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Forage Yield and Water Use Efficiency of Alfalfa Applied with Silicon under Water Deficit Conditions

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A pot experiment was conducted to investigate the response in terms of forage yield components and water use efficiency (WUE) of alfalfa (*Medicago sativa* L.) plants to silicon (Si) application (4 kg K_2SiO_3 per pot) at varying soil moisture environments [35%, 50%, 65% and 80% of field water capacity (FWC)]. Alfalfa forage biomass and number of branches increased with increase in soil moisture level. Application significantly increased both parameters only at 50% and 65% of FWC. It also increased the instantaneous WUE of alfalfa plants at all soil moisture levels. On the other hand, the increase in cumulative WUE with Si application was significant only at 50% and 60% FWC. Si concentration in the shoot was highest at 65% of FWC, while in the roots, higher concentrations were obtained at 50% and 65% of FWC relative to the other soil moisture levels. Si application reduced both the transpiration rate and stomatal conductance but had no effect on photosynthetic rate. The results revealed that the promotive effect of Si application on biomass and WUE was regulated by the soil moisture conditions.

Key Words: alfalfa, *Medicago sativa* L., silicon, soil moisture condition, water use efficiency, yield component

Abbreviations: FWC – field water capacity, WUE – water use efficiency

INTRODUCTION

Alfalfa (*Medicago sativa* L.) is an important forage crop because of its good nutritional quality for livestock and its ability to improve soil fertility (Guo et al. 2005). As such, it is used in many farming systems throughout Europe, North America (Grimes et al. 1992), Australia (Ballard et al. 2003) and China (Guo et al. 2004). Irrigation is widely used to maintain the higher biomass of alfalfa pasture in arid and semi-arid regions (Guo et al. 2007). However, water scarcity threatens sustainability of world alfalfa production, as agricultural irrigation accounts for 80% of global water resource consumption and this level of use is thought to be unsustainable (Shan 2005). To ensure water supply for the future, alfalfa growers have been forced to use water more efficiently (Guo et al. 2007). Previous studies have mainly focused on comparison of water use efficiency (WUE) of alfalfa genotypes (McElgunn and Heinrichs 1975) and the differences between irrigation patterns (Donovan and Meek 1983; Grimes et al. 1992; Sun et al. 2007) to select alfalfa genotypes with higher WUE and efficient irrigation practices. The basic physiological WUE (instantaneous WUE) is equal to the ratio of photosynthetic rate to transpiration rate (Karaba et al. 2007) and has been widely applied in previous studies (Ma et al. 2002; Gao et al. 2004; Zou et al. 2005; Gunes et al. 2008), although this measure neglects water loss by evaporation. Sun et al. (2007) argue that water loss by evaporation should be taken into consideration in actual field production because evaporation is not avoided and is easily influenced by environmental conditions and vegetation cover. Cumulative WUE has been proposed to measure the actual WUE in field production and is a measure of the biomass produced per unit of water consumption rather than transpiration (Shan 2005). To achieve biological water saving in both irrigated and rain-fed production (Wang et al. 2002), many previous studies have shown that water and fertilizer nutrient coupling is an effective way to get a high yield and WUE (Sun et al. 2007; Gunes et al. 2008).

Silicon (Si), as an environmental mineral element, has been found to simultaneously increase the vegetative biomass and physiological WUE of Compositae and gramineous plants such as sunflower, maize and rice (Ma et al. 2002; Gao et al. 2004; Zou et al. 2005; Gunes et al. 2008) by reducing transpiration and xylem sap flow rate and by maintaining high water potentials in plant leaves (Gao et al. 2006; Chen et al. 2011). Due to low Si content in the shoots of legume plants, the benefit of Si on legume plants is not defined. Recent studies showed that Si application increases the growth of cowpea, soybean and alfalfa plants using pot experiments (Li et al. 2004;

Guo et al. 2006; Guntzer et al. 2012). However, the influence of Si on WUE has not been investigated yet, and this limits the application of Si fertilizer to the management of alfalfa pasture. Although Si application has been proven to benefit the growth of shoots and roots of alfalfa (Guo et al. 2006), understanding the response of forage yield components (branches per plant, height, biomass per branch) to Si application may provide plant breeders with specific morphological targets for enhancing yield potential in stressful conditions (Turner 2004) and provide useful information for alfalfa growers (Suzuki 1991). This study was therefore conducted to determine the effect of Si application on the WUE and yield of alfalfa plants across a range of soil moisture conditions.

METHODS

Soil Preparation

Soil is considered as Si deficient in China when the available Si content of the soil is below 150 mg kg^{-1} (Li et al. 2004; Guo et al. 2006). The dominant soil type in the Loess Plateau, known locally as "loessial soil" (Guo et al. 2004), was chosen for use in the experiment. Soils were randomly collected from Dingxi county of Gansu province, China (104° 35′ E, 35° 28′ N; 1970 m a.s.l.) by 50 soil columns with 0.25 m^2 area and 15 cm depth. After air drying at room temperature, the experimental soil was screened through a 2-mm sieve. Ten samples of experimental soil were used to analyze the soil features. Organic matter, P, and K content were analyzed by use of the Walkley-Black wet combustion method, the molybdate-blue method, and by atomic absorption spectrophotometry, respectively (NIS 1980). Total N and available Si content were determined with a Carlo Erba NA 1500 CNS elemental analyzer equipped with an autosampler (Fisons Instruments, Milan, Italy) and analyzed colorimetrically by the molybdate-blue method (NIS 1980). The organic matter, pH, total N content, and K, P and available Si concentrations were 0.66%, 7.2, 0.11%, 240 mg kg^{-1}, 57.66 mg kg^{-1} and 112.14 mg kg^{-1}, respectively. The available water of the soil was approximately 11.5% and the proportion of sand and silt particles of the soils were 35% and 26%, respectively.

Pot Experiment

Pot experiments were conducted in a glasshouse with open wind at the College of Pastoral Agriculture Science and Technology of Lanzhou University (E103° 43′ 48″, N36° 01′ 48″) China from May 15 to September 15, 2008. The equivalent of 23.8 kg oven-dried soil was placed into 32 plastic pots (with 22.5 cm bottom diameter, 28.5 cm top diameter, and 28 cm height), divided into four moisture content regimes: 80% of field water capacity (FWC) (considered as wet conditions); 65% of FWC (lightly drought-stressed conditions); 50% of FWC (moderately drought-stressed conditions); and 35% of FWC (severely drought-stressed conditions) based on water potential curve (Guo et al. 2003).

During the experiment, FWC was maintained approximately at preset water-holding capacity in the morning of each day by weighing and adding distilled water. All pots were arranged randomly on trolley benches and the positions were rearranged every fortnight. Each moisture environment was divided into two treatments with 4 replicates. Potassium silicate (K_2SiO_3) was used as the source of Si in the Si-applied treatment (+Si) and potassium chloride (KCl) in the Si-deficient treatment (–Si). The K material was ground into powder and scattered on the soil surface, and then the soil was stirred ten times. Four grams of K_2SiO_3 were added to the pot for the +Si treatment (this concentration has previously been demonstrated to maximize alfalfa growth) (Guo et al. 2006) and 5.19 g KCl (with the same amount of K) was added to the corresponding control pot as –Si treatment, respectively. Alfalfa seeds were sown into the pots on June 5, and then thinned to 10 seedlings per pot 10 d after germination. The climatic conditions during the experiment are shown in Table 1. Weeds growing in the pots were removed by hand throughout the experiment.

Plant Biomass, Physiological Indicators and Content of Si

Sampling was conducted at the beginning of flowering (120 d after thinning, with 10% of plants flowering). The photosynthetic rate, transpiration rate, stomatal conductance and leaf area were measured in clear and sunny weather at 9:00–11:00 a.m. using a portable photosynthesis system (LI-6400, LI-COR Inc., made in

Table 1. The climatic conditions during the experiment.

Month	Mean Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	Mean Relative Humidity (%)	Mean Wind Speed (0.1 m s^{-1})
May	17.0	34.7	1.0	48	13
June	20.4	36.8	5.7	54	12
July	22.4	39.8	9.8	59	11
August	21.1	37.3	8.6	63	10

USA). The stem height was measured from the soil surface to the tip of the youngest visible leaf. The number of branches per plant developing from the root crown was counted. Forage biomass (fresh and dry) per plant was measured. Biomass was dried in an oven at 85 °C (Guo et al. 2006). The content of Si in shoots and roots was determined colorimetrically by the molybdate-blue method (Dakora and Nelwamondo 2003).

Determination of WUE

The instantaneous WUE (WUE_I, mmol CO_2 mol^{-1} H_2O) was estimated as $WUE_I = Pn/Tr$, where Pn is photosynthetic rate and Tr is transpiration rate (Gao et al. 2006). The cumulative WUE (WUE_C, g kg^{-1}) was estimated as $WUE_C = Y/ET$ (Shan 2005), where Y is the forage yield (g) and ET is the total evapotranspiration (kg) from the soil surface of the pot over the growing season. ET for individual pots was determined using the following soil water balance equation: $ET = \Delta S+P+I-D$, where ΔS is the change in soil water storage of the soil profile considered between planting and harvest ($\Delta S = 0$ because soil water content was held constant during the experiment); P is the precipitation (P was zero because a plastic shield was used to protect the pots from rainfall); I is the amount of irrigation (kg) that was measured every day; and D is the downward drainage from the root zone ($D = 0$ because soil moisture was below field water capacity). Thus, in this study, we calculated WUE_2 based on the equation $WUE_C = Y/I$.

Data Analysis

The effect of soil moisture, Si and their interaction on plant biomass, physiological indicators, silicon content and WUE were analyzed by two-way ANOVA. Fishers Least Significant Difference (LSD) test or independent t tests were performed to compare means among various treatments following the two-way ANOVA. Statistical analysis was performed using the STATISTIC software package (SPSS 10.0, USA).

RESULTS AND DISCUSSION

Forage Biomass and its Components

The forage biomass of +Si and −Si plants significantly increased with soil moisture content (Table 2). Si application did not affect forage biomass at 35% and 80% of FWC conditions, but significantly increased biomass when plants grew at lightly and moderately drought-stressed conditions (50% and 65% of FWC conditions). Similar to what was observed for forage biomass, the number of branches increased with soil moisture content and Si application significantly increased this parameter only at 50% and 65% of FWC. This result confirmed that the biomass of alfalfa plant was low due to seriously drought-stressed conditions (Guo et al. 2004) and high soil water content (Guo et al. 2007). These results suggest that the effect of Si on plant growth varies with soil moisture conditions in which alfalfa plants grow (Guo et al. 2006).

Table 2. Biomass and number of branches per plant of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (% of FWC)	Treatment	Forage Biomass (g $plant^{-1}$)	Branch (no. $plant^{-1}$)
35	+Si	1.17 ± 0.03 f	2.5 ± 0.03d
	−Si	1.25 ± 0.05 f	2.1 ± 0.06 d
50	+Si	6.97 ± 0.13 d	4.4 ± 0.09 b
	−Si	5.65 ± 0.22e	3.4 ± 0.08c
65	+Si	14.28 ± 0.96 b	5.9 ± 0.45 a
	−Si	11.28 ± 0.63 c	4.2 ± 0.12b
80	+Si	21.46 ± 1.23 a	5.9 ± 0.25 a
	−Si	21.35 ± 1.34 a	5.9 ± 0.35 a
Significance			
Soil water		**	**
Si		**	*
Si × soil water		**	*

FWC = field water capacity; +Si = 4 g K_2Si0_3 per pot
Values sharing a common letter within a column are not significantly different at 0.05 level using LSD.
*, ** Significant at 0.05 and 0.01 levels, respectively

Only the main effects of soil moisture and Si were found to affect plant height. Plant height increased with soil moisture content and Si application (Table 3). This result was consistent with the results obtained from similar studies on maize, in which silicon application was found to enhance stem elongation (Corrales et al. 1997).

Branch biomass (Table 4) and leaf area (Table 5) were not influenced by Si application but both parameters generally increased with increase in soil moisture.

Water Use Efficiency

In the absence of Si, the instantaneous WUE increased with an increase in soil moisture from 35% to 50% of FWC, and no further change was observed beyond 50% FWC (Table 6). With Si, the instantaneous WUE increased significantly with moisture content only up to 65% FWC. However, the cumulative WUE of +Si and –Si plants first increased and then decreased as the soil moisture increased, peaking at 50% of FWC conditions. This result is consistent with results obtained from *Sorghum bicolor* (Hattoria et al. 2005) in which Si application did not affect the cumulative WUE in wet or dry conditions. The instantaneous WUE is estimated on the basis of water lost through transpiration from individual plants, whereas the cumulative WUE is estimated based on the evapotranspiration from alfalfa plant population (Shan 2005).

For optimum growth, alfalfa plant needs a rational threshold value of soil water content (Guo et al. 2007). The alfalfa plant suffers from drought stress when the soil water content is below this rational threshold value,

Table 3. Plant height of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (% of FWC)	Height (cm)		Soil Moisture Main Effect
	+ Si	−Si	
35	11.1	11.2	11.2d
50	24.9	20.8	22.9c
65	30.8	30.1	30.5b
80	38.0	37.4	37.7a
Si main effect	26a	24.8b	
Significance			
Soil moisture	**		
Si	**		
Si × Soil moisture	ns		

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter within a column or row are not significantly different at 0.05 level using LSD.
** Significant at 0.01 level; ns – not significant

Table 4. Branch biomass of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (% of FWC)	Branch Biomass (g)		Soil Moisture Main Effect
	+ Si	−Si	
35	0.056	0.060	0.058d
50	0.157	0.168	0.163b
65	0.242	0.268	0.255b
80	0.358	0.373	0.367a
Significance			
Soil moisture	*		
Si	ns		
Si × Soil moisture	ns		

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter within a column are not significantly different at 0.05 level using LSD.
* Significant at 0.05 level; ns – not significant

Table 5. Leaf area of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (% of FWC)	Leaf Area (cm^2)		Soil Moisture Main Effect
	+ Si	−Si	
35	7.190 ± 0.44	6.946 ± 0.33	7.068c
50	9.490 ± 0.34	7.320 ± 0.34	8.405b
65	9.157 ± 0.55	9.147 ± 0.39	9.152ab
80	10.320 ± 0.36	10.340 ± 0.45	10.33a
Significance			
Soil moisture	**		
Si	ns		
Si × Soil moisture	ns		

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter within a column are not significantly different at 0.05 level using LSD.
** Significant at 0.01 level; ns – not significant

Table 6. The instantaneous and cumulative water use efficiency (WUE) of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (%)	Treatment	Instantaneous WUE (mmol CO_2 mol^{-1} H_2O)	Cumulative WUE (g kg^{-1})
35% of FWC	+Si	6.24 ± 0.32 c	1.27 ± 0.12 d
	−Si	4.79 ± 0.23 d	1.28 ± 0.13 d
50% of FWC	+Si	9.00 ± 0.46 b	1.83 ± 0.16 a
	−Si	6.00 ± 0.34 c	1.35 ± 0.14 c
65% of FWC	+Si	12.25 ± 0.41 a	1.62 ± 0.09 b
	−Si	6.74 ± 0.24 c	1.34 ± 0.11 c
80% of FWC	+Si	13.77 ± 0.43 a	1.26 ± 0.23 d
	−Si	7.25 ± 0.48 c	1.22 ± 0.28 d
Significance			
Soil water		**	*
Si		**	**
Si × soil water		**	*

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter within a column are not significantly different at 0.05 level using LSD.
*, ** Significant at 0.05 and 0.01 level, respectively; ns – not significant

which decreases the instantaneous WUE through regulating the photosynthetic process. The instantaneous WUE is kept stable as the soil water content is increased at or beyond the rational threshold value of soil water content. The cumulative WUE is regulated by the loss of water via evaporation (which is related to plant cover) and transpiration (Shan 2005). In actual alfalfa production, water loss from evaporation is inevitable. Therefore, the cumulative WUE is an indicator of the actual water use in plant production.

In severely drought-stressed conditions, the low water potential of leaves would reduce the transportation capacity of sap flow from roots to shoots (Deng et al. 2005), and soil water becomes unavailable for alfalfa plants because the soil water potential is lower than that of alfalfa roots. Furthermore, evaporation water loss under this condition is greater than under other drought-stressed conditions because cover is low due to poor plant growth. In wet conditions, water is not completely used and a portion of irrigating water remains in the soil, which increases water loss when the cumulative WUE is calculated.

Absolute Amount of Silicon Concentration in Shoots and Roots

The Si concentration in shoots increased and then decreased with increase in soil moisture (Table 7), peaking at 65% of FWC condition. Si level in alfalfa was higher in plants treated with Si. The trend in the Si concentration in roots as a function of soil moisture was similar to what was observed for the shoot, with optimum level at 50% of FWC (Table 8). Si application significantly increased the Si concentration in the root at all soil moisture content levels except at 85% of FWC. Higher levels of Si in the root were observed at 50% and

Table 7. Concentration of silicon in shoots of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (% of FWC)	Silicon Concentration in Shoot (mg kg^{-1})		Soil Moisture Main Effect
	+ Si	−Si	
35	0.3382 ± 0.013	0.3317 ± 0.034	0.3350 ± 0.031c
50	0.5093 ± 0.044	0.4303 ± 0.009	0.4698 ± 0.027b
65	0.6056 ± 0.035	0.4682 ± 0.026	0.5369 ± 0.019a
80	0.2082 ± 0.036	0.2225 ± 0.025	0.2154 ± 0.032d
Si main effect	0.4153 ± 0.025a	0.3632 ± 0.029b	
Significance			
Soil moisture	**		
Si	**		
Si × Soil moisture	ns		

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter within a column or row are not significantly different at 0.05 level using LSD.
** Significant at 0.01 level; ns – not significant

Table 8. Concentration of silicon in the root of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (% of FWC)	Silicon Concentration in Root (mg kg^{-1})	
	+ Si	−Si
35	0.6481 ± 0.024b	0.5364 ± 0.031c
50	0.8611 ± 0.044a	0.6364 ± 0.021b
65	0.8434 ± 0.055a	0.6552 ± 0.036b
80	0.4375 ± 0.046d	0.4411 ± 0.035d
Significance		
Soil moisture	**	
Si	**	
Si × Soil moisture	*	

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter are not significantly different at 0.05 level using LSD.
*, ** Significant at 0.05 and 0.01 level, respectively

65% of FWC. These results imply that moderate drought stress increased the silicon deposition in alfalfa plants because plant root growth is restricted under severe drought stress conditions (Guo et al. 2003) and the roots suffer from decomposition to some extent at higher FWC (Guo et al. 2007). Si concentration in the shoots was lower than that in the roots for all soil moisture conditions, indicating that Si is mainly deposited in the root for alfalfa plants.

Transpiration Rate, Photosynthetic Rate, Stomatal Conductance and Leaf Area

There was no significant interaction between soil moisture and Si application in terms of transpiration, photosynthesis and stomatal conductance. The transpiration rate of plant leaves at 35% and 80% of FWC condition was greater than that at 50% and 65% of FWC conditions (Table 9). Si application significantly reduced the transpiration rate of alfalfa leaves across all soil moisture conditions. The reduction in transpiration with Si application could probably be due to the thickening of the cuticle by silica deposits on the leaf epidermal tissue (Hattoria et al. 2005; Kaya et al. 2006), which could regulate stomatal conductance (Gao et al.

Table 9. Transpiration rate of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (% of FWC)	Transpiration Rate (mmol H_2O m^{-2}s^{-1})		Soil Moisture Main Effect
	+ Si	−Si	
35	0.477 ± 0.02	0.638 ± 0.01	0.558 ± 0.02a
50	0.381 ± 0.02	0.580 ± 0.03	0.481 ± 0.03b
65	0.357 ± 0.03	0.641 ± 0.04	0.499 ± 0.01b
80	0.392 ± 0.03	0.731 ± 0.02	0.562 ± 0.02a
Si main effect	0.402 ± 0.04b	0.648 ± 0.03a	
Significance			
Soil moisture	**		
Si	**		
Si × Soil moisture	ns		

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter within a column or row are not significantly different at 0.05 level using LSD.
** Significant at 0.01 level; ns – not significant

2006) and alleviate the water-flow rate in xylem vessels by increasing the hydrophilic nature of the cell wall (Epstein 1999; Ma et al. 2002). This result is in agreement with the results of a previous hydroponic experiment involving sunflower (Zou et al. 2005), and rice and maize in pot experiments (Agarie et al. 1998; Gao et al. 2006).

Photosynthetic rate of plant leaves was affected only by soil moisture, which generally increased with soil moisture content (Table 10). Regardless of Si treatment, the stomatal conductance first increased and then decreased with increase in soil moisture, peaking at 65% of FWC (Table 11). Si application reduced the stomatal conductance of plant leaves across all soil water conditions, similar to what was observed for transpiration rate. The adjustment of stomatal opening caused by adding silicate is a way to reduce leaf transpiration rate, which increases the maize instantaneous WUE (Gao et al. 2006).

Ma and Yamaji (2006) have reported that silicon has a beneficial role in plant growth by participating in plant physiological process and increasing biotic and abiotic stress resistance of plants; however, benefits are only obtained when deposition is above a certain threshold of Si deposit that varies with species and genotypes. This study shows that the wet and severely drought-stressed conditions are detrimental to the uptake of silicon by alfalfa because alfalfa root growth is poor under these conditions.

CONCLUSION AND RECOMMENDATION

This study investigated the response in terms of yield and water use efficiency of alfalfa plants to silicon application under different soil moisture conditions. Our findings demonstrated that Si application increased plant biomass and number of branches only at 50% and 65% of FWC. Treatment with Si also improved the alfalfa instantaneous WUE at all levels of soil moisture, with the highest values at 65% of FWC and beyond. On the other hand, cumulative WUE was increased with Si application only at 50% and 60% of FWC. These results suggest that the positive effect of silicon on alfalfa plant is dependent on soil moisture content.

Table 10. Photosynthetic rate of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture % of FWC	Photosynthetic Rate ($\mu mol\ CO_2\ m^{-2}s^{-1}$)		Soil Moisture Main Effect
	+ Si	−Si	
35	2.973 ± 0.24	3.052 ± 0.13	3.013 ± 0.023d
50	3.430 ± 0.14	3.480 ± 0.14	3.455 ± 0.018b
65	4.375 ± 0.35	4.320 ± 0.19	4.348 ± 0.021b
80	5.400 ± 0.16	5.300 ± 0.25	5.350 ± 0.027a
Significance			
Soil moisture	**		
Si	ns		
Si x Soil moisture	ns		

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter within a column are not significantly different at 0.05 level using LSD.
** Significant at 0.01 level; ns – not significant

Table 11. Stomatal conductance of alfalfa (*Medicago sativa* L.) with (+Si) and without (−Si) silicon under different soil moisture content.

Soil Moisture (% of FWC)	Stomatal Conductance ($mmol\ H_2O\ m^{-2}s^{-1}$)		Soil Moisture Main Effect
	+ Si	−Si	
35	0.112 ± 0.01	0.115 ± 0.01	0.114 ± 0.01d
50	0.248 ± 0.01	0.590 ± 0.01	0.419 ± 0.02c
65	0.532 ± 0.03	1.657 ± 0.02	1.095 ± 0.03a
80	0.435 ± 0.02	1.343 ± 0.01	0.889 ± 0.02b
Si main effect	0.332 ± 0.02b	0.926 ± 0.03a	
Significance			
Soil moisture	*		
Si	*		
Si x Soil moisture	ns		

FWC = field water capacity; +Si = 4 g K_2SiO_3 per pot
Values sharing a common letter within a column or row are not significantly different at 0.05 level using LSD.
* Significant at 0.05 level; ns – not significant

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