all levels under both normal and deficit water supply. For hybrid FH-810 the higher silicon levels (100 and 150 mg/kg) mostly were equally effective under well watered and water deficit environment. Silicon mediated drought stressed (−0.5MPa, simulated with 20% polyethylene glycol) plants of soybean maintained 29.53% higher RWC than Si deprived water stressed seedlings (Shen *et al*., 2010). Decrease in relative water content in leaves of drought stressed plants may be due to lower water availability the in soil (Shalhevet, 1993) or root systems, that may not so efficient to maintain water lost through the transpiration (Gadallah, 2000). The improved ability of silicon treated plants to retain water status under water deficit condition might be related to decrease in cuticular transpiration because of silicon deposition under the cuticle (Gao *et al*., 2006).

Generally it is known that reduced photosynthetic rate leads to reduced plant growth in most plants. The reduction in photosynthetic activities of drought stressed plants might be due to closing of stomata so leaf internal CO_2 level is decreased (Parveen and Ashraf, 2010). The photosynthetic rate and transpiration rate were drastically reduced in both hybrids under water deficit condition. However, exogenously applied Si significantly enhanced the photosynthetic rate and reduced the leaf transpiration appreciably at all its levels under optimum (100% FC) and limited moisture supply (60% FC) in both hybrids (Fig. 6). The increase in photosynthetic rate could be the primary factor for Si induced growth improvement in maize under stressed and non-stressed conditions (Parveen and Ashraf, 2010). The silicon deposited as colloidal gel in the conducting tissues i.e. xylem vessels and cell walls of leaves restricts the transpired water bypass flow and hence offers an obstacle to transpiration through cutical (Carvalho- pupatto *et al*, 2005; Savvas *et al*, 2009). Thus improves the water status of plants consequently strengthens the stem and keeping the leaves erect so checks lodging and increases light penetration hence improving photosynthetic efficiency of plants under water deficit situation (Abdalla, 2009). The silicon based increase in the photosynthetic activities of drought stressed plants might also be linked to the improved efficiency of chlorophyll content and photosynthetic enzymes like ribulose-bisphosphate carboxylase and NADP+ dependent glyceroldehyde-3-phosphate dehydrogenase under abridged moisture condition (Gong *et al*., 2005).

***Conclusion*:** In the current study, water deficit stress affected the various morphological and physiological characteristics of maize hybrids while exogenous application of various silicon concentrations significantly improved these attributes under either of the moisture regimes. The silicon application @ 50, 100 and 150 mg/kg resulted in an increase of 6.38, 21.68 and 20.15% in plant dry weight of maize hybrid P-33H25 while an improvement of 5.21, 25.48 and 26.03%, respectively in dry matter production of hybrid FH-810 under water deficit situation. However, the silicon levels 100mg/kg and 150mg/kg were statistically equally effective in plant dry matter production under either of the moisture regimes so most economic level is 100 mg/kg for maize hybrids under normal and water deficit condition.

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