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Impact of foliar silicon application on yield attributes of wheat (*Triticum aestivum* L.) under water deficit environment

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Abstract

The consequences of climate change, particularly in the form of water deficiency are now evident in different parts of the world that negatively affecting the crop productivity. The current study was conducted to explore the involvement of exogenously applied silicon in reducing the negative effects of drought stress on yield of wheat. The wheat cultivar "Faisalabad- 08" was subjected to two water regimes (normal irrigation and no irrigation) and four levels of silicon including no spray, 0, 0.01 and 0.1 *mM*. All the silicon levels were applied at three different stages of wheat growth. The sources of the silicon used in the current experiment were sodium silicate, potassium silicate and silicic acid. At maturity of crop different yield parameters (number of tiller per plant, number of spike per plant, number of spikelet per plant, spike length, number of grain per plant, number of grain per spike, number of grain per spikelet, single grain weight and yield per hector) were recorded. The results indicated that the yields of related attributes were significantly reduced under water deficit environment. The application of silicon from the two different sources sodium silicate and potassium silicate was more beneficial to alleviate the negative effects of water deficit on wheat yield. Sodium silicate (0.01 and 0.1 *mM)* and potassium silicate (0.1 *mM)* were found more beneficial for enhancing wheat yield under water stress to enhance wheat productivity.

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Introduction

Silicon is a potential contender to recover the negative pressures of ever increasing climatic changes. It is considered to be one of the most important beneficial elements for plants (Li *et al.*, 2009). Among all beneficial nutrients of plants the role of the silicon in plant growth and development is always been debatable (Ma and Takahashi, 2002; Ashraf *et al.,* 2009). Despite of some ambiguities regarding uptake and transportation of silicon in the plants, the positive effects of the silicon has been well reported (Epstein, 1999; Ashraf *et al.,* 2009;Li *et al.*, 2009). Silicon is reported to be involved in the enhancement of growth and yield, improvement of mechanical properties of plants, resistance to lodging, reduction of transpiration and resistance to drought stress, salinity and metal toxicities (Epstein, 2001; Ashraf *et al.,* 2009; Li *et al.,* 2009; Liang, 2015).

Among the most lavish element in the soil, silicon ranked at second number after the presence of oxygen constituting 50-70% of soil as silicon dioxide; the plants grown in soils have been found to contain some amount of silicon in their tissues naturally (Epstein, 1999; Ma and Takahashi, 2002; Richmond and Sussman, 2003). It has been observed that, the application of fertilizers such as nitrogen and phosphorous can diminish the silicon concentration in soils (Ma*et al.,* 2004). Silicon can be applied as potassium, magnesium and calcium silicate both in soil or as foliar application (Liang *et al.,* 2015). Calcium silicate is the most commonly applied silicon fertilizers for field application (Ma *et al.,* 2004). In rice and sugarcane, the silicon fertilizers are routinely applied to improve yield attributes and the growth of these crops (Ma and Yamaji, 2006). The silicone uptake system and transporters have also been characterized in rice and wheat (Ma *et al.,* 2004).

Wheat, maize and rice are considered the most important cereal crops of the world. Among all crops, the status of wheat is considered more important. About 100% of our population used wheat as staple food (Morris, 2002). Wheat is ranked at the third position among the cereal crops and considered one of the most ancient grains worldwide (Poudel and Bhatta, 2017). The common wheat (hexaploid wheat) cultivation is reported to be started thousands years ago with the hybridization of tetraploid and diploid wheat (Feuillet *et al.,* 2008). It's been twelve thousand years that hexaploidwheat is used as a staple food around the globe. Now a day's wheat is grown at large scale in different regions of the world including France, Russia, USA, China, India and Pakistan (Poudel and Bhatta, 2017). Wheat grains are most important source of carbohydrates, proteins, some dietary fibers, antioxidants and some important vitamins (Shewry*et al.,* 2013). The most astonishing properties of wheat which make it more suitable for agriculture farming is adaptability to vast range of climatic zones (Bond and Liefert, 2016).

The outcome of the wheat crop in terms of yield and seed quality fluctuates per annum due to the looming climatic conditions (Brouns*et al.,*2012).The continues anthropogenic activities are the leading causes of present day global warming resulting change in precipitation pattern of different areas (Nelson *et al.,* 2009). The fluctuation in rain fall pattern is considered a key factor for reduction in crop yield by increasing the susceptibility of plants towards biotic and abiotic stresses (Barnabas *et al.,* 2008; Emam, 2011).

Among all abiotic stresses water deficiency is the most critical situation for production of the cereal crops, particularly in developing countries (Barnabas *et al.,* 2008; Chen *et al.,* 2011). Plant breeders are trying to cope up this challenging situation of less water availability by developing high yielding and tolerant genotypes of crops (Fereres and Soriano, 2007). The reduced water supply cause series of changes in their morphological, physiological and biochemical attributes of wheat which ultimately hampered the yield (Naumann*et al.,* 2010; Emam, 2011; Chen *et al.,* 2011). Moreover, closure of stomata, reduction in water potential and transpiration rates, accumulation of some drought related substances and production of reactive oxygen species in response to moisture stress has also been reported (Yournadov*et al.,* 2003).

Keeping in view the mentioned facts, the current study was has been planned to investigate the outcomes of silicon application in terms of yield related parameters of wheat plants grown under rainfed environment. The objective of the study is to draw parallel between the application of silicon level and yield related attributes of wheat plants experiencing shortage of water.

Material and methods

For current studies,a field trial was conducted at Wheat Section, Ayub Agriculture Research Institute (AARI) Faisalabad, Pakistan under water deficit environment (rainfed conditions). The foliar application of silicon different levels was used from different sources to evaluate the effects of foliar feeding of silicon on wheat yield attributes grown under water stress. For current studies, local wheat line (Faisalabad 08) was grown under two water levels; normal water irrigation and rainfed (rain water only) environment. Each treatment was grown in three repeats and the experimental design was randomized complete block designing. Three silicon sources (sodium silicate, potassium silicate and silicic acid) were used for foliar feeding of the plants twice at each stage in four different levels which include no spray, 0, 0.01 and 0.1 *mM*. The silicon was applied at different growth stages of crop that is tillering, booting and grain filling. The final data for yield related attributes was collected at the maturity stage of the crop. The data was subjected to CoStat (CoStat version 6.2, CoHort Software, 2003, Monterey, CA, USA) for statistical analysis.At the maturity of the crop, the data regarding the tillers per plant, spike per plant, spikelet per plant, spike length (cm), grain per tiller, grain per spike, grain per spikelet, single grain weight (g) and yield per hectare were recorded .

Results

Tiller per plant

The number of tiller per plant showed statistical differences grown under two water treatments. Plants grown under water shortage showed highly significant reduction in the number of tillers per plant. Under the less availability of water plants depicts 28% reduction in number of tiller per plant.

The application of silicon from different sources showed statistically non-significant values for this trait (Table 1).

Table 1. Mean square values of wheat yield attributes influenced by the foliar silicon application under rainfed conditions.

SOV	d.f	tiller/plant	Spike/ plant	spikelet / plant	Grain/ tiller	Grain/ spike	Grain/ spikelet	Spike length	Single seed weight	Yield per hector
Block	2	0.307ns	0.064ns	6.3952*	10.147ns	49.052ns	22.313ns	3.13*	1.313ns	445102.509
Lev	7	1.314ns	0.200ns	4.226ns	32.632ns	104.25ns	7.738ns	1.603ns	4.515ns	4463856.55**
Str	1	23.613***	20.89***	77.995***	1669.90***	1948.95***	279.17***	145.95***	7.969ns	640415893***
Interaction of Si level into stress	7	0.200ns	0.377ns	1.714ns	17.379ns	61.199ns	8.097ns	0.461ns	9.201ns	1687539.133ns
Error	30	0.638	0.366	1.884	76.646	76.121	5.985	0.747	6.528	1218696.100
Total	47									

Under the normal irrigation L4 (0.1 *mM*sodium silicate*)* and L8 (0.1 *mM*potassium silicate) showed the maximum values for the number of tiller per plant as compared to the untreated plants. Whereas under water deficit conditions the application of 0.1 *mM*of sodium silicate showed the 21.5% increased values for this trait as compared to the plants which were not treated with any source of silicon (Fig.1).

Number of spike per plant

The plants showed highly significant differences in values of spike per plant. The plants experiencing the water shortage showed 30% decreased in number of spike per plant (Table 1).

The application of silicon showed some beneficial effects on the number of spike per plants (fertile tillers). Under the normal irrigation 15.8% increase was observed in plants treated with 0.1 *mM*of sodium silicate as compared to the untreated ones. Under the water deficit conditions the most pronounced effects of silicon application was recorded with 0.01 *mM*of sodium silicate as compared to the controlled plants (Fig. 2).

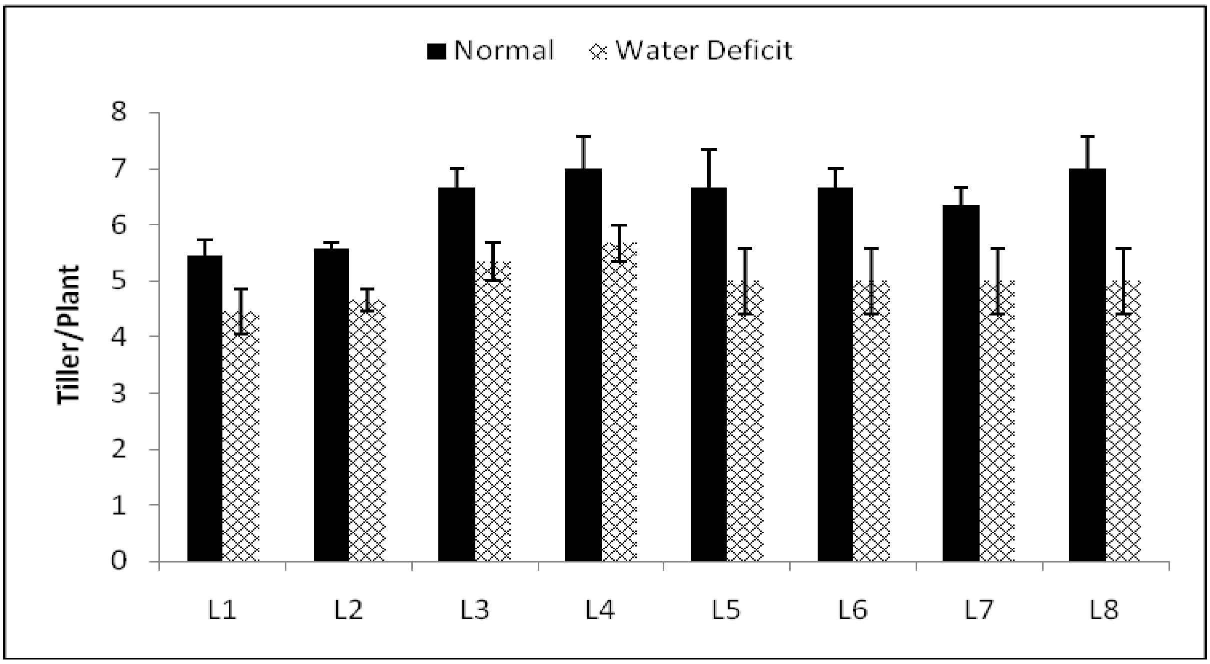

Fig. 1. Impact of foliar silicon application on tillers per plant of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01 *mM*Na_2SiO_3 , L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate).

Number of spikelet per plants

The number of spikelet per plants statistically showed highly significant reduction when experienced the water stress. Under the water deficit conditions 28.47% reduction was observed in the spikelet per plant (Table 1).

The application of silicon in normal irrigation showed the 9.8% increased when apply 0.01 *mM*of potassium silicate. The plants experienced water stress showed 19.07% increase in spikelet per plant when applied higher concentration of the silicic acid 0.1 *mM*(Fig. 3).

Length of the spike per plants

Length of the spike per plants showed the highly significant effects of water shortage. Plants experiencing water stress showed the 34.86% decreased spike length of plants. The maximum spike length of the plants was recorded with the application of 0.01 *mM*silicic acid and it showed about 12.83 % increase in plants grown under well watered conditions. The plants experiencing the water deficit conditions showed the highest values by the application of 0.1 *mM*potassium silicate and showed 10.76% increased in this attribute of yield (Fig. 4).

Grain per tiller of the plants

Grain per tiller of the plants showed the highly significant effects of water shortage. Plants experiencing water stress showed the 26.60% increased number of grain per tiller of plants. The highest number of grains per tiller of the plants was recorded with the application of 0.01 *mM*potassium silicate and it showed about 2.3 % increase in plants grown under well watered conditions. The plants experiencing the water deficit conditions showed the highest values by the application of 0.1 *mM*silicic acid and showed 2.99% increased in this attribute of yield (Fig.5).

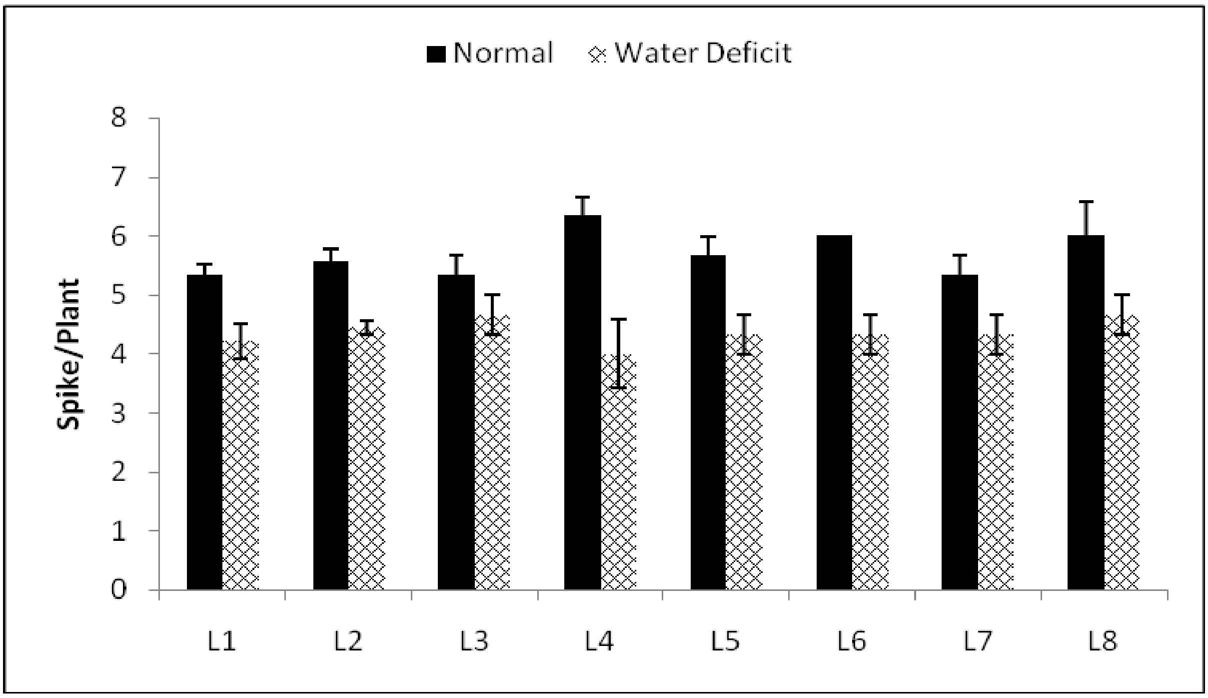

Fig. 2. Impact of foliar silicon application on number of spike per plant of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01 *mM*Na_2SiO_3 ,L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate).

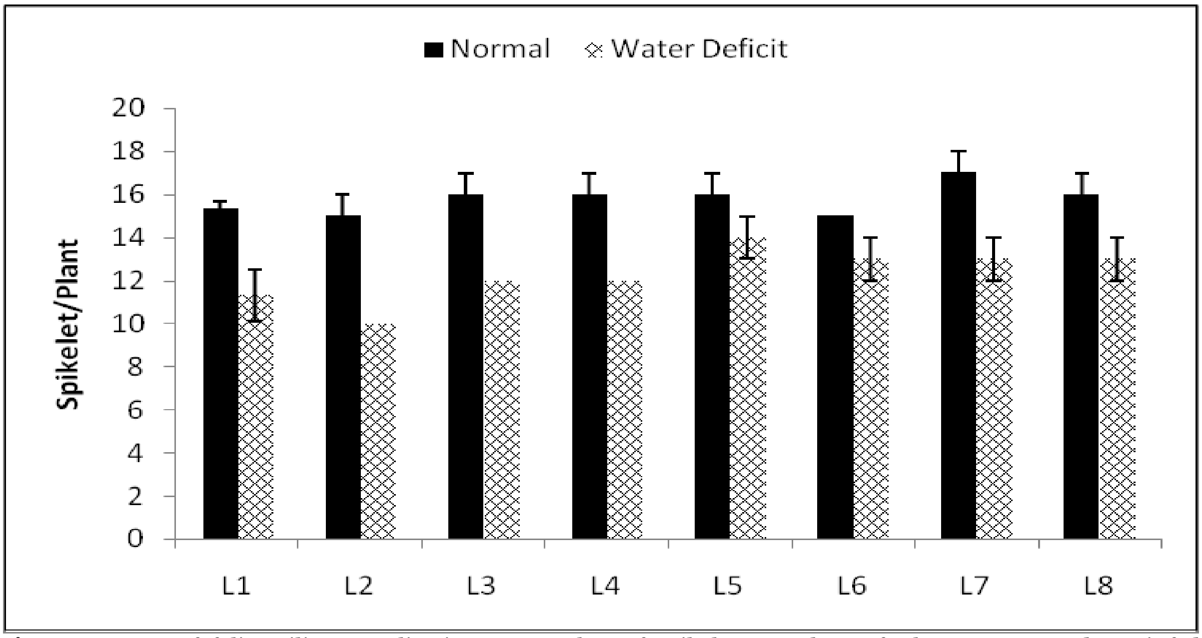

Fig. 3. Impact of foliar silicon application on number of spikelet per plant of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01*mM*Na_2SiO_3 , L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate).

Number of grain per spike

The number of grain per spike showed statistical differences grown under two water treatments. Plants grown under water shortage showed highly significant reduction in the number of grain per spike. Under the less availability of water plants depicts 25.09% reduction in number of grain per spike. The application of silicon from different sources showed statistically non-significant values for this trait (Table 1).

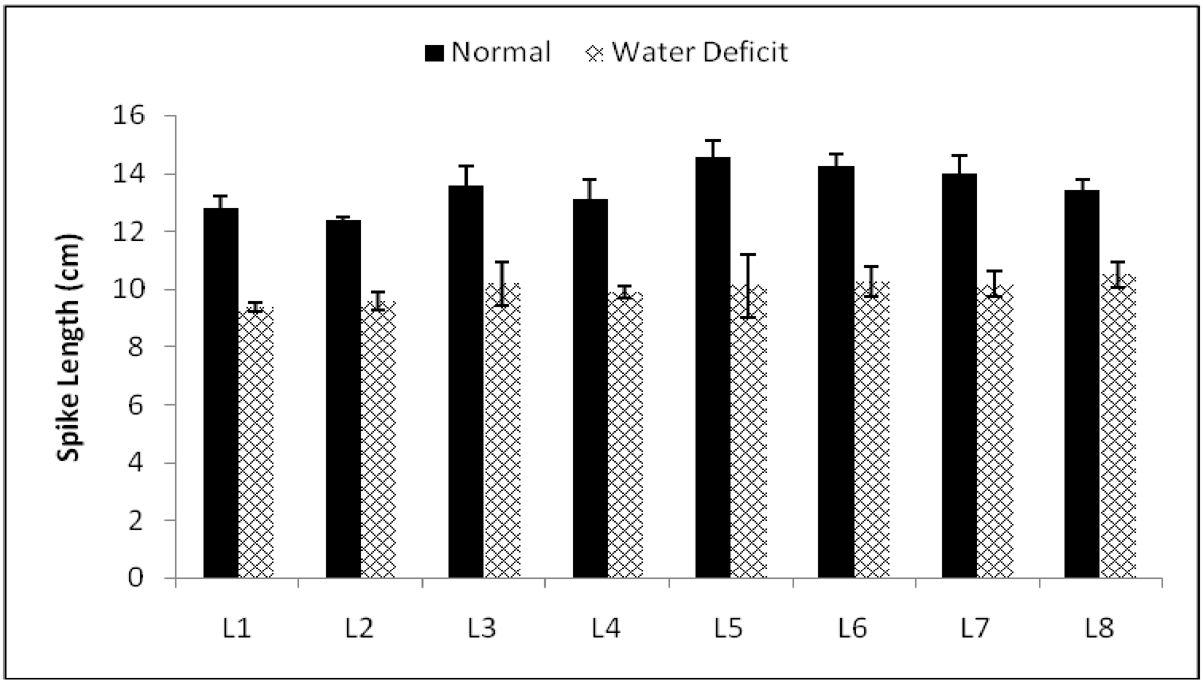

Fig. 4. Impact of foliar silicon application of spike length (cm) of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01 *mM*Na_2SiO_3 , L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate).

Under the normal irrigation L3 (0.01 *mM*sodium silicate*)* showed the maximum values for the number of grain per spike as compared to the untreated plants. Whereas under water deficit conditions the application of 0.1 *mM*of sodium silicate showed the 17.02% increased values for this trait as compared to the plants which were not treated with any source of silicon (Fig.6).

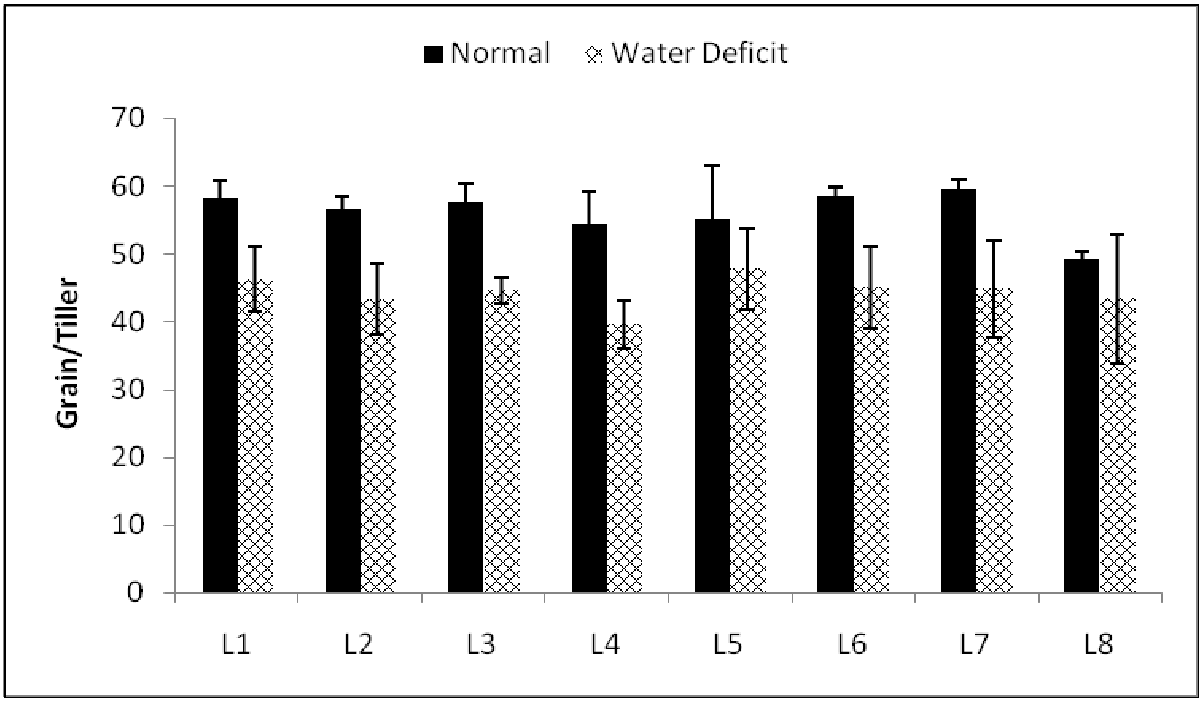

Fig. 5. Impact of foliar silicon application on number of grain per tiller of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01 *mM*Na_2SiO_3 , L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate).

Number of grain per spikelet

The number of grain per spikelet statistically showed highly significant reduction when experienced the water stress. Under the water deficit conditions 26.94% reduction was observed in the number of grain per spikelet (Table 1). The application of silicon in normal irrigation showed the 14.49% increased when apply 0.01 *mM*of sodium silicate. The plants experienced water stress showed 7.75% increase in number of grain per spikelet when applied lower concentration of the sodium silicate 0.01 *mM* (Fig.7). The single grain weight of the plant showed the non-significant results under stress conditions. The application of the silicon also showed highly non-significant values for this parameter of wheat yield (Fig. 8).

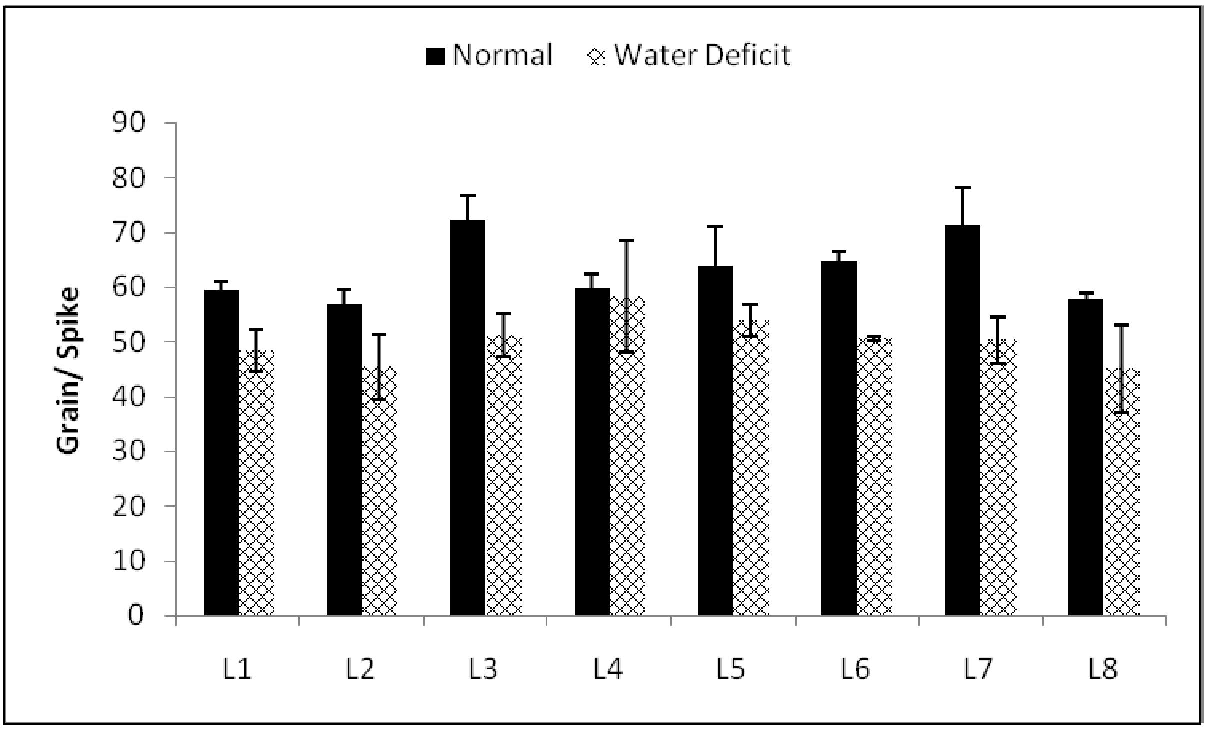

Fig. 6. Impact of foliar silicon application on number of grain per spike of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01 *mM*Na_2SiO_3 , L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate).

Yield per hector

The yield per hector of the plants showed the highly significant results grown under the water deficit conditions. The plants experiencing the drought stress showed the 61.5% reduction in yield per hector. The plants which grown under the well watered conditions showed 13.46% increased yield per hector when applied 0.01 *mM*of sodium silicate through leaves of the plants. The yield per hector of the stressed plants increased 14.27% when they received the 0.1 *mM*of the silicic acid as foliar application of the silicon (Fig.9).

Discussions

Effects of water stress at wheat production

Among cereal crops, wheat retains its own status and considered one of the major food grain source worldwide (Cordain, 1999; Ray, 2013). According to an estimation the prevailing scenarios of food scarcity hits the agriculture sector seriously and induces the pressure of more sustainable production of cereal crops to meet the basic rations of the human population globally. The agriculture production is highly affected by biotic and abiotic factors (Kadam*et al.,* 2014), particularly vulnerability of water, increase in temperature and fluctuation in the precipitation pattern (Li *et al.,* 2000; Jaleel*et al.,* 2007). The yield response of crops depends upon the adopted mechanism of the plants used to overcome the moisture stress and to complete life cycle (Blum, 2005).

Response of yield attributes under rainfed

The results of the current findings indicated that all the recorded yield attributes reduced significantly under the moisture shortage. The production of the tiller per plant and the fertility of the spikes severely affected due to the reduced availability of the water. The reduction in above mentioned yield attributes might be due to the reduced physiological processes; diminishing of chlorophyll contents and photosynthetic activity directly regulate the most critical growth and reproductive processes of plants including the development of pollen (Blum, 2005; Jaleel*et al.,* 2007; Christopher *et al.,* 2008).

The reduction in other yield related attributes of wheat plants including the production gains might be the result of the pollen sterility due to the less availability of water (Christopher *et al.,* 2008).

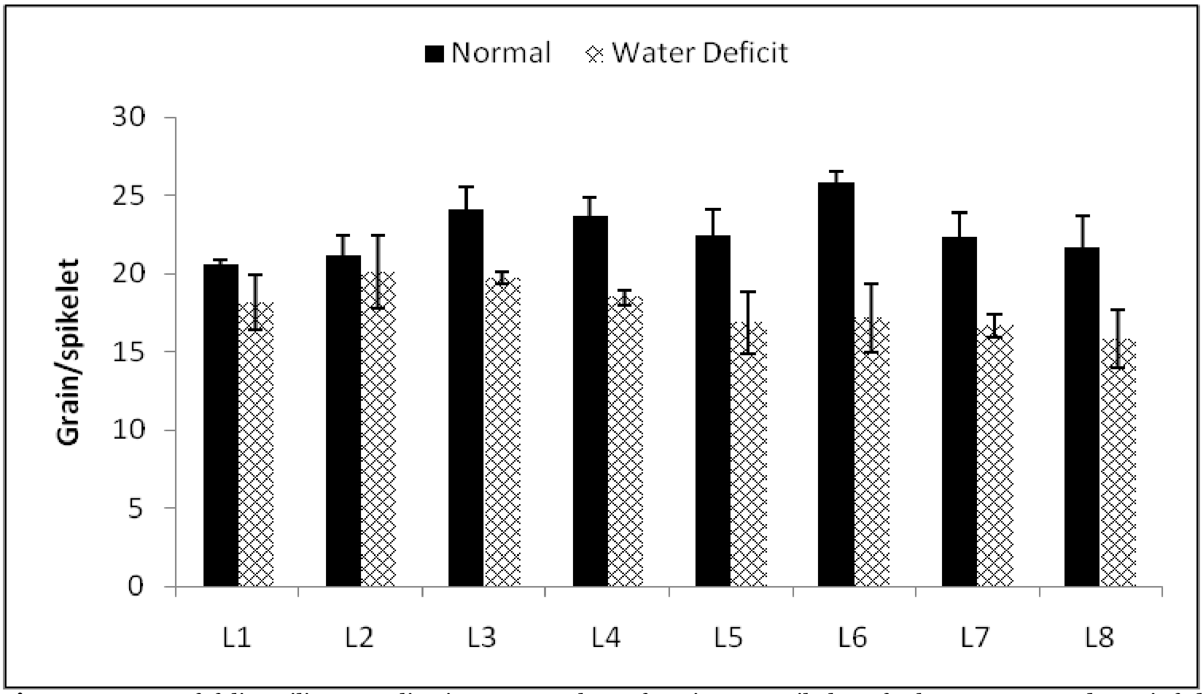

Fig. 7. Impact of foliar silicon application on number of grain per spikelet of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01 *mM*Na_2SiO_3 , L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate).

Role of silicon in wheat production under water stress

Among different strategies to alleviate the drought stress in cereal crops, the use of silicon is considered one of the potential candidate to reduce the abiotic stresses in grasses (Neumann and Nieden, 2001).

It is well reported that silicon can reduce the different abiotic stresses and increased the yield of crop by improving yield components under rainfedconditions (Ma *et al.*, 2001; Xia *et al.*, 2001). The present study indicated that under drought stress different yield attributes reduced due to the disturbance in the various physiological processes as well as insufficient supply of water disturb the assimilation and translocation of nutrients (Raza*et al.* 2013).

The findings of current study showed that exogenously feeding if silicon significantly improved growth and yield attributes of wheat under both normal and water deficit conditions.

The exogenous supply of the silicon enhanced the wheat grain yield by maintain different physiological processes as photosynthesis and enhance the cell membrane stability that considered important processes to improve the yield components (Karmollachaab*et al.*, 2013).

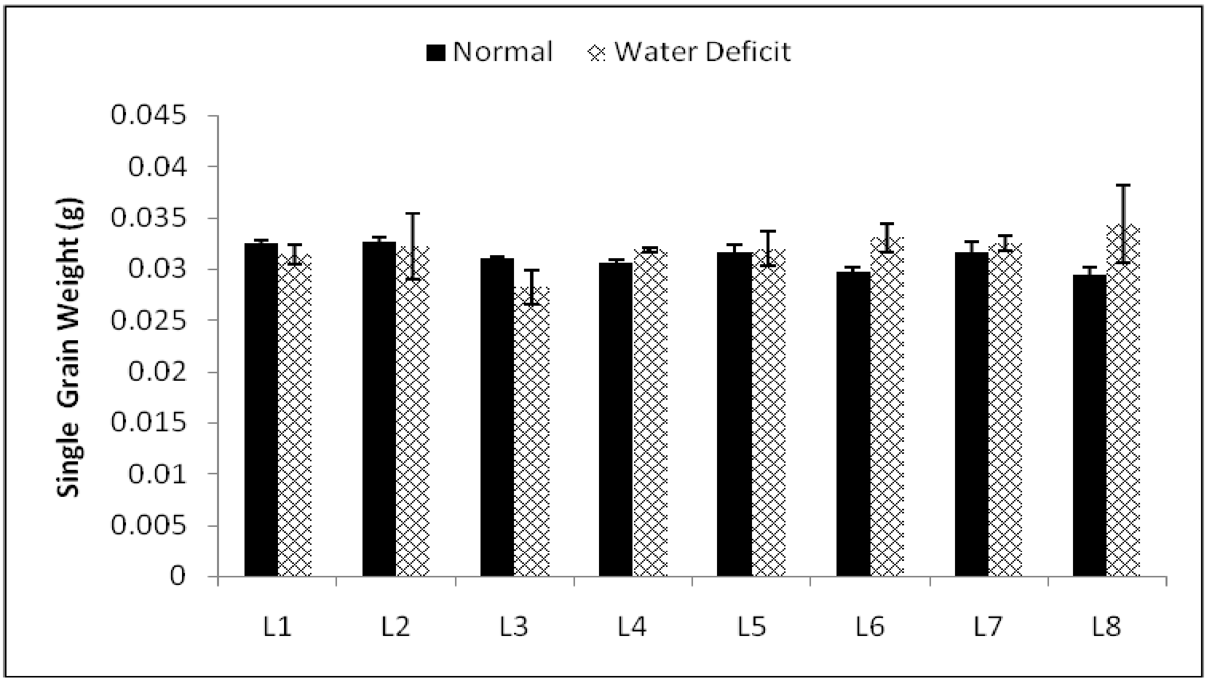

Fig. 8. Impact of foliar silicon application on single grain weight (g) of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01 *mM*Na_2SiO_3 , L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate).

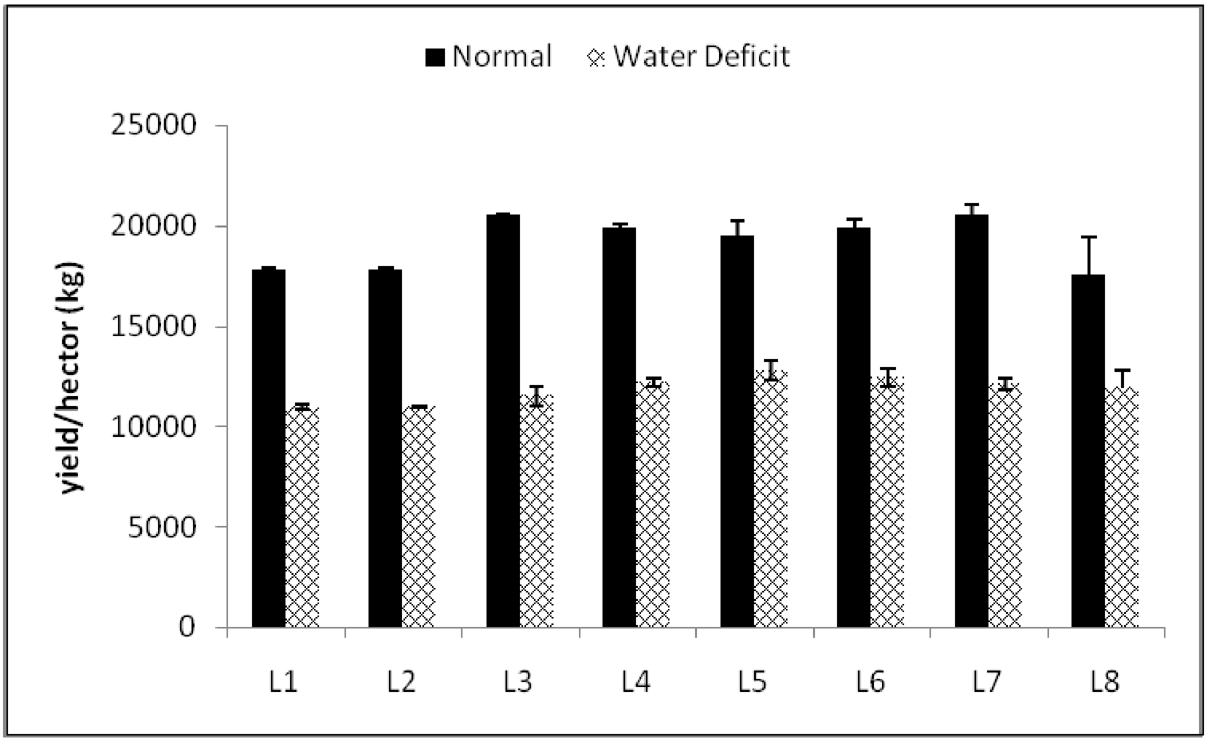

Fig. 9. Impact of foliar silicon application on yield per hector (kg) of wheat grown under rainfed conditions (Key to figure: L1= no spray, L2= 0 *mM,* L3= 0.01*mM*Na_2SiO_3 , L4= 0.1 *mM*Na_2SiO_3 ,L5= 0.01 *mM*Silicic acid, L6= 0.1 *mM*Silicic acid, L7= 0.01 *mM*potassium silicate, L8= 0.1 *mM*potassium silicate)

The application of different silicon concentrations improved the dry matter of wheat under water shortage and also improves the leaf pigments of the plants and improves the water use efficiency that resulted in increased values of yield components (Gong *et al.*, 2003).

Conclusion

The results of the current studies concluded that foliar silicon application improves the yield attributes of wheat when applied at 0.1*mM* from the potassium silicate. The use of the sodium silicate also showed some positive results under water stress when applied in lower concentration 0.01*mM* as compared to the untreated ones.

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