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Effect of silicon application on wheat (*Triticum aestivum* L.) growth under water deficiency stress

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Abstract: Silicon is known to ameliorate the deleterious effects of drought on plant growth. We evaluated growth of wheat (CV. Inqlab-91) on different soil water regimes as affected by Si application. Silicon was added in soil @ 50 mg/kg and 150 mg/kg of soil. Plants were grown with three levels of soil water contents viz 50%, 75% and 100% of field capacity. Water deficiency in soil significantly reduced shoot biomass and spike weight of wheat plants. Silicon application significantly ($p<0.01$) increased plant biomass, plant height and spike weight at all levels of water contents. Poor growth of plants in water deficient conditions was significantly improved with Si application. Silicon application significantly increased Si concentration and uptake in wheat plants grown at all three soil water levels. Mechanisms underlying growth improvement under drought are still unclear and must be explored.

Keywords: Drought, silicon, wheat.

تأثير إضافة السيلكون على القمح (*Triticum aestivum* L.) المزروع تحت تأثير الأجهاد المائي

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الملخص: يعرف السيلكون بمقدرته على تخفيف الآثار الضارة للجفاف على نمو النبات. لقد تم تقييم نمو القمح (CV. Inqlab-91) في أنظمة ماء مختلفة للتربة بناء على تأثير السيلكون. حيث تم إضافة السيلكون إلى التربة بمعدلات 50 ملغم/كلغم و 150 ملغ/كلغ تربة. وتم استخدام ثلاثة مستويات من المحتوى الرطوبي للتربة(50%، 75%، و100%) من السعة الحقلية. ان نقص الماء في التربة أدى إلى خفض كتلة المجموع الخضري ووزن السنبلة بدلالة إحصائية في نباتات القمح. إلا أن إضافة السيلكون إلى التربة ساهم في زيادة كتلة النبات (بدلالة إحصائية ($p<0.01$))، طول النبات، ووزن السنبلة في كل مستويات المحتوى الرطوبي للتربة. كما أدى وبدلالة إحصائية إلى تحسين نمو النباتات ذات النمو الضعيف تحت تأثير الإجهاد المائي.إن إضافة السيلكون أدى إلى زيادة في تركيز السيلكون وامتصاصه من قبل نباتات القمح التي نمت تحت جميع مستويات رطوبة التربة. إن التقنية التي يتبعها النبات لتحسين نموه تحت ظروف الجفاف مازالت مبهمة وتحتاج إلى مزيد من الدراسة والاكتشاف.

الكلمات المفتاحية: الجفاف، سيليكون، القمح.

Introduction

Silicon, the second most abundant element in the earth's crust, has not yet received the title of essential nutrient for higher plants, as its role in plant biology is poorly understood (Epstein, 1999). However, various studies have demonstrated that Si application increased plant growth significantly (Alvarez and Datnoff, 2001). Beneficial effects of Si are more prominent when plants were subjected to multiple stresses including biotic and abiotic stresses (Aziz et al., 2002; Rodrigues et al., 2003; Ma, 2004; Tahir et al., 2006). Silicon is also known to increase drought tolerance in plants by maintaining plant water balance, photosynthetic activity, erectness of leaves and structure of xylem vessels under high transpiration rates (Melo et al., 2003; Hattori et al., 2005). Gong et al., (2003) observed improved water economy and dry matter yield of water by Si application. Silicon application is reported to enhance leaf water potential under water stress conditions (Matoh et al., 1991). They suggested that a silica-cuticle double layer formed on leaf epidermal tissue is responsible for this higher water potential. Lux et al. (2002) reported that endodermal tissue accumulates large amounts of Si in drought tolerant cereal cultivars. Results of Hattori et al. (2003) and Lux et al. (2003) suggested that Si plays an important role in water transport and root growth under drought conditions in sorghum.

Certain cereal crops especially from the Gramineae and Cyperaceae families accumulate large amounts of Si (Mitani and Ma, 2005), and Si application to these crops ensured better growth. Being a member of Gramineae family, wheat is also considered as Si accumulator. Wheat is the major staple food of the people of Pakistan. Wheat, being a single largest crop of the rainfed areas, contributes 12.5% to the national wheat production (Alvi and Shrif, 1995). Average wheat yield under rainfed conditions is very low (<600 kg/acre) compared to irrigated wheat (~1200 kg/acre). Among major yield limiting factors, drought is very important as it seriously affects plant growth, yield and mineral nutrition (Garg et al., 2004; Samarah et al., 2004). To ensure food security and sustainable economy, it is extremely important to find ways to improve drought tolerance of wheat. Keeping in view the importance of wheat, we evaluated the beneficial effects of Si application on wheat growth under different soil water contents.

Material and Methods

The experiment was conducted in a rain protected wire house under normal conditions. The bulk sample of surface soil (sandy clay loam) was collected from the Institute Research Area, University of Agriculture, Faisalabad. The soil was air dried and ground to pass through a 5 mm sieve. 4.5 kg of prepared soil was put in plastic pots. Nitrogen, phosphorus and potassium were mixed in every pot @ 80, 60 and 50 mg kg-1, respectively. Silicon was added in the soil @ 50 and 150 mg kg-1 of soil to each half of the pots using sodium silicate (after dissolving it in 50% NaOH and H_2O_2). The experimental design was CRD with three replicates of each treatment.

A commonly grown wheat cultivar, Inqlab-91, was selected for the present study because it is drought sensitive (Akram et al., 2004). Ten seeds of wheat were sown per pot and reduced to four plants per pot after fifteen days of seedling emergence. Distilled water was used for irrigation and all of the pots were kept at field capacity till 15 d. Three moisture levels viz 50%, 75% and 100% of field capacity were then maintained in these pots till harvesting. After 75 days, height of plants was measured from the surface of soil by using measuring tape. After measuring plant height, the plants were harvested and washed thoroughly with distilled water. After 2 days of air drying, samples were oven dried at 70ºC in a forced air driven oven and dry weight was recorded. The dried samples were ground in a grinding mill to fine powder and mixed thoroughly. Samples (0.20 g) were digested in 50 % NaOH and 50% H_2O_2 in open vessels (Teflon beakers) on a hot plate at 150ºC for 2h. The digest was used for Si estimation by the colorimetric molybdenum blue method (Elliot and Snyder, 1991). To 1 ml of supernatant filtrate liquid, 25 ml of 20% acetic acid, 10 ml of ammonium moblybdate (54 g/L) solution was added in a 50 ml polypropylene volumetric flask. After 5 minutes, 5 ml of 20% tartaric acid and 1ml of reducing solution was added to the flask and the volume was made up with 20% citric acid. After half an hour, the absorbance was measured at 650 nm with a spectrophotometer (Shimadzu, Japan). The reducing agent was prepared by dissolving 1 g Na_2SO_3, 0.5 g 1 amino-2-naphthol-4-sulfonic acid and 30 g $NaHSO_3$ in 200 ml water. The data was analyzed statistically using MSTAT-C software (Russel and Eisensmith, 1983).

Results and Discussion

Biomass Production

There were significant main and interactive effects of water contents (WC) and silicon (Si) application on shoot dry matter (SDM) (Table 1). A gradual decrease in WC from 100% field capacity (FC_3) to 75 % (FC_2) and 50% (FC1) caused a significant decrease ($p<0.01$) in SDM, averaged over both Si levels. The plants grown at FC3 and FC2 produced 67% and 82% of their SDM when grown with 100% FC, respectively. Gunes, et al. (2006) reported significant decrease in dry matter production in chickpeas under drought stress. Shoot dry matter production of the plants grown with 150 mg/kg Si was significantly ($p<0.01$) higher than those grown with 50 mg/kg Si in soil (Table 1) at all levels of soil WC. Maximum increase in SDM due to applied Si was observed when plants were grown with lowest WC in soil (FC1) (Fig. 1). The Increase in SDM due to applied Si at FC2 and FC3 was almost the same. This indicated that application of Si improved SDM significantly but increase was more profound when plants were suffering water stress (FC1). Rafi et al. (1997) and Hattori et al. (2005) also reported significant improvement in plant biomass by Si application under drought stress. Gong et al. (2003) reported lower transpiration rate, greater leaf weight ratio and lower specific leaf area of Si fed wheat plants under water stress condition. It may be the reason for increased photosynthesis and dry matter production by Si application under dry conditions.

There were significant ($p<0.01$) main and interactive effects of soil WC and Si levels on plant height (Table 1). Plant height was significantly more in plants grown with higher WC (FC3) (58.6 cm) than those grown with FC2 (47.6 cm) and FC1 (39.3 cm). Averaged on all WC, plant height was more when Si was applied @ 150 mg/kg than those supplied with 50 mg/kg Si. The height of wheat plants grown with 50 mg/kg of Si ranged from 37.7 cm in FC1 to 57.7 cm in the FC2 treatment. Silicon application significantly improved plant height under drought conditions. In Si fed plants, plant height ranged from 41.1 in FC1 to 61.7 cm in the FC3 treatment.

There was a significant main effect of WC on spike weight of wheat plants; however the main effect of Si levels was non significant (Table 1). The interactive effect of Si levels and WC was significant on spike weight. Averaged over Si levels, spike weight was decreased from 0.80 g/spike in FC3 to 0.60 g/spike in FC2 and to 0.39 g/spike in FC1. Spike weight in plants grown with 50 mg/kg Si ranged from 0.36 g/spike in FC1 to 0.77 g/spike in FC3. In plants grown with 150 mg/kg Si, spike weight ranged from 0.40 g/spike in FC1 to 0.84 g/spike in FC3.

Silicon Concentration and Uptake

There were significant main and interactive effects of Si levels and WC on shoot Si concentration in wheat plants (Table 2). Silicon concentration in plants grown with 150 mg/kg (Si_2) was significantly more than in those plants grown with 50 mg/kg (Si_1) Hattori et al., (2005) also reported that silicon concentration in leaf blades of sorghum was increased by Si application regardless of soil water regime. Silicon concentration in plants grown with FC3 was highest (11.8 mg/g), followed by those grown with FC2 (10.0 mg/g) and FC3 (8.99 mg/g). Baligar et al., (2001) reported that decreasing water availability under drought reduced the concentrations of mineral nutrients in crop plants. Silicon concentration in plants grown with Si_1 ranged from 6.70 mg/g in FC1 to 8.81 mg/g in FC3. In plants grown with Si_2, Si concentration ranged from 11.28 mg/g to 14.82 mg/g.

There were significant main and interactive effects of Si levels and WC on Si uptake by shoots (Table 2). The higher Si level (Si_2) caused a significant increase (1.75 fold) in Si uptake by wheat averaged over all three WC. Silicon uptake was significantly decreased as WC decreased gradually in soil. Jones and Handreck (1976) also reported that Si uptake increases with an increase in water contents as it is passively absorbed via mass flow. Silicon uptake had significant positive interaction with SDM at all levels of water supply (Fig. 3). Silicon uptake in plants grown with Si_1 (50 mg/kg) ranged from 24.3 mg/pot (FC1) to 52.5 mg/pot in FC3. In plants grown with Si_2 (150 mg/kg), Si uptake ranged from 49.4 mg/pot to 90.5 mg/pot. Relative Si uptake in plants grown with FC1 and FC2 were 46% and 54% compared to that grown with FC3 at the Si_1 level (Fig 2). In plants grown at the Si_2 level, relative Si uptake was 54% and 71% compared to that grown with FC3. Higher water supply in soil caused a significant increase in Si uptake grown either with Si_1 and Si_2.

Table 1. Shoot dry matter and plant height of wheat grown with 50 mg/kg (Si_1) and 150 mg/kg (Si_2) of Si at three levels of soil water contents viz. 50%, 75% and 100% of field capacity (FC_1, FC_2 and FC_3). Plants were harvested after 75 d of sowing. Values are means of three replications. Means followed by similar letters do not differ statistically at 0.05 probability.

Soil Water contents	Shoot dry matter (g/pot)		Plant Height (cm)		Spike weight (g/spike)	
	Si1	Si2	Si1	Si2	Si1	Si2
FC1	3.60 d	4.39 c	37.7 c	41.1 c	0.36 d	0.40 d
FC2	4.80 bc	5.07 b	46.3 b	51.0 b	0.59 bc	0.65 b
FC3	5.70 a	6.11 a	57.7 a	61.7 a	0.77 ab	0.84 a
LSD	0.60		5.04		0.07	

Table 2. Si concentration and uptake of wheat grown with 50 mg/kg (Si_1)and 150 mg/kg (Si_2) of Si at three levels of soil water contents viz. 50%, 75% and 100% of field capacity (FC_1, FC_2 and FC_3). Plants were harvested after 75 d of sowing. Values are means of three replications. Means followed by similar letters do not differ statistically at 0.05 probability.

Soil Water contents	Si concentration (mg/g)		Si uptake (mg/pot)	
	Si1	Si2	Si1	Si2
FC1	6.70 e	11.28 c	24.3 e	49.4 c
FC2	7.33 e	12.80 b	35.3 d	64.9 b
FC3	8.81 d	14.82 a	52.5 c	90.5 a
LSD	0.92		8.29	

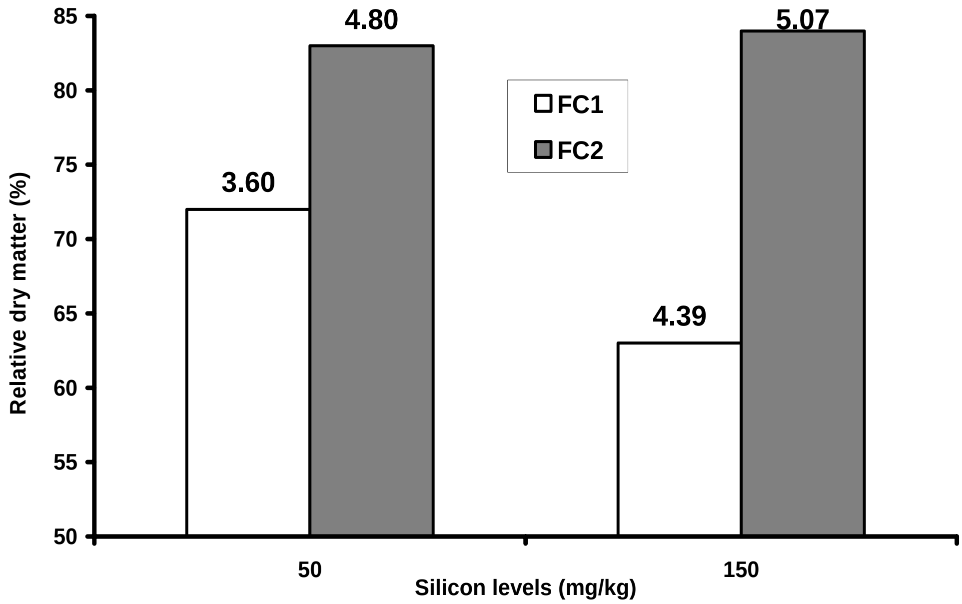

Fig. 1. Percent dry matter production of plants grown with FC_1 and FC_2 relative to those grown with FC_3

Values on top of bars are absolute SDM and Si contents in FC_1 and FC_3

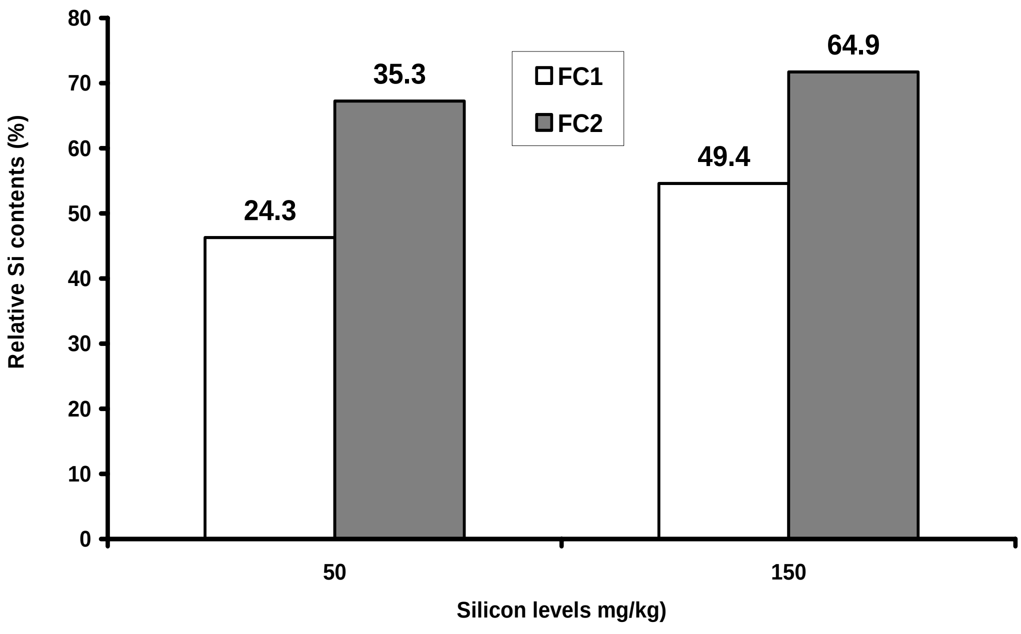

Fig. 2. Relative Si contents in plants grown with FC_1 and FC_2 compared with those grown with FC_3

Values on top of bars are absolute SDM and Si contents in FC_1 and FC_3

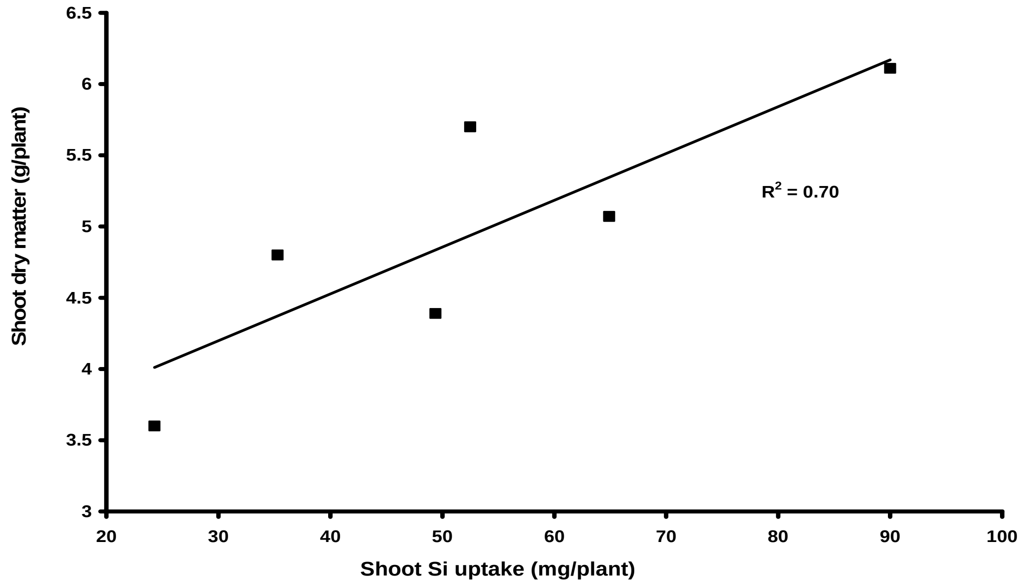

Fig. 3. Correlation of shoot dry matter with shoot Si uptake

Conclusion

Silicon application increased dry matter production of wheat at all soil water contents levels. Dry matter reduction in plants due to low water contents was significantly increased when Si was applied, indicating increased tolerance of wheat plants to drought. The mechanisms of drought tolerance are still unclear and must be explored in further experimentation.

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