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OPTIMIZATION OF SOURCE AND RATE OF SOIL APPLIED SILICON FOR IMPROVING THE GROWTH OF WHEAT

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Silicon (Si) is known to be a beneficial element that involved in improving the growth of many crops. It was hypothesized that effective source and optimized rate of soil applied Si could promote the growth of the wheat under normal condition. Thus, this study aimed to assess the effective source and best level of soil applied Si on the growth of the wheat seedling. Experiment was comprised of three silicon sources (sodium silicate, calcium silicate and silicic acid) and four concentrations (0, 50, 100 and 150 mg kg^{-1}). Wheat plants were harvested 40 days after sowing and evaluation was made on the basis of different morphological characteristics of the plants. Results revealed that soil applied Si improved the growth of wheat plant when compared to control. Significantly the higher shoot and root length, their fresh and dry weights, shoot: root ratio, total plant biomass was obtained when 100 and 150 mg kg^{-1} Si applied from Ca-silicate. However, these two levels were at par with each other in many parameters observed. The current results also enabled us to select the most effective (100 mg kg^{-1}) out of four levels of Si from Ca-silicate.
Keywords: Silicon, sources, concentration, wheat, *Triticum aestivum*, growth

INTRODUCTION

After oxygen silicon (Si) is second most abundant element on earth (Savant *et al*., 1997; Singer and Munns, 2006; Nanayakkara *et al.*, 2008). Despite such a large abundance, Si is scarcely available in most soils. Repeated cropping usually reduces the available Si to the extent that additional fertilization is required for fetching maximum yield. Although the essentiality of silicon has not been established thus far, increasing number of studies show that it has a beneficial role in yield exhibition for many crop species (Epstein, 1994; Epstein and Bloom, 2005). Available reports show rice and sugarcane yield increased remarkably with Si fertilization (Liang *et al*., 2006; Datnoff *et al*., 2001; Ma and Takahashi, 2002). In rice, Si application increased the availability of water, improving water use efficiency, and reduced the toxicities associated with Mn, Fe and Al, together with increased mechanical strength of stems, improved growth, reduced seed shattering, and also helped in controlling insect pests attack (Ma, 2004; Fallah, 2012; Ma *et al*., 2001; Epstein, 1999). A recent report showed that Si improved salinity tolerance in lettuce (Milne *et al*., 2012). Silicon is taken up by the plant root as monosilicic acid (H_4SiO_4) (Jones and Handreck, 1967). Having been absorbed and transported to aerial parts, silicic acid is deposited as hard polymerized silica gel called as plant opal on the epidermis (Yoshida *et al*., 1962). Although the capacity of wheat to accumulate Si is seldom known, other species of family Poaceae such as rice and sugar cane and cereals have been shown to accumulate Si on a dry matter basis between 4.6 to 6.9% and between 0.5 to 1.5%, respectively (Datnoff and Rutherford, 2004). Some reports show that Si-triggered leaf growth expansion was principally the result of increase in size of the individual cells. Increase in cell size may be a result of enhanced water uptake into the cell and greater tugor (Hossian et al., 2002). Si involved in the extensibility of the cell wall that resulted in expansion plant cell (Cosgrove, 2005). Beside these studies, there are some evidence which suggest that Si promotes the growth by altering the physiological phenomena like photosynthesis, changes the chemical composition of the cell wall and increases the availability of nutrients (Hattori et al., 2003). Plants of one species containing different concentrations of Furthermore, plant species, which are known for responsiveness to Si proved non-responsive when they were grown in certain soils (Rodriguez and Ponce, 1983). Datnoff *et al*. (1991) assigned this inability to use low amount of Si fertilizers or less available Si in soil.

In view of the above information, it is important to determine the plant responsiveness to Si fertilization for wheat crop in order to investigate the beneficial effects of Si. Moreover, currently available sources of Si vary widely in their concentration, solubility and plant availability. We hypothesize that various sources of Si show differential availability and effects on wheat (*Triticum aestivum* L.) growth and development Therefore, it is highly imperative to evaluate the effects of Si sources and rates of their application to determine the specific their response on wheat and optimize Si levels from each of these sources.

MATERIALS AND METHODS

Experiment was conducted in pots containing the soil medium. Soil was taken from research area, Department of Agronomy, University of Agriculture, Faisalabad. Wheat cultivar Sahar-2006 was used for these experiments. Wheat cultivar was obtained from Ayub Agricultural Research Institute, Faisalabad, Pakistan. Twelve kg of prepared soil was filled in each pot. A basal dose of N @ 100 mg kg^{-1} as urea, P @ 90 mg kg^{-1} as DAP and K @ 60 mg kg^{-1} as potassium sulphate was mixed into soil prior to seed sowing. In each pot 10 seeds were sown and maintained 5 plants per pot after seedling emergence. The pots were arranged according to completely randomized design (CRD) with three replications. Experiment was conducted to optimize the source and level of Si as soil application. The experiment comprises of following treatments:

Factor A. Sources of silicon
- i) Sodium silicate
- ii) Calcium silicate
- iii) Silicic acid

Factor B. Levels of silicon
- i) 0 (Control)
- ii) 50 mg kg^{-1}
- iii) 100 mg kg^{-1}
- iv) 150 mg kg^{-1}

Following observation were recorded 40 days after emergence; shoot and root length, their fresh and dry weights, shoot: root ratio and total biomass.

Plants were harvested after 40 days after emergence. The harvested fresh samples were washed thoroughly with distilled water and separated into roots and shoots. Root and shoot lengths and fresh weights were measured. The samples were then oven-dried at 75 ºC till a constant weight and dry weights of root and shoot were recorded. Root shoot ratio was calculated on dry weight basis. Root and shoot dry weights were pooled and total biomass weight was also calculated. Experimental data was analyzed using Fisher's analysis of variance technique and the treatment means was compared by least significant test at 5% probability level by using the software Statistix 8.1.

RESULTS

***Shoot length*:** The data (Fig.1) showed that soil applied silicon from all sources significantly affected the shoot length of wheat. Different level of silicon from all sources significantly enhanced the shoot length when compared to the control. Maximum shoot length was recorded when calcium silicate was applied at the rate of 100 mg kg^{-1} of soil that was statistically at par with 150 mg kg^{-1}. 100 mg kg^{-1} and 150 mg kg^{-1} silicon from sodium silicate and silicic acid had similar effects on shoot length of wheat which was followed by the 50 mg kg^{-1}silicon from these sources.

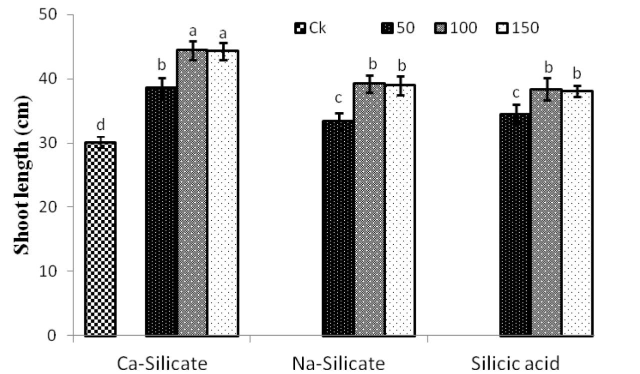

Figure 1. Influence of various sources and levels of silicon on shoot length (cm) of wheat ± SE. Ck (control), 50 mg kg^{-1}, 100 mg kg^{-1}, 150 mg kg^{-1}

Shoot fresh weight: Higher shoot fresh weight indicates better growth response of wheat seedling to the treatments. A perusal of data (Fig. 2) on shoot fresh weight showed that soil applied silicon from all sources promoted the growth of wheat when compared to the control. Higher shoot fresh weight was recorded when 100 mg kg^{-1} silicon was applied from calcium silicate which was statistically equal to the 150 mg kg^{-1} silicon from that source and followed by 100 and 150 mg kg^{-1} silicon applied from a source sodium silicate. Minimum shoot fresh weight was observed when silicon was applied from source silicic acid as compared to other sources.

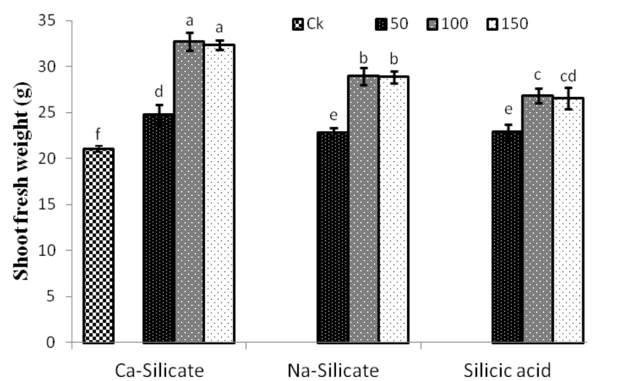

Figure 2. Influence of various sources and levels of silicon on shoot fresh weight (g) of wheat ± SE

Shoot dry weight: Vigorous seedling give healthier shoots higher in dry matter accumulation. Data presented (Fig. 3) showed that shoot dry weight was significantly affected by various sources and levels of silicon. 100 mg kg^{-1} silicon from calcium silicate produced higher shoot dry weight that have similar to the 150 mg kg^{-1} silicon of that source and followed by 100 and 150 mg kg^{-1} silicon applied from a source sodium silicate. Minimum shoot dry weight was recorded when silicon was applied through silicic acid as compared to the other sources but higher than control.

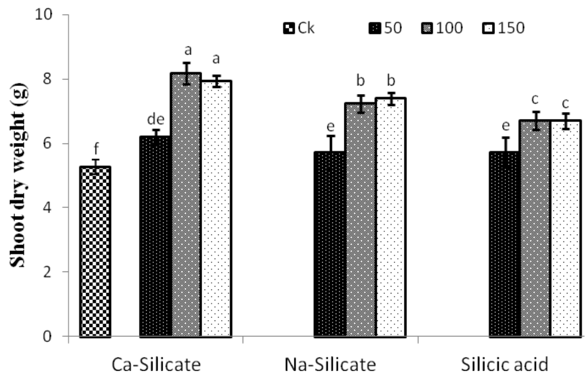

Figure 3. Influence of various sources and levels of silicon on shoot dry weight (g) of wheat ± SE

Root length**:** Seedling produced healthier and deeper root considered to be more vigorous. The comparison of different sources and their levels indicate that all sources and their levels improved the root length in wheat as compared to control (Fig. 4). Longer and statistically similar root length was produced when silicon was applied at the rate of 100 and 150 mg kg^{-1} from calcium silicate respectively. 100 mg kg^{-1} and 150 mg kg^{-1} silicon from sodium silicate and silicic acid had similar effects on root length of wheat which was followed by the 50 mg kg^{-1}silicon from these sources, whereas minimum root length was observed in control where silicon was not applied.

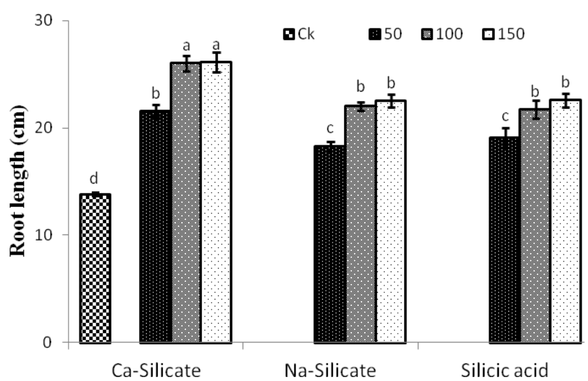

Figure 4. Influence of various sources and levels of silicon on root length (cm) of wheat ± SE

Root fresh weight**:** Vigorous seedlings bear healthier and penetrating roots. Results show that all the silicon sources and their levels significantly improved the root fresh weight as compared to control (Fig. 5). Maximum root fresh weight was recorded when silicon was applied with the concentration of 100 mg kg^{-1} from calcium silicate that was statistically at par with 150 mg kg^{-1} silicon. Application of 100 and 150 mg kg^{-1} silicon from both sodium silicate and silicic acid significantly increase the root fresh weight but lower than calcium silicate. Minimum root fresh weight was observed in control where silicon was not supply.

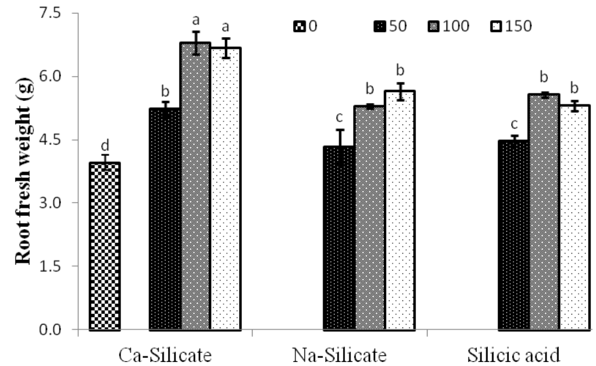

Figure 5. Influence of various sources and levels of silicon on root fresh weight (g) of wheat ± SE

Root dry weight**:** Data on root dry weight shows that root dry weight was significantly influenced by soil applied silicon sources and their levels (Fig. 6). Wheat plants supplied with 100 and 150 mg kg^{-1} silicon from calcium silicate produced higher root dry weight as compared to the concentration of other sources of silicon. 100 mg kg^{-1} and 150 mg kg^{-1} silicon from sodium silicate and silicic acid had similar effects on root length of wheat which was followed by the 50 mg kg^{-1}silicon from these sources, whereas minimum root length was observed in control where silicon was not applied.

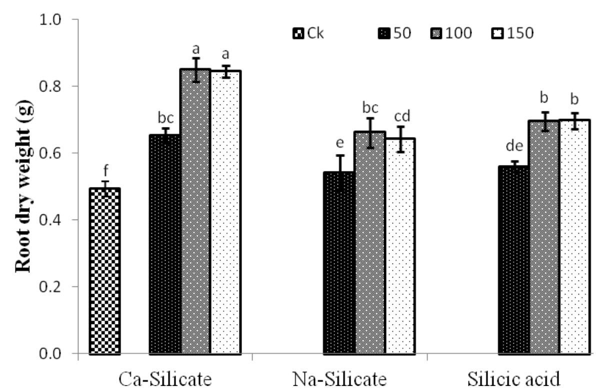

Figure 6. Influence of various sources and levels of silicon on root dry weight (g) of wheat ± SE

Root/shoot ratio**:** The data regarding root shoot ratio (Fig. 7) reveal that there was no significant difference among concentration or levels of various sources of Si for root/shoot ratio in wheat. Minimum root shoot ratio was observed in control where silicon was not supply.

Total biomass**:** The data regarding the total biomass indicate that there was significant effect of source and their levels on total biomass of wheat (Fig. 8). The comparison of means

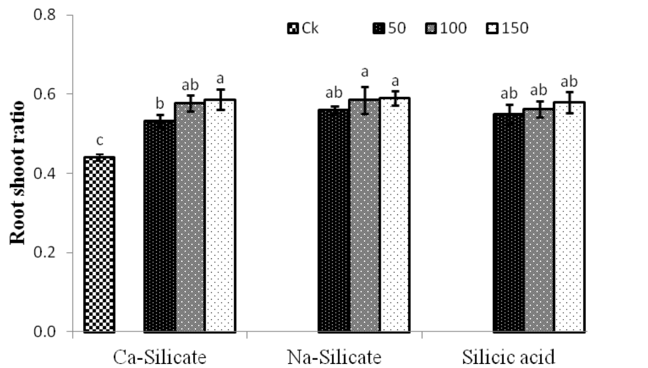

Figure 7. Influence of various sources and levels of silicon on root shoot ratio of wheat ± SE

shows that all the sources and their concentration improved the total biomass when compared to control. With the increasing rate of silicon from all sources steadily increased the total biomass of wheat. Both 100 and 150 mg kg^{-1} Si from Ca-silicate gave the highest values of total biomass over all other Si sources. These two levels were observed statistically at par with each other. This indicated that there was a linear increase in biomass up to 100 mg kg^{-1} of Si applied. Therefore, 100 mg kg^{-1} level of Si was selected for further experiments. These results (Fig. 8) indicated a significant linear relationship between Si-levels applied and total biomass.

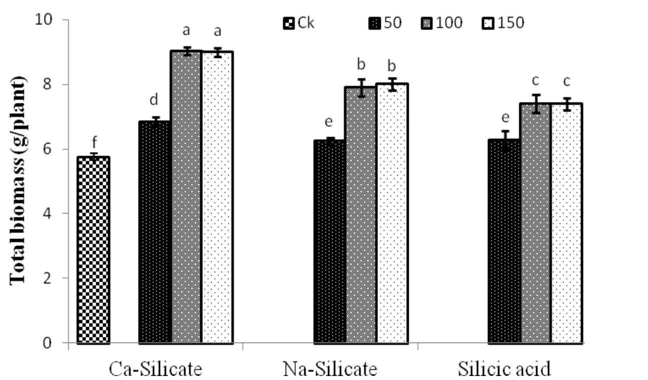

Figure 8. Influence of various sources and levels of silicon on total biomass (g/plant) of wheat ± SE

DISCUSSION

It is evidence from the present study that soil applied Si enhanced the growth of wheat seedling at all concentrations. However, maximum increase in growth attributes of wheat seedling was recoded at 100 mg kg^{-1} Si. Si not only increase the total biomass of wheat plant (Fig.8) but also increase the expansion growth parameters like shoot length (Fig. 1), root length (Fig. 4) of young wheat seedling. A number of previous studies indicate that Si is a nutrient that can enhance the growth and biomass production in various plant species including maize (Vaculík *et al*., 2009), rice (Alvarez and Datnoff, 2001), barley (Liang *et al*., 1996), cucumber (Zhu *et al*., 2004), cowpea (Mali and Aery, 2009) and alfalfa (Guo *et al*., 2006). Well-marked influences of Si were noted on growing regions of plant like root, shoot and leaves. These results are conform to the previous reports, which witness that the soil augmented Si increased the growth of younger plant parts more than the older ones (Hossain *et al*., 2002; Hattori *et al*., 2003, 2005; Hossain *at al*., 2007).

Different authors have different opinions on the role of Si in plant growth and developmental phenomena. Some reports suggest that soil-applied Si enhances the growth by modulating the morphological and biochemical attributes (Epstein, 1994). In this respect, Si changed the overall structure of the leaves leading to changed leaf area and its thickness (Epstein, 1999; Isa *et al*., 2010). Moreover, Si increased the growth and yield of cucumber by making the mature leaves more rigid, resulting in changes orientation of leaves, which apparently helped in better interception of light (Miyake and Takahashi, 1983; Adatia and Besford, 1986). Additionally, Si deposited in leaves mediated an increase in the phenol and anthocyanins concentrations, which acted as solar screen to protect the leaf tissues from damage by ultraviolet radiations (Goto *et al*., 2003; Shen *et al*., 2010).

The current study showed that soil applied Si enhanced the shoot and root fresh and dry weight (Fig. 2, 3, 5 and 6) which might be due to higher photosynthetic rate resulting into higher dry matter production. In line with these results, various studies showed that exogenous application of Si enhanced shoot dry and fresh weight in wheat (Gong *et al*., 2002) and rice (Yeo *et al*., 1999). It was proposed that Si form a silica body in the mesophyll cells act as window that enhanced the light use efficiency by facilitating the transmission of light for photosynthesis (Kaufman *et al*., 1979). Application of Si also enhanced the CO_2 fixation in rice (Ma *et al*., 2002) and 31% increased the Rubisco activity in cucumber on dry weight basis compared to the control (Adatia and Besford, 1986). Gong *et al*. (2006) reported that Si application increased 15 % root dry weight in barley compared to control. However, some contradictory results were obtained for root growth where Si added to solution culture did not alter the root growth (Moussa, 2006; Al-aghabary *et al*., 2004).

Si primarily exists in the soil in different minerals of silicate. Most of these minerals are largely insoluble, though low levels of mono- and polysilicic acid invariably found dissolved in the soil solution. The ability of soils to meet plant requirements for Si depends upon the Si solubility and the dissolution kinetics of various silicate minerals under typical soil conditions is not well understood. Similarly, the response of crops to Si application at different growth stages is not well established. Many Si containing products have been used for Si fertilizer but there is great variation in their composition, solubility and amount of available Si (Datnoff *et al*., 2001; Ma and Takahashi, 2002).

Efficiency of Si also depends upon its formulation. Various form of Si is being used. These include sodium silicate, calcium silicate and silicic acid. Results indicate that Ca-silicate found to be the best source of Si for the wheat growth. Ca-silicate might be more soluble and provide available Si to the rooting media as compared to other sources. A number of studies showed that Ca-silicate as a source of Si was one of the most effective source in rice (Prakash *et al*., 2010; Prakash, 2002; Singh, 2006). Synder (1989) reported that application of Ca-silicate increased the yield of rice mainly due to the more supply of plant available Si. Ca-silicate suitable for use as soil fertilizer, however, its effectiveness is mostly dependent on their reactivity and solubility rather than total Si contents (Ma and Takahashi, 2002; Gascho, 2001).

It is concluded that soil applied Si significantly enhanced the growth of wheat. Better results were obtained when Si was applied as Ca-silicate at the rate of 100 and 150 mg kg^{-1} of soil. The current results also enabled us to select the most effective (100 mg kg^{-1}) out of four levels of Si.

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