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Potential of Silicon Amendment for Improved Wheat Production

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Summary

MANY STUDIES HAVE SHOWN POSITIVE RESPONSES of various crops to silicon (Si) application in relation to plant health, yield, and quality. Although not classified as an essential plant nutrient, Si is recognized as a "beneficial substance" due to its key role in plant mineral nutrition, especially under stressed conditions. The University of Idaho (UI) team conducted a study to evaluate the effect of Si on wheat plant growth and grain production. The experiment was carried out for two consecutive growing seasons (2016 and 2017) in southern Idaho. Three Si fertilization rates (140, 280, and 560 kg Si/ha) corresponding to 25%, 50%, and 100% of manufacturer-recommended rates and two application times (at planting and tillering) were applied. MontanaGrow (0–0–0–5) by MontanaGrow Inc. (Bonner, Montana, USA) used in this study was an Si product sourced from a high-energy amorphous volcanic tuff. There was no significant effect of Si rate and application time on plant height, nutrient uptake, grain yield, or grain protein content of irrigated winter wheat grown in nonstressed conditions. We are planning to further investigate the effect of Si on growth and grain production of wheat and other crops grown in nonstressed versus stressed conditions utilizing several different Si sources and application methods.

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Introduction

Balanced mineral nutrition is important for wheat yield and quality. Silicon (Si) was recorded as one of the elements required for plant life in the early 1910s (Halligan 1912). However, Si importance for plant growth and development is still unclear due to the lack of evidence showing its direct role in plant metabolism. Although Si is not recognized as an essential plant nutrient, it is classified as a "beneficial substance" based on the evidence of its functionality for a variety of crops (IPNI 2015). Lack of Si is known to cause negative physical impacts on plant growth, development, and reproduction in wheat (Rafi et al. 1997).

Si is the second most plentiful element in the Earth's crust; however, it exists in a polymerized form, which is not readily available for plant uptake. Intensive crop cultivation results in depletion of plant-available Si from the soils (Meena et al. 2014). Plants can take up Si in its depolymerized form—the mono silicic acid (H2SiO4). This soluble form of Si is easily absorbed by plant roots and accumulated in plant tissues, with typical concentrations between 0.1% and 10% (Pati et al. 2016). Wheat is considered a high Si accumulator: grasses and cereals contain between 1% and 3% Si (IPNI 2015). Si is deposited within the plant leaves, where it becomes condensed into a polymerized Si gel (SiO_2-nH_2O) known as a phytolith (Raven 1983). Phytoliths are immobile structures that make up a protective layer within plant cell walls that helps to alleviate biotic and abiotic stresses.

Some of the benefits of Si to cereal crops grown under stress include i) improve growth and increase biomass production (under drought and salt stress) (Janislampi 2012); ii) decrease the intensity of oxidative cell damage (under flooded conditions) (Balakhnina et al. 2012); iii) increase potassium (K+) concentration in the shoots, which helps to maintain water potential and enhance biomass and grain production (under drought) (Ahmad et al. 2016); and iv) increase chlorophyll content and enhance the activity of several anti-stress enzymes (under salinity stress) (Saleh et al. 2017).

Field Experiment in Southern Idaho

The majority of previous studies have investigated the effect of Si rate, source, and application time on crop growth separately. Most Si-related work has been focused on assessing the potential of Si to alleviate plant stress. The objective of the study was to evaluate the effect of Si rates and application times on growth, yield, and protein of irrigated winter wheat grown in Idaho's semiarid conditions. In addition, we assessed the impact of Si fertilization on the uptake of other nutrients [phosphorous (P), K, magnesium (Mg), and calcium (Ca)].

Experimental fields were located at the University of Idaho (UI) Southwest Research and Extension Center, Parma. Two fields were used in the 2015–16 growing season and one field in the 2016–17 growing season. Soft white winter wheat (var. Stephens) was planted in the fall at 155 kg/ha seeding rate. Following a preplant soil test, all plots were treated at seeding with N, P, and K to achieve UI-recommended levels for wheat. The experimental design was a randomized split plot design with four replications. The main plot treatments were two application times (at planting and at tillering) and subplot treatments were three Si rates (140, 280, and 560 kg Si/ha) corresponding to 25%, 50%, and 100% of manufacturer-recommended rates. An unfertilized check plot to which no Si was applied was used to assess an overall wheat response to Si.

All plots were treated with MontanaGrow Si soil amendment (0–0–0–5) by MontanaGrow Inc. (Bonner, Montana, USA)—an Si product sourced from a high-energy amorphous (noncrystalized) volcanic tuff. It contains 76% plant-available Si easily absorbed by plants. The manufacturer lists several potential benefits of the MontanaGrow Si, including strengthening of plant roots, stems, and foliage; superior overall crop health with increased stress and disease resistance; higher yields; and increased water use efficiency. For wheat, specifically, the potential benefits included boosted grain yield and grain quality and increased resistance to lodging. Plots were irrigated using a sprinkler irrigation system weekly from late April through mid-June. Wheat was mechanically harvested at physiological maturity in late July–early August.

Figure 1. Application of Si at 560 kg/ha (100% rate) at planting (right) resulted in notably taller, greener, healthier-looking plants compared to no Si applied (left).

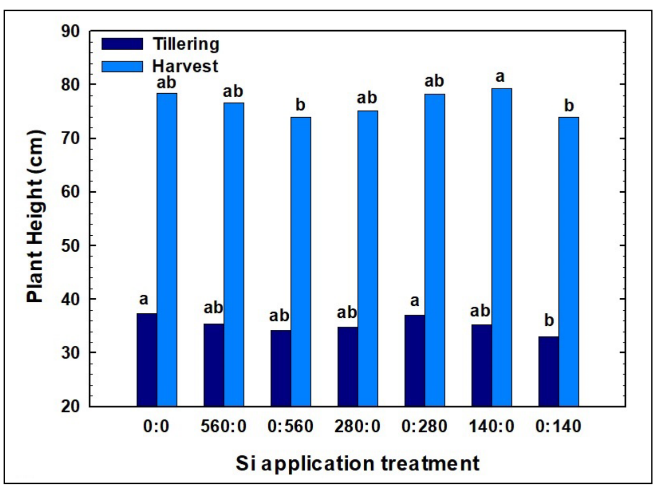

Table 1. Effect of different silicon (Si) rates and application time on winter wheat height at tillering and before harvest in 2017. Treatments were designated in the format x:y, where x and y are the fertilizer Si rates in kg Si/ha applied at planting and at tillering, respectively. Bars within the same year followed by the same letter are not significantly different ($p > 0.1$) based on a Duncan's multiple range test.

Figure 2. Wheat spikes from one randomly selected plant from no-Si check (left) and Si applied at 100% rate at tillering (right).

Visual Assessment

Visual examination of wheat plants midseason has shown some positive effects on wheat growth and development (Figures 1 and 2). Application of Si at 560 lb/ac (100% rate) at planting (right) resulted in notably taller, greener, healthier-looking plants compared to no Si applied (left, Figure 1). Plant stand from Si applied at tillering was visually comparable to no-Si check. Figure 2 shows wheat spikes from one randomly selected plant from no-Si check (left) and Si applied at 100% rate at tillering (right). Plants receiving no Si had fewer, smaller, shorter spikes, compared to those receiving Si at tillering.

Plant Height

Previous studies have shown that Si application can positively affect wheat plant metabolism, growth, and yield. However, plant response to Si may depend on the applied Si fertilizer source. The deposition of Si within the plant cells increases plant erectness, indirectly increasing plant height. While Si fertilization was shown to increase wheat plant height under nonstressed conditions, the response to Si is typically more substantial under drought stress.

In our study, plant height measured at tillering ranged from 33.0 to 37.3 cm (Table 1). The tallest plants at this growth stage were observed for the check plot to which no Si was applied. The rate of Si fertilizer applied at planting had no effect on plant height.

At harvest time, plant height ranged from 74.0 to 79.3 cm (Table 1). While the maximum plant height was measured for plots to which 140 kg Si/ha was applied at planting, overall there was no consistent trend associated with the timing of Si fertilization.

Content of Si and Other Nutrients in Biomass

Wheat biomass Si content measured at tillering ranged from 1.28% to 1.48% (Table 2). At harvest, biomass Si content ranged from 0.93% to 1.21%, with the highest biomass Si values observed for 560 kg Si/ha applied at tillering (Table 2). Biomass Si content decreased consistently from tillering to harvest, likely due to the "dilution effect" as plant size increased, and (partially) due to Si translocation to the grain. Typical biomass content of phosphorus (P), sodium (K), magnesium (Mg), and calcium (Ca) was observed in this study. Phosphorus ranged from 0.38% to 0.39%, K ranged from 0.50% to 0.54%, Mg ranged from 0.12% to 0.13%, and Ca ranged from 0.04% to 0.05%. Although the differences were not significant, the highest mean P and Ca were observed for the check plot to which no Si was applied. While numerically higher mean Mg content was obtained at a fertilizer Si rate of 280 kg Si/ha applied at planting, overall Si application did not improve P, K, Mg, and Ca uptake.

Silicon application can be very site- and plant-specific in terms of affecting various plant parts differently. Some previous studies showed positive trends in macronutrient uptake in some crops following Si application. Our findings indicated that Si application did not improve Si, P, K, Mg, or Ca uptake in wheat.

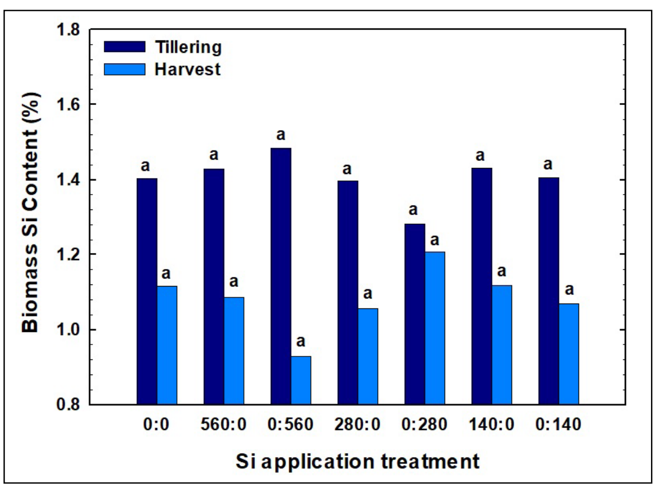

Table 2. Effect of different Si rates and application time on winter wheat biomass Si content (%) at tillering and before harvest in 2017. Treatments were designated in the format x:y, where x and y are the fertilizer Si rates in kg Si/ha applied at planting and at tillering, respectively. Bars within the same year followed by the same letter are not significantly different ($p > 0.1$) based on a Duncan's multiple range test.

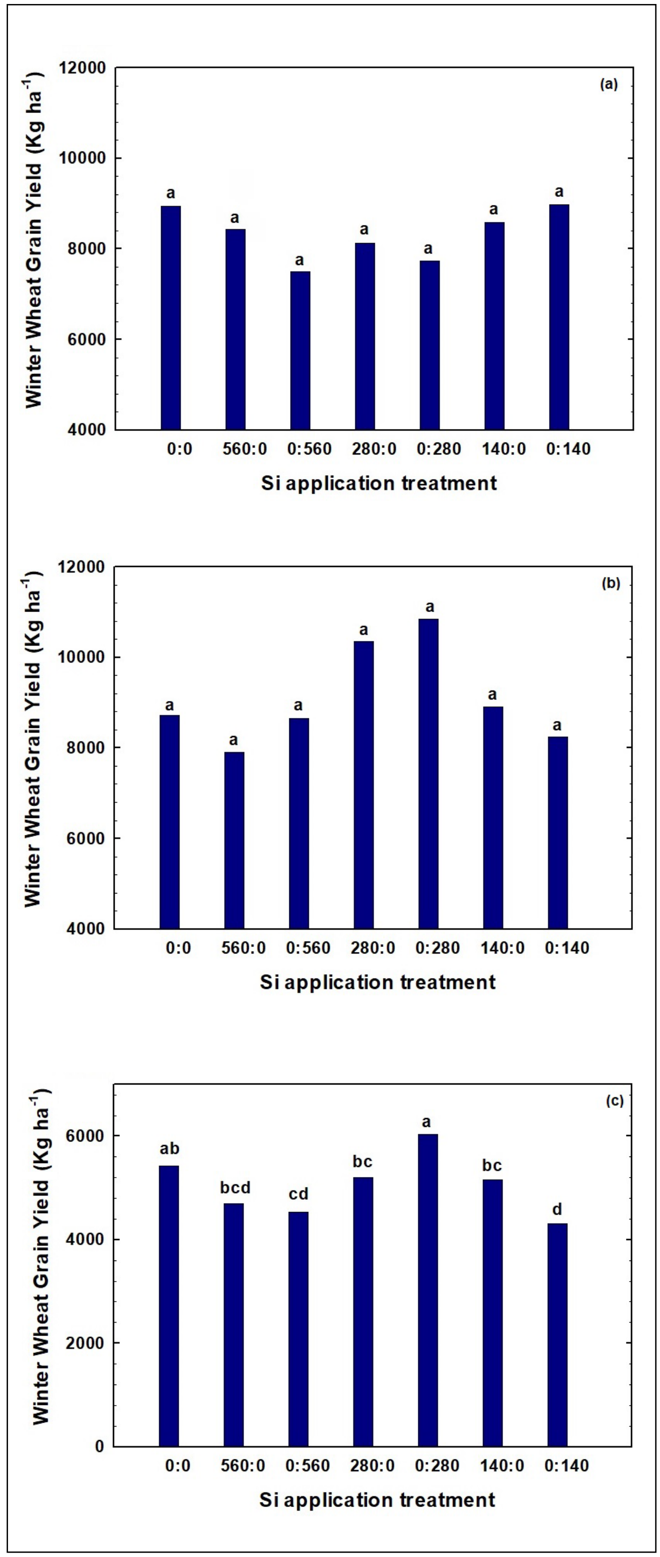

Table 3. Effect of different Si rates and application time on winter wheat grain yield in (a) Field E1 in 2016, (b) Field M2 in 2016, and (c) Field A3 in 2017. Treatments were designated in the format x:y, where x and y are the fertilizer Si rates in kg Si/ha applied at planting and at tillering, respectively. Bars within the same year followed by the same letter are not significantly different ($p > 0.1$) based on a Duncan's multiple range test.

Grain Yield and Grain Protein Content

Silicon applications can enhance crop yield via various indirect actions such as decreased shading due to changes in leaf architecture. Leaf erectness as a result of Si fertilization could account for up to a 10% increase in the photosynthesis rate, thereby indirectly increasing yield (Ma and Takashi 1993). There have been reports that Si fertilization may increase wheat grain yield by over 25% (Soratto et al. 2012). However, the positive effects of Si application yield or physiological quality of wheat grain are very limited.

In our study, the rate and application times of Si fertilizer did not significantly affect wheat yields for either of the two fields in 2016 (Table 3).

Considering all three site-years, the 280 kg Si/ha produced relatively higher yields, independent of the application times. In 2017, wheat yields were comparable for all Si rates applied at planting. However, Si applied at tillering at 140 kg Si/ha resulted in yields comparable to the check plot. An increase in Si rate to 280 kg Si/ha significantly increased wheat yield. This trend did not continue with a further increase in the rate of Si applied at tillering—application of 560 kg Si/ha resulted in relatively lower yield.

Grain protein values were typical for soft white winter wheat, ranging from 10.4% to 13.2% (Table 4). For all three site-years, the rate and application times of Si fertilizer had no positive effect on wheat grain protein content. In fact, Si application had, indeed, resulted in numerically slightly lower grain protein values, compared to the non-Si check.

Conclusion

The lack of response of wheat to Si fertilization in our study could be due to the source of Si fertilizer. Very limited information on Si source MontanaGrow showing its efficacy as a fertilizer has been published. In addition, the most beneficial responses to Si application has been documented for crops grown in stressed environments. We are planning to further investigate the effect of Si on growth and yield of wheat and other crops grown in nonstressed versus stressed conditions utilizing several different Si sources and application methods.

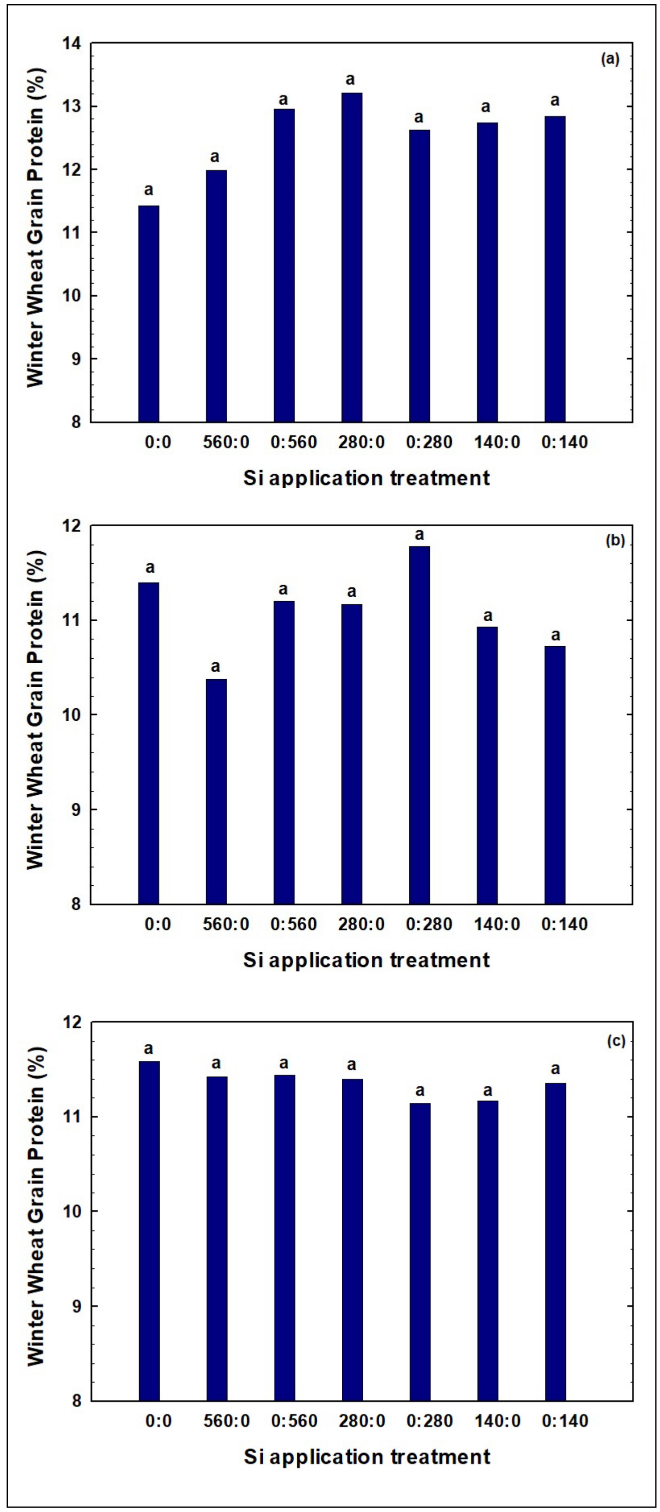

Table 4. Effect of different Si rates and application time on winter wheat grain protein in (a) Field E1 in 2016, (b) Field M2 in 2016, and (c) Field A3 in 2017. Treatments were designated in the format x:y, where x and y are the fertilizer Si rates in kg Si/ha applied at planting and at tillering, respectively. Bars within the same year followed by the same letter are not significantly different ($p > 0.1$) based on a Duncan's multiple range test.

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