MISSISSIPPI SOYBEAN PROMOTION BOARD
PROJECT NO. 73-2016 (YEAR 2)
FINAL REPORT

Title of Project: The effect of silicon on the growth and yield of soybean grown on nonirrigated sites

Name of PI: Jiaxu Li**:** JL305@BCH.msstate.edu

EXECUTIVE SUMMARY

About 50% of Mississippi soybeans are grown on dryland or nonirrigated sites; thus, these soybean are more susceptible to yield loss from drought stress. Therefore, there is a great need to develop production systems to maintain consistent yields of soybeans grown on these sites across years.

Silicon (Si) has recently been recognized as an important element in plant nutrition, and has been associated with biomass production, cell wall integrity, and increased drought tolerance in crop plants. Possible physiological mechanisms behind increased drought tolerance from silicon application include reduced water loss through stomatal and cuticular transpiration, and increased water use efficiency.

In the soil, the total silicon content may be large, but the amount of soluble silicon (silicic acid) available for plant uptake is limited. Plants take up soluble silicon into their tissues, but it is not returned to the soil through biodegradation. Thus, continuous cropping of land can cause deficiency of soluble silicon in the soil.

Because of the beneficial effects of silicon on crops described above, silicon application to soil may prove to be a strategy that will improve the growth and yield of soybeans grown on dryland or nonirrigated sites. The objectives of this research were to determine 1) if silicon application to soil benefitted soybean plant traits associated with increased drought tolerance, and 2) its effect on seed yield of soybean grown on nonirrigated sites.

Studies conducted for this project showed that soil application of potassium silicate 1) can improve vegetative growth of soybean via increasing the water use efficiency of plants growing under water-limiting conditions, 2) silicate application can improve soil moisture retention under water-limiting conditions, and 3) silicate application to nonirrigated field sites can increase seed yield of soybeans grown on those sites.

The cost of the potassium silicate product used in this study is prohibitively expensive to use in dryland soybean production systems. However, alternate sources such as rice husk ash and blast furnace slag are being explored for use in these environments to obtain the same benefits as those found in these studies.

BACKGROUND AND OBJECTIVES

About 50% of Mississippi soybeans are grown on dryland or nonirrigated sites; thus, these soybean are more susceptible to yield loss from drought stress. The Intergovernmental Panel on Climate Change predicts that drought will increase in intensity and frequency in the United States, especially in Southern states. Therefore, there is a great need to develop production systems to maintain consistent yields of soybeans grown on dryland or nonirrigated sites across years.

Silicon (Si) has recently been recognized as an important element in plant nutrition. Silicon is now designated as a "plant beneficial substance" by the Association of American Plant Food Control Officials. Silicon has been shown to increase plant biomass in rice, sorghum, and wheat. Plants with supplies of soluble silicon produce stronger cell walls making them more heat and drought tolerant. When supplemented with soluble silicon, several crops, including corn, wheat and rice, showed marked increases in drought tolerance compared to unamended plants. Additionally, under drought conditions, silicon applied to plants resulted in higher relative water content compared to those plants without the silicon treatment.

Possible physiological mechanisms behind increased drought tolerance from silicon application include reduced water loss through transpiration at leaf stomata and the cuticle and increased water use efficiency. In the soil, the total silicon content may be large, but the amount of soluble silicon (silicic acid) available for plant uptake is limited. Plants take up soluble silicon into their tissues, but it is not returned to the soil through biodegradation. Thus, continuous cropping of land can cause deficiency of soluble silicon in the soil.

Because of the beneficial effects of silicon on crops described above, silicon application may prove to be a strategy to improve the growth and yield of soybeans grown on dryland or nonirrigated sites. Our preliminary results in the greenhouse indicate that application of potassium silicate to soil could enhance drought tolerance in soybeans.

The objectives of this project are to: 1) evaluate the effects of silicon application on the vegetative growth of soybeans grown under water deficit conditions; and 2) evaluate the effects of silicon application on the seed yield of soybeans grown on nonirrigated sites.

REPORT OF PROGRESS/ACTIVITY

Objective 1: Evaluate the effects of silicon application on the vegetative growth of soybeans grown under water deficit conditions.

The first set of experiments were conducted to determine the optimal concentration of silicon on soybean growth. Asgrow 5332 soybean plants were grown outside in 2-liter plastic pots containing different amounts of potassium silicate (Agsil16H; PQ corporation) at the Environment and Plant Physiology Laboratory, Mississippi State University. To cancel the effect of potassium, a similar amount of potassium chloride was used as controls. At 45 days after planting (DAP), different parameters such as plant height, number of nodes, and soil moisture content were measured. As shown in Figure 1, 500 ppm of silicon was found to be the optimal concentration for soybean vegetative growth.

The next set of experiments after determining the optimal silicon concentration for soybean were conducted to evaluate the effect of potassium silicate (500 ppm Si) on vegetative growth of two soybean varieties (Asgrow 5332 and Progeny 5333) subjected to different levels of water deficit. Sixty PVC pots (five pots for each treatment) were filled with a 5.5 kg mixture of sand and soil (3:1 ratio) without and with 500 ppm silicon (potassium silicate. Plants were irrigated through an automated and computer-controlled drip system that delivered water three times a day (08:00, 12:00, and 17:00 h) with Hoagland's nutrient solution. Three different levels of irrigation water representing 100%, 66%, and 33% of the computed irrigation water requirement were imposed on soybean plants at different vegetative grwoth stages.

In the first study, water limiting conditions (irrigated with 66 % or 33% of the computed irrigation water requirement) were imposed on seedlings immediately after emergence (7 DAP) grown in soil with or without 500 ppm of silicon. After 20 days of water deficit treatments (66 % or 33% of the required water), different growth parameters such as plant height, leaf area, root branch number and root volume, and total dry weight were recorded (Figures 2-5). Overall, silicate-treated plants were taller, greener, and stronger than corresponding control plants grown under water deficit conditions. The biomasses (total dry weight) of both soybean varieties grown in soil containing 500 ppm silicon were significantly greater than those of plants grown in soil without applied silicon under water limiting conditions (Figure 5). These results indicate that silicon application can improve vegetative growth and biomass production of soybean plants at the VE to V2 stage of development under water limiting conditions.

In the second study, water limiting conditions (irrigated with 66 % or 33% of required water) were imposed on plants at 20 DAP grown in soil with or without 500 ppm of silicon. After 20 days of water deficit treatments, different morpho-physiological parameters such as plant height, leaf area, root volume, total dry weight, photosynthesis, stomatal conductance, and soil moisture were measured (Figures 6-9). Soybean plants grown in soil containing 500 ppm silicon were significantly taller than plants grown in soil without applied silicon under water limiting conditions (Figure 6). The quantum efficiency of photosystem II (Fv'/Fm') of silicate-treated plants was greater than those of plants grown in soil without applied silicon (Figure 7). Stomatal conductance decreased in silicate-treated plants compared to control plants on the diminished water level (Figure 8). The decrease in stomatal conductance was responsible for maintaining the mid-day leaf water potential under stress conditions.

There was also a significant interaction in the ratio of internal to external CO_2 concentration (C_i/C_a) between the treatments but not in the cultivars. Furthermore, silicate application improved water use efficiency of both soybean varieties grown under water limiting conditions. These results show that silicon application can improve vegetative growth via increasing water use efficiency of soybean plants at the V1 to V5 stage of development under water limiting conditions.

A key finding from these studies was that silicate application could improve soil moisture retention under water limiting conditions (Figure 9). Taken together, the results from our studies indicate that silicon application can improve the vegetative growth of soybeans under reduced water conditions via increasing water use efficiency of plants and enhancing the soil's ability to retain moisture.

Objective 2: Evaluate the effects of silicon application on the seed yield of soybeans grown on nonirrigated sites.

Two Soybean varieties (Asgrow AG 5332 and Progeny 5333) were planted in the field on the Mississippi State University's North Farm. Potassium silicate (Agsil16H) was applied in the respective plots before sowing. Potassium chloride (Muriate of Potash) was applied to control plots to balance the same total potassium as in the potassium silicate-applied plots to cancel the effect of potassium and to identify the effect of silicon. Growth parameters such as plant height and total main stem nodes were recorded.

Each plot was four rows wide and 15 feet long with three replications. In 2016, one rate of potassium silicate (89 pound/acre) was applied. The plants grown in potassium silicate-applied plots had slightly greater height and increased node numbers compared to the plants grown in the soil with only potassium chloride. The seed yield of Asgrow 5332 plants grown in the soil with potassium silicate was about 5% greater than that of plants grown in control plots. These results indicate that silicon application could increase the seed yield of Asgrow 5332 soybean (an indeterminate variety). However, the same application rate of potassium silicate did not increase the seed yield of Progeny 5333 (a determinate variety).

In 2017, two rates of potassium silicate (178 pound/acre and 445 pound/acre) were applied. The plants grown in potassium silicate-applied plots were significantly taller than the plants grown in the soil with only potassium chloride (Figure 10). The whole plant dry weight of soybean grown in potassium silicate-applied plots was greater than that of plants grown in soil with only potassium chloride (Figure 11). Also, application of potassium silicate resulted in increased silicon contents in leaves of soybean plants (Figure 12). The seed yield from soybean grown in the soil with applied potassium silicate was increased significantly above that from soybean grown in soils with applied potassium chloride or without any applied chemicals (Figure 13).

In conclusion, studies from this project showed that soil application of potassium silicate could improve vegetative growth via increasing water use efficiency of soybean plants growing under water limiting conditions. Silicate application could increase the seed yield of soybeans grown on nonirrigated sites.

IMPACTS AND BENEFITS TO MISSISSIPPI SOYBEAN PRODUCERS

Water deficit stress constrains plant growth and reduces crop yield. Drought can affect soybean plants at any time during the growing season in US southern states such as Mississippi. Thus, effective strategies to cope with drought for soybean production are needed. We have found that potassium silicate application to the soil can significantly improve vegetative growth and maintain vigor of soybeans under water limiting condition. Also, potassium silicate application can increase seed yield of soybean grown in the field on nonirrigated sites.

Soil application of silicon may be used as a drought-coping strategy to maintain consistent yields of soybean grown under water limiting conditions. This should benefit all Mississippi soybean producers who grow soybean on nonirrigated sites.

END PRODUCTS–COMPLETED OR FORTHCOMING

Presentations:

Saroj Kumar Sah, Meng Li, Muteb Alrifdi, K. Raja Reddy, and Jiaxu Li (2017). Silicon improves soybean growth under water limiting conditions. The Mississippi Academy of Sciences 81st Annual Meeting, Hattiesburg, MS, February 23-24, 2017.

Our graduate student, Saroj Sah, won the third place for oral presentation at the Mississippi Academy of Sciences 81st Annual Meeting (February 23-24, 2017, Hattiesburg, MS).

Saroj Kumar Sah, K. Raja Reddy, and Jiaxu Li (2016). The effect of silicon on the growth and drought resistance of soybeans. Educational exhibit (poster), North Mississippi Row Crops Field Day, Verona, MS., August 11, 2016.

Saroj Kumar Sah, K. Raja Reddy, and Jiaxu Li (2016) "Effect of silicon on the growth and drought resistance of soybeans" A poster for the annual meeting of Mississippi Academy of Sciences (February 18-19, 2016, Hattiesburg, MS).

Our graduate student, Saroj Sah, won the third place for the poster presentation at the annual meeting of Mississippi Academy of Sciences (February 18-19, 2016, Hattiesburg, MS).

Publications:

Saroj Sah et al. (2017). Silicon improves vegetative growth and water use efficiency of soybean plants under water limiting conditions. Submitted to Journal of Crop Improvement.

Submission of a manuscript on the effects of silicon application on seed yield of soybeans grown on nonirrigated sites is anticipated by the end of 2017.

Saroj Kumar Sah, K. Raja Reddy, and Jiaxu Li (2016). Abscisic acid and abiotic stress tolerance in crop plants. Frontiers in Plant Science 7:571. doi: 10.3389/fpls.2016.00571

Graphics/Tables

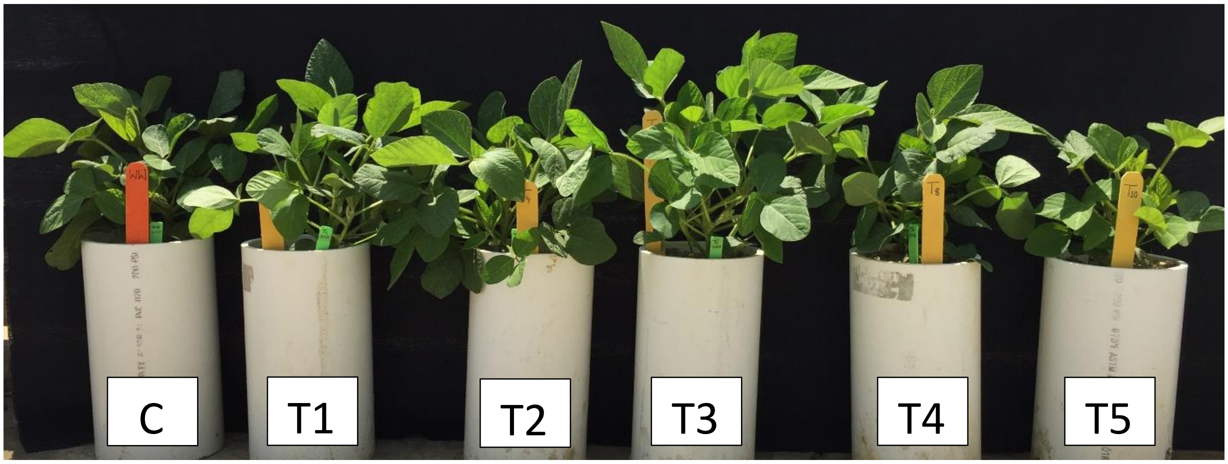

Figure 1. The effect of silicon on vegetative growth of soybean plants.
Potassium silicate was incorporated into soils to give different silicon concentrations: T1 (50 ppm), T2 (150 ppm), T3 (500 ppm), T4 (1500 ppm), and T5 (2000 ppm). The control pots (C) contained soils with no added potassium silicate. Asgrow 5332 soybean plants were grown in pots with soil and nutrient supply at natural light and temperature conditions for 45 days.

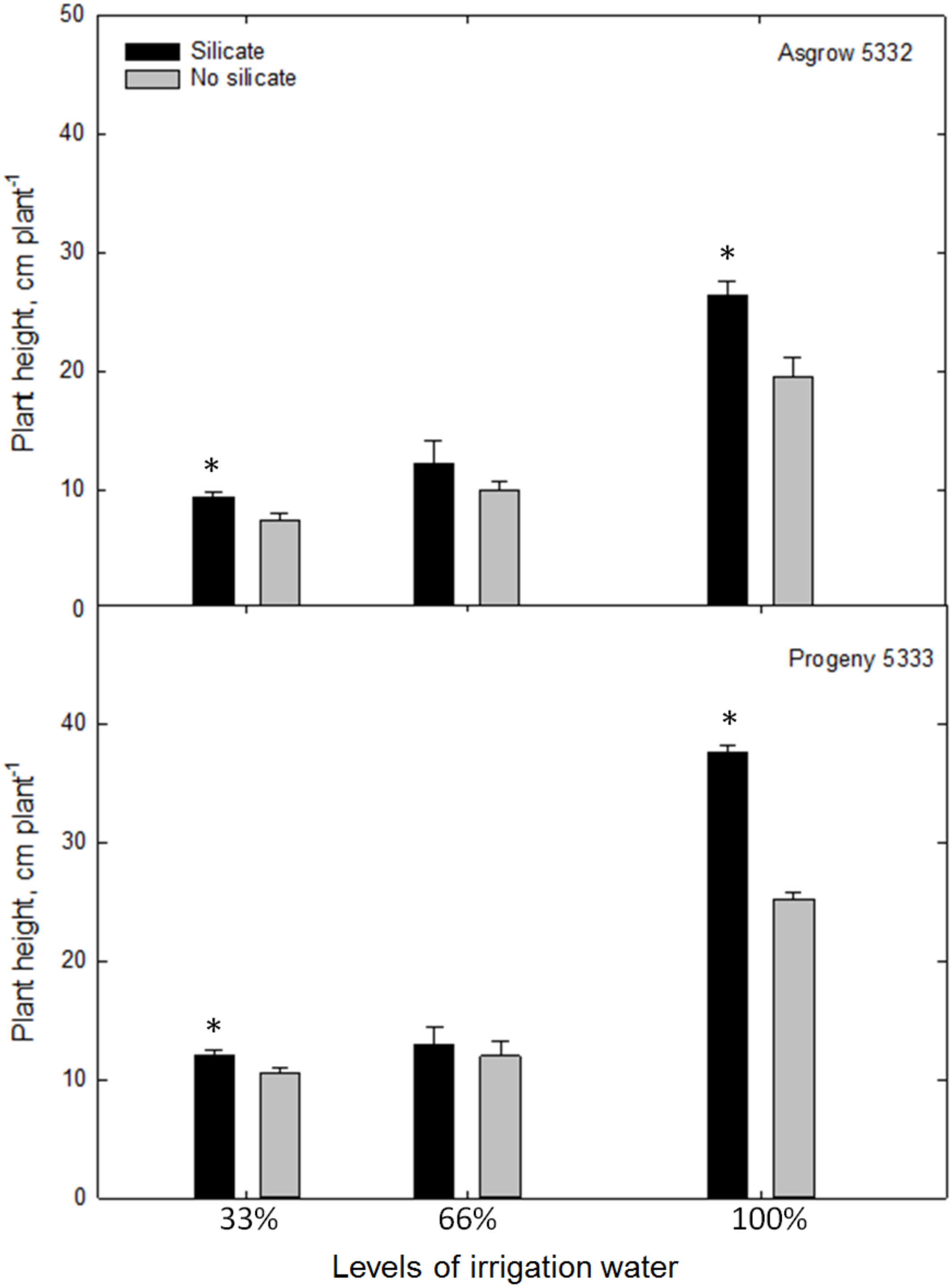

Figure 2. Effect of silicon application on plant height of two soybean varieties harvested at 27 DAP. Plants were supplied with normal (100%) or reduced (66% or 33%) amount of water for 20 days. Values are means and standard errors of five replications in each treatment. Asterisk (*) indicates significant difference compared with the control (no silicate) ($p < 0.05$).

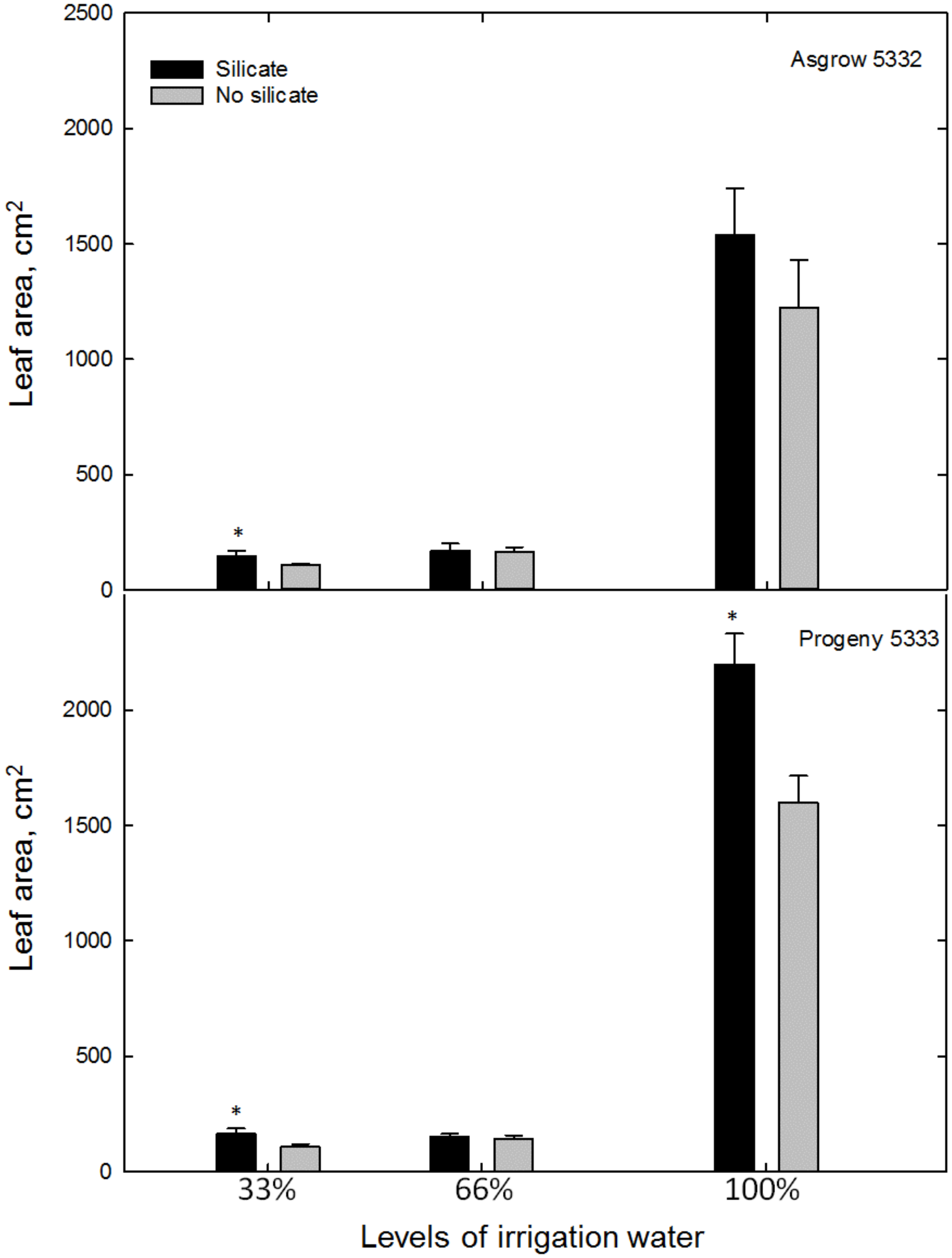

Figure 3. Effect of silicon application on leaf area of two soybean varieties harvested at 27 DAP. Plants were supplied with normal (100%) or reduced (66% or 33%) amount of water for 20 days. Values are means and standard errors of five replications in each treatment. Asterisk (*) indicates significant difference compared with the control (no silicate) ($p < 0.05$).

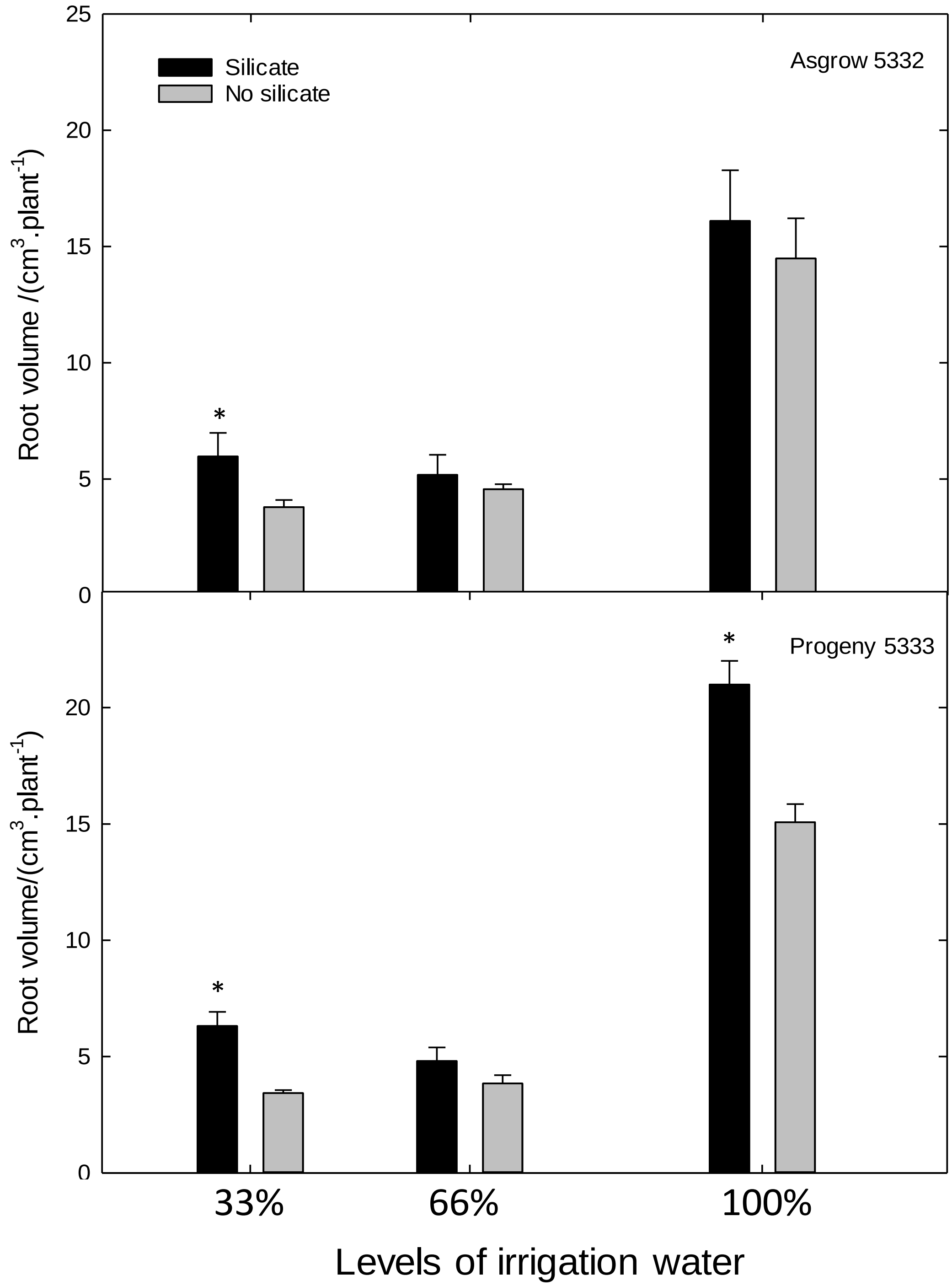

Figure 4. Effect of silicon application on root volume of two soybean varieties harvested at 27 DAP. Plants were supplied with normal (100%) or reduced (66% or 33%) amount of water for 20 days. Values are means and standard errors of five replications in each treatment. Asterisk (*) indicates significant difference compared with the control (no silicate) ($p < 0.05$).

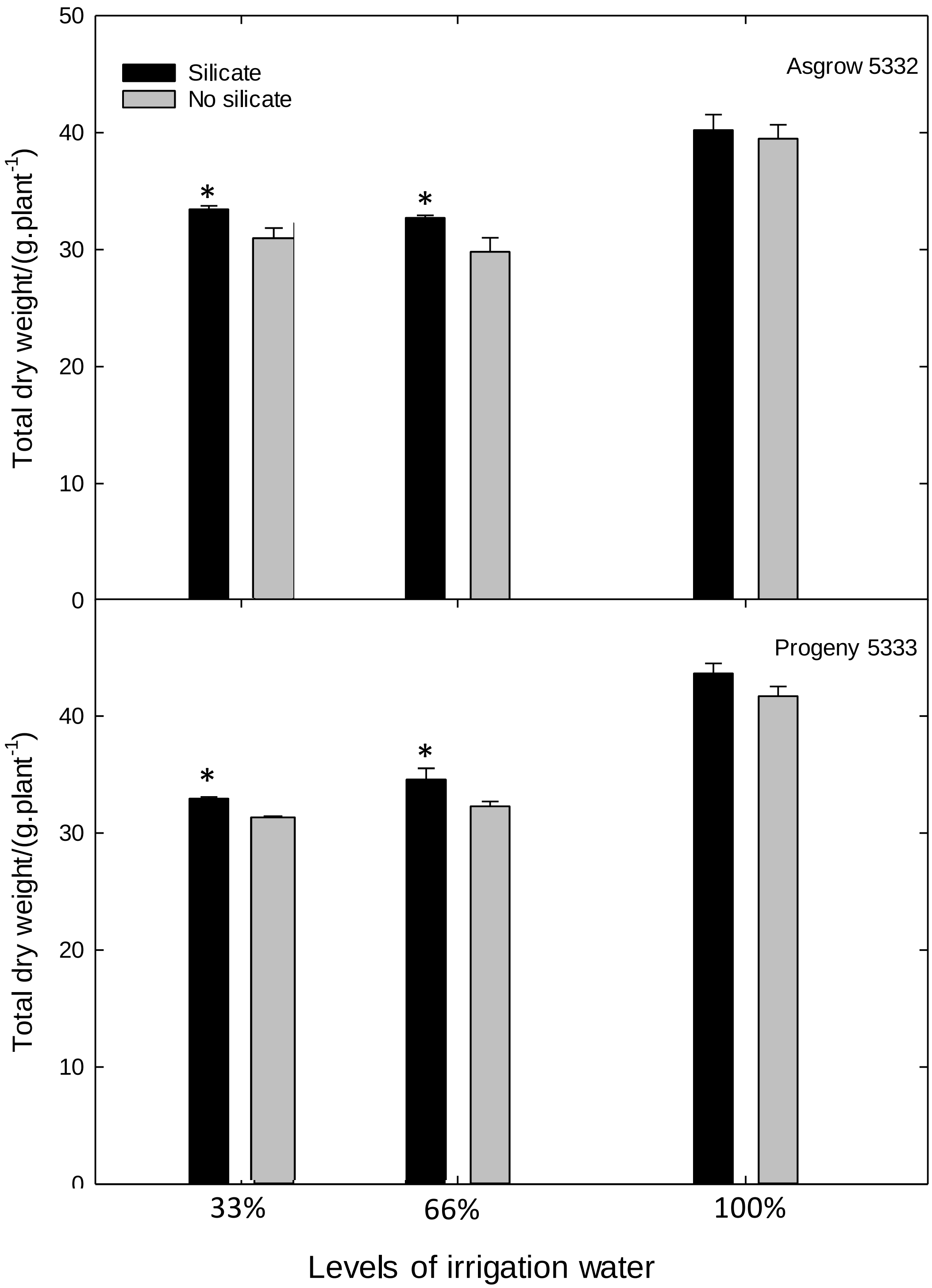

Figure 5. Effect of silicon application on total dry weight of two soybean varieties harvested at 27 DAP. Plants were supplied with normal (100%) or reduced (66% or 33%) amount of water for 20 days. Values are means and standard errors of five replications in each treatment. Asterisk (*) indicates significant difference compared with the control (no silicate) ($p < 0.05$).

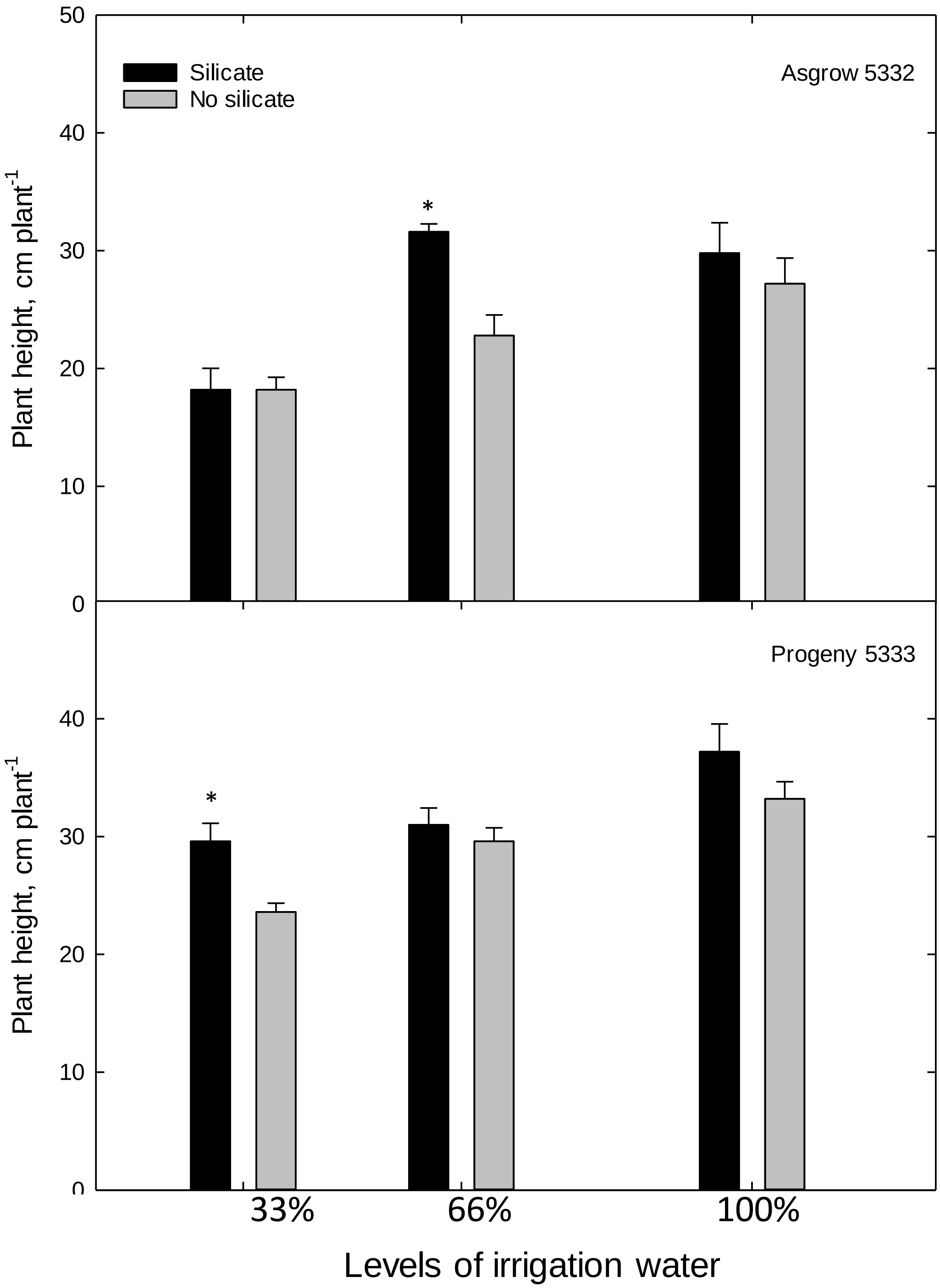

Figure 6. Effect of silicon application on plant height of two soybean varieties harvested at 45 DAP. Three irrigation treatments (33%, 66%, or 100% of required water) were imposed on plants at 20 DAP and continued for 25 days. Values are means and standard errors of five replications in each treatment. Asterisk (*) indicates significant difference compared with the control (no silicate) ($p < 0.05$).

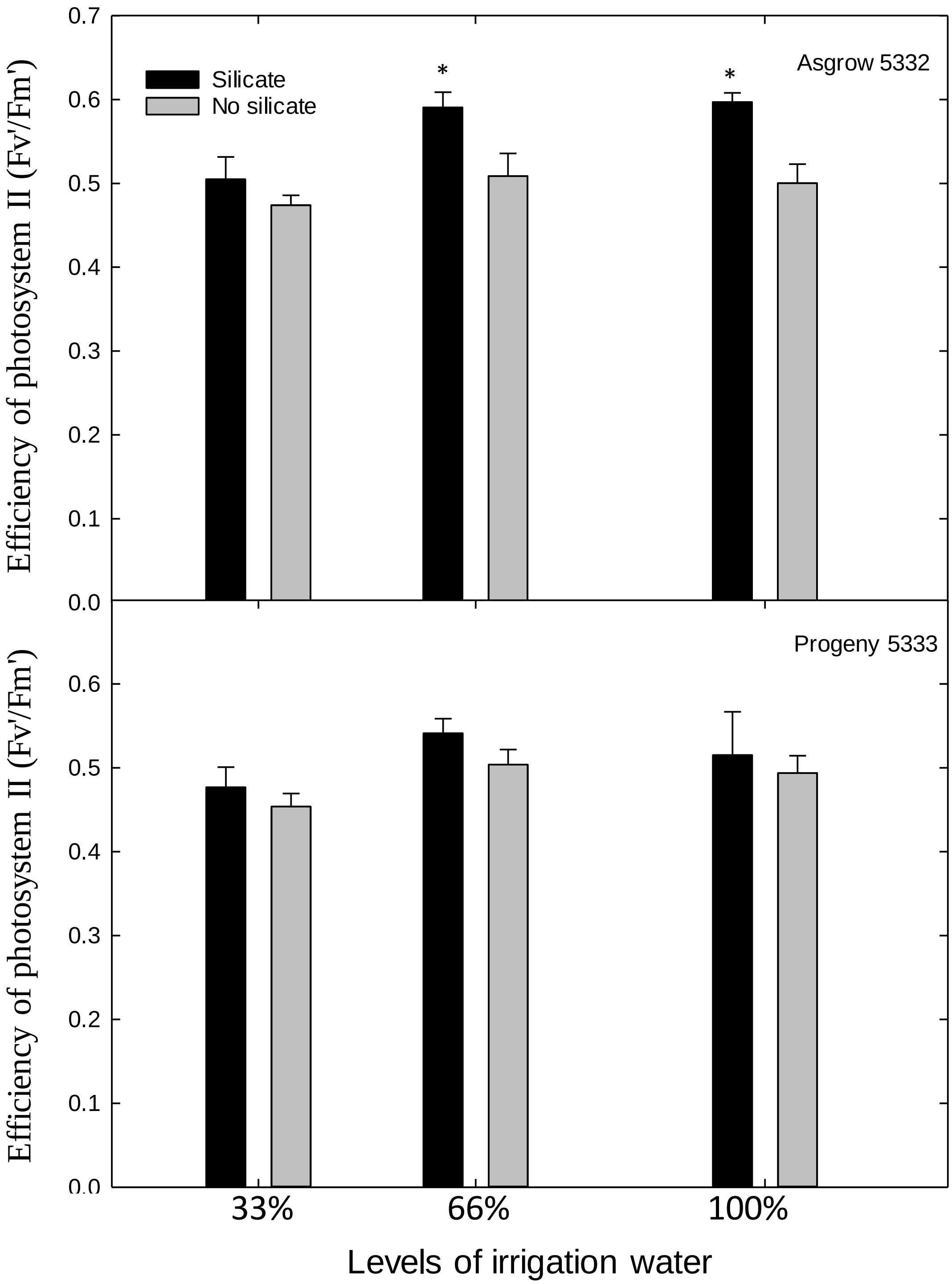

Figure 7. Effect of silicon application on efficiency of photosystem II of two soybean varieties harvested at 45 DAP. Three irrigation treatments (33%, 66%, or 100% of required water) were imposed on plants at 20 DAP and continued for 25 days. Values are means and standard errors of five replications in each treatment. Asterisk (*) indicates significant difference compared with the control (no silicate) ($p < 0.05$).

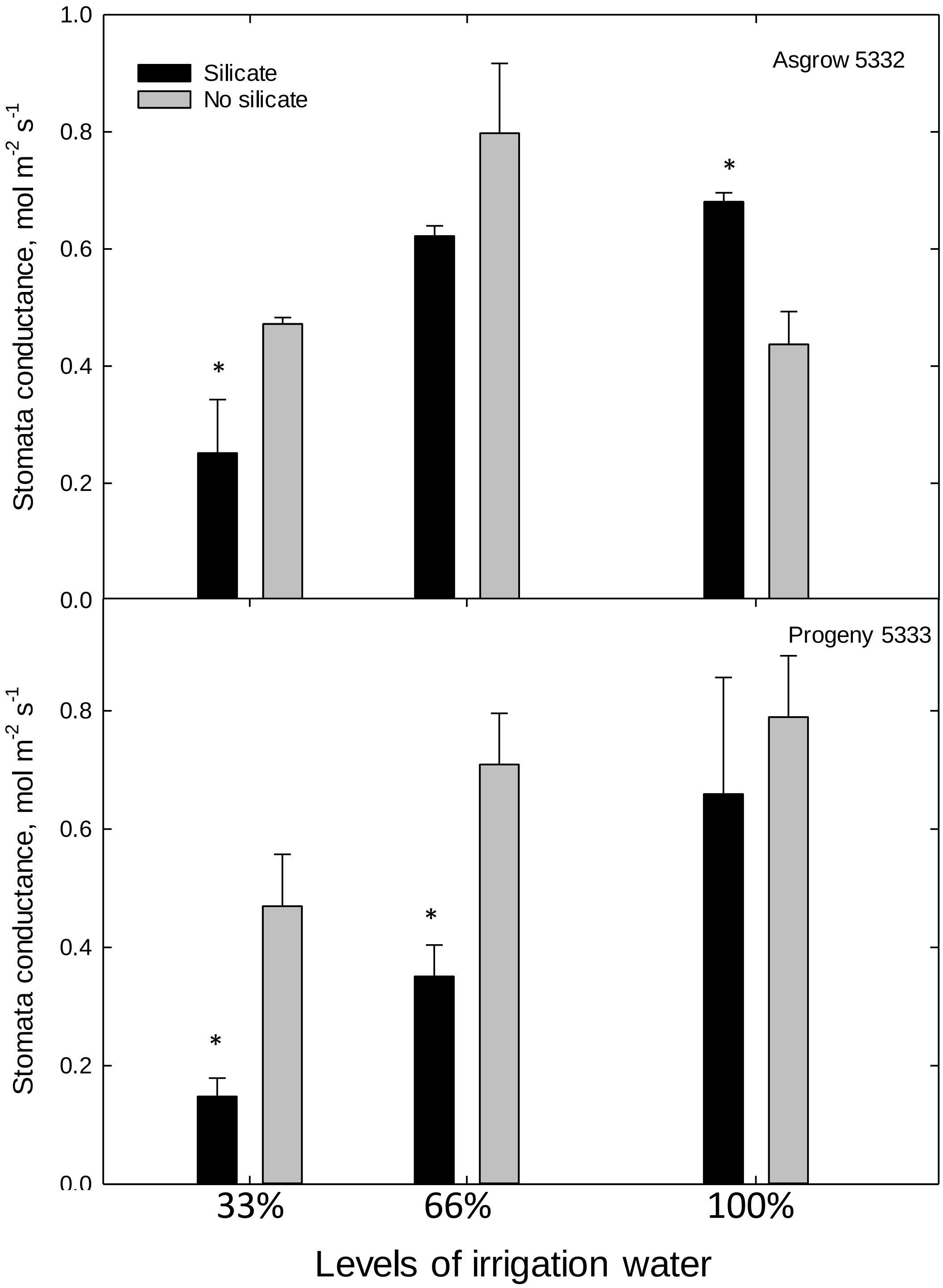

Figure 8. Effect of silicon application on stomatal conductance of two soybean varieties harvested at 45 DAP. Three irrigation treatments (33%, 66%, or 100% of required water) were imposed on plants at 20 DAP and continued for 25. Values are means and standard errors of five replications in each treatment. Asterisk (*) indicates significant difference compared with the control (no silicate) ($p < 0.05$).

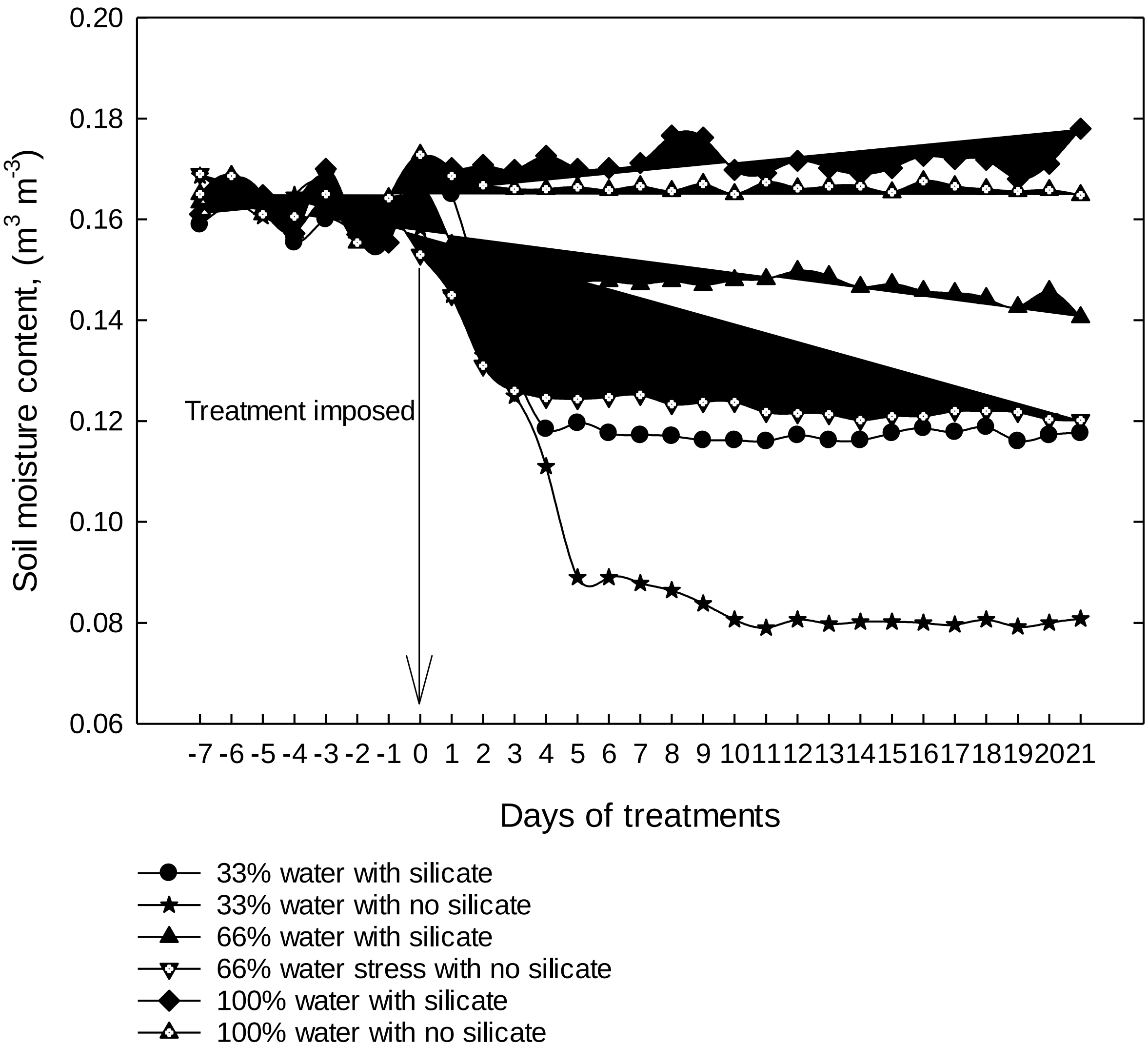

Figure 9. Silicate application increases soil moisture content under water limiting conditions. Two soybean varieties (Asgrow 5332 and Progeny 5333) were grown in a natural environment in polyvinyl chloride pots containing soil supplemented with or without potassium silicate (500 ppm Si). Soil moisture content was measured every day for 29 days using an HH2 moisture sensor meter (Delta-T Devices Ltd). During the first 7 days (-7 to -1) of measurements, all pots were supplied with normal amount of water (100%). On day 0 and afterwards, plants were supplied with normal (100%) or reduced (66% or 33%) amount of water.

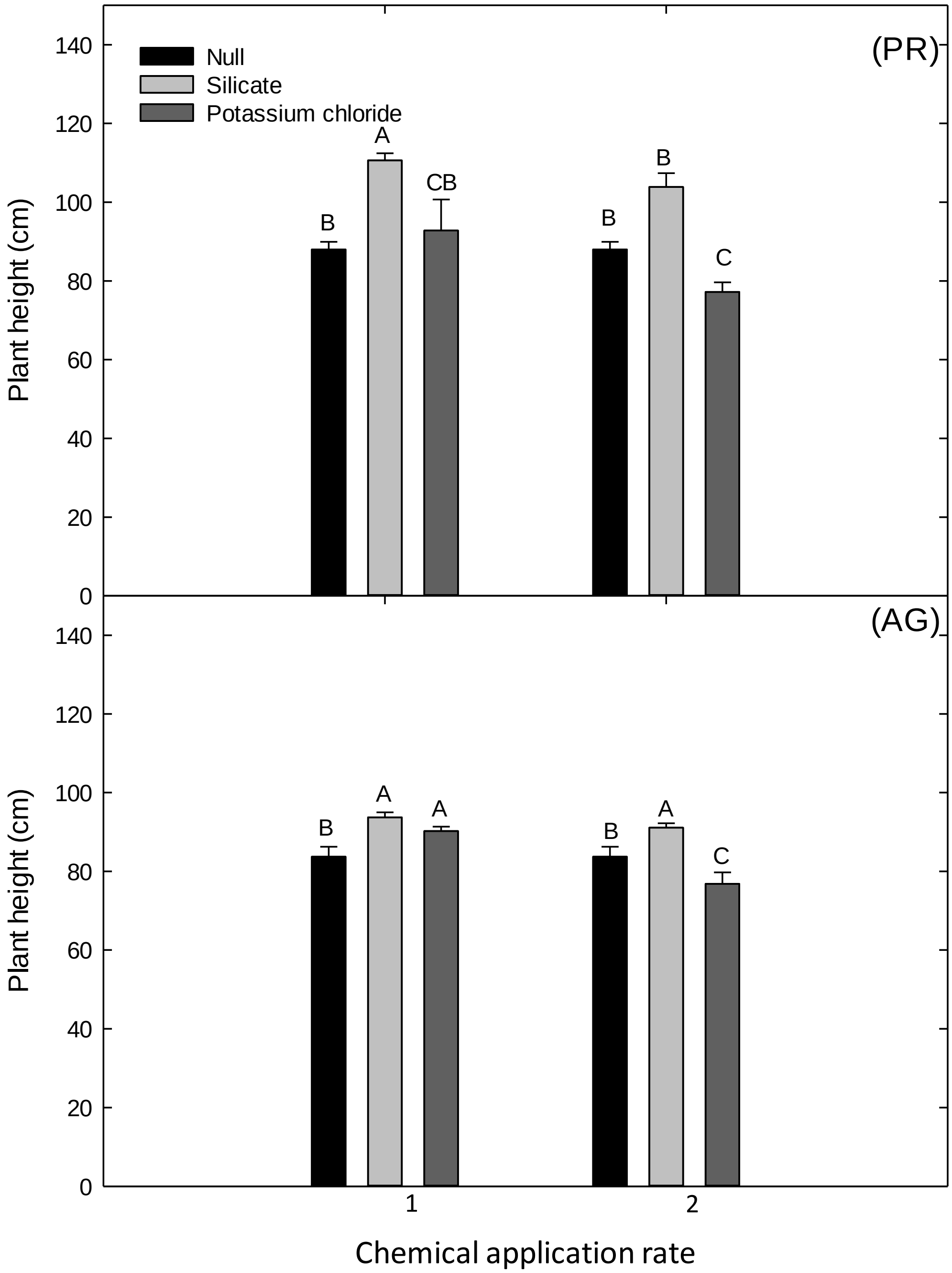

Figure 10. Effect of silicon application on plant height of two soybean varieties grown in the field. Two soybean varieties (PR: Progeny 5333; AG: Asgrow 5332) were grown in the field with applied potassium silicate (178 and 445 pound/acre) or potassium chloride as a control to balance the same total potassium. Measurements were conducted at 120 DAP. Values are mean and standard errors of 20 replications in each treatment. Bars with different letters indicate significant differences (Tukey test, $p < 0.05$).

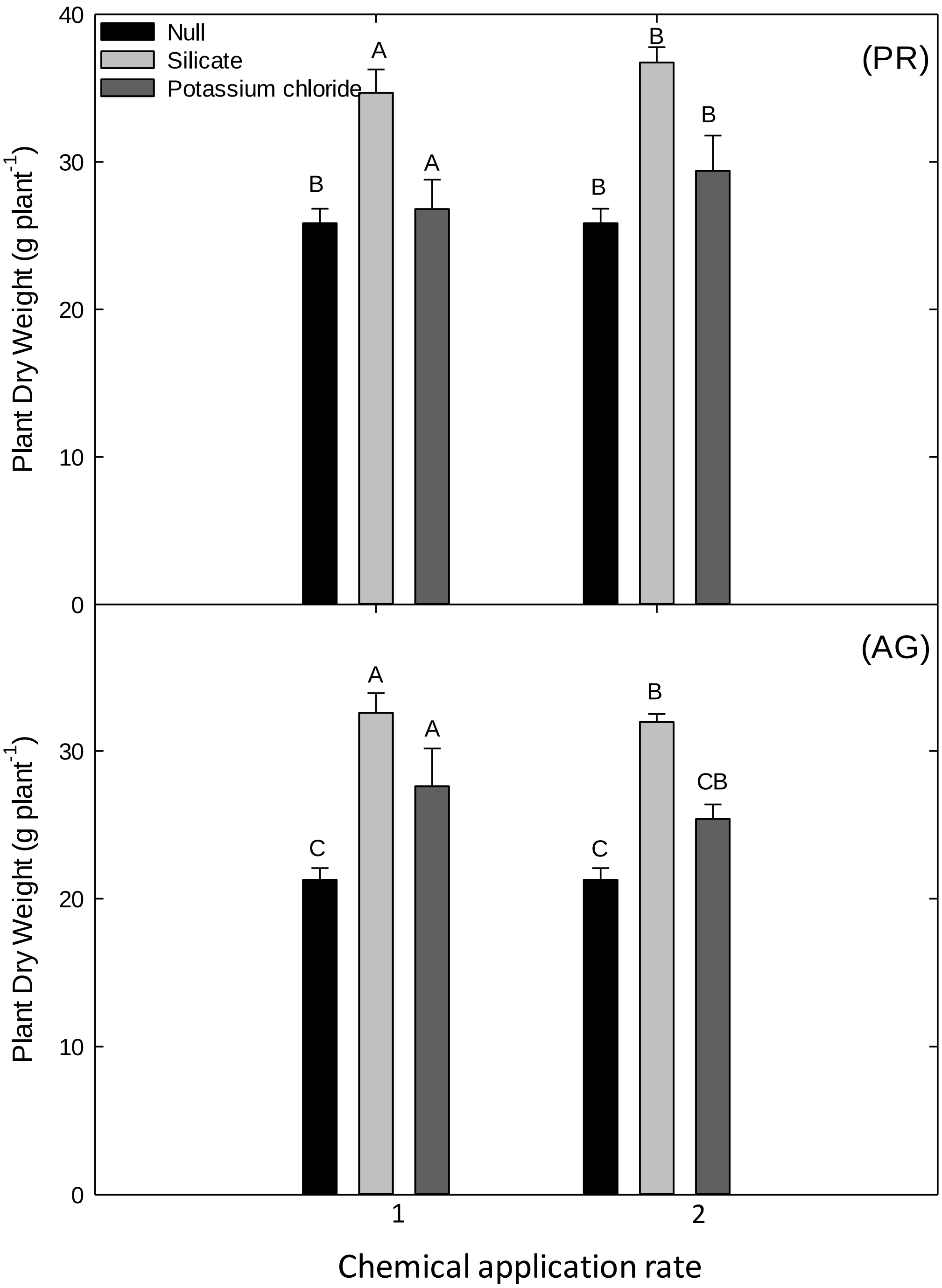

Figure 11. Effect of silicon application on plant dry weight of two soybean varieties grown in the field. Two soybean varieties (PR: Progeny 5333; AG: Asgrow 5332) were grown in the field with applied potassium silicate (178 and 445 pound/acre) or potassium chloride as a control to balance the same total potassium. Measurements were conducted at 120 DAP. Values are mean and standard errors of 20 replications in each treatment. Bars with different letters indicate significant differences (Tukey test, $p < 0.05$).

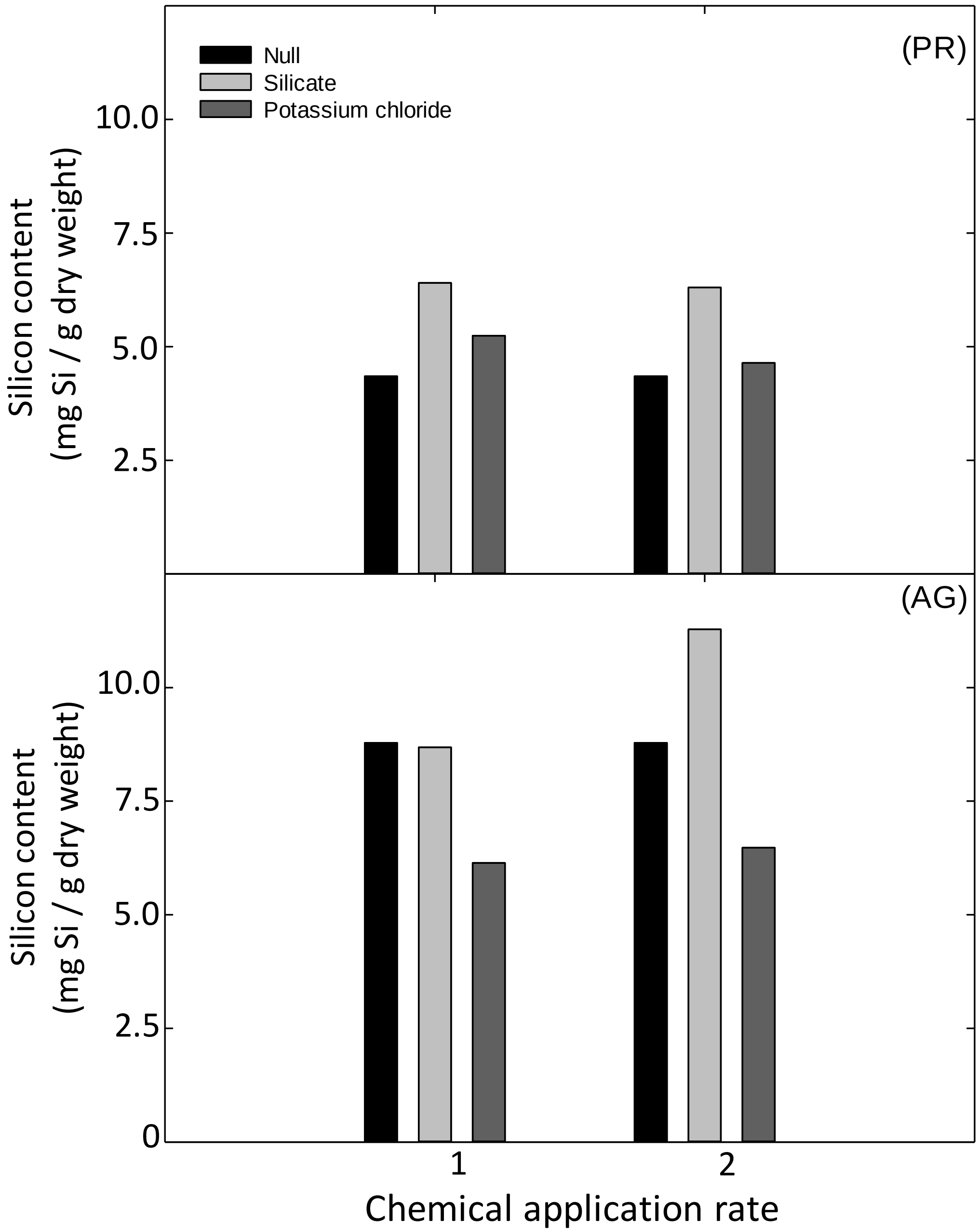

Figure 12. Effect of silicon application on plant silicon contents of two soybean varieties grown in the field. Two soybean varieties (PR: Progeny 5333; AG: Asgrow 5332) were grown in the field with applied potassium silicate (178 and 445 pound/acre) or potassium chloride as a control to balance the same total potassium. Measurements were conducted at 120 DAP. Values are silicon contents of leaves from 8 plants in each treatment.

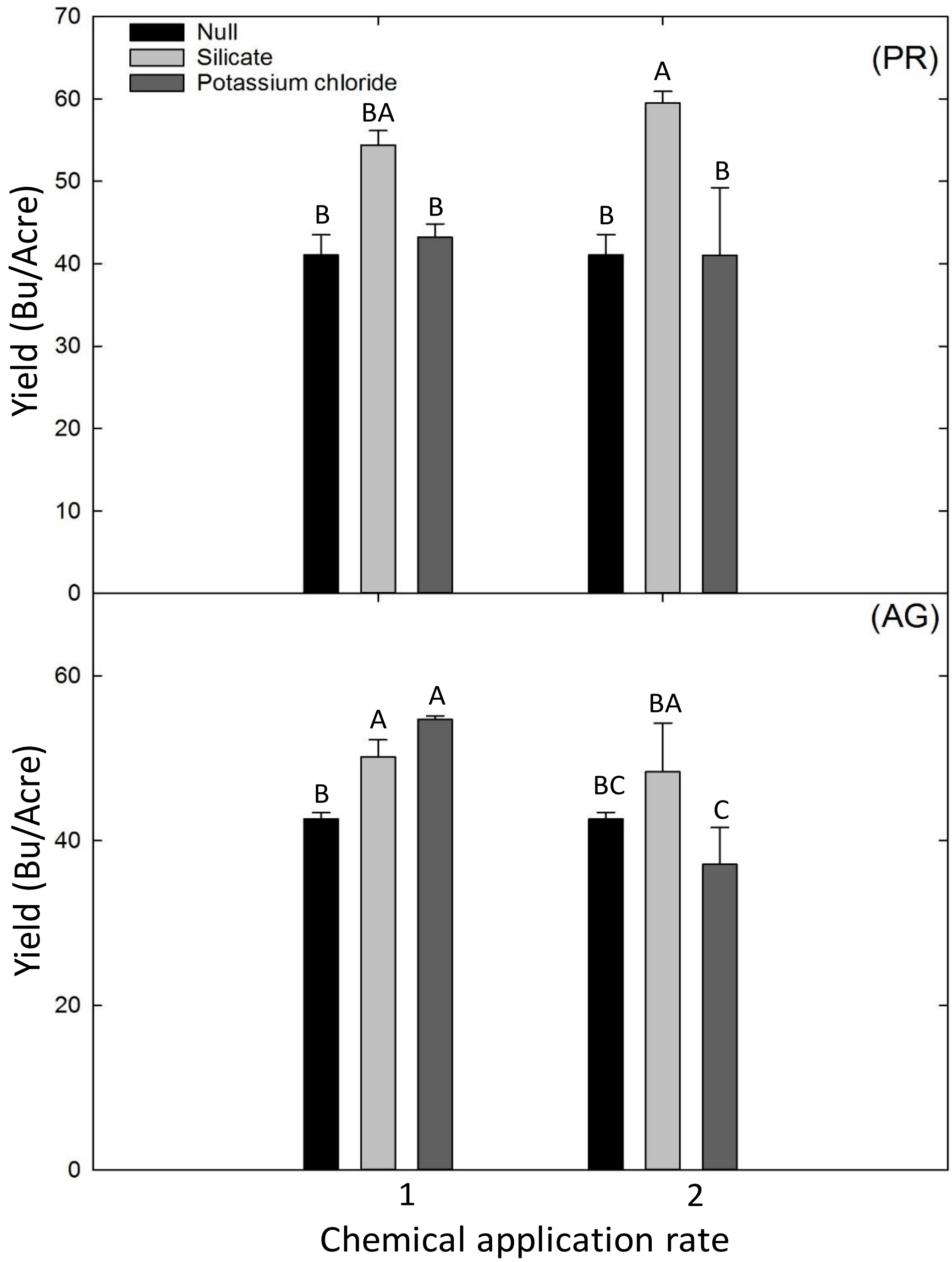

Figure 13. Effect of silicon application on seed yield of two soybean varieties grown in the field. Two soybean varieties (PR: Progeny 5333; AG: Asgrow 5332) were grown in the field with applied potassium silicate (178 and 445 pound/acre) or potassium chloride as a control to balance the same total potassium. Values are mean and standard errors of three plots in each treatment. Bars with different letters indicate significant differences (Tukey test, $p < 0.05$).