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# FOLIAR SILICATE FERTILIZATION ASSESSMENT ON BEAN DEVELOPMENT AND ITS WATER DEFICIT STRESS TOLERANCE

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**ABSTRACT -** Bean's productivity is below its productive potential, and among the related factors is the sensitivity to water deficiency. Silicate fertilization may aid to better tolerate this abiotic stress. Therefore, this work aims to evaluate the effects of foliar silicon (Si) doses in the development and tolerance of water deficiency for the bean's cultivation. The experiment was conducted in a greenhouse, with a completely randomized block design in a 6x2 factorial scheme with four repetitions. Six doses of silicon (0; 0.5; 1.0; 1.5; 2.0; 2.5 kg Si $ha^{-1}$) with and without water deficiency in flowering were used. The pots with a capacity of 2 L were filled with dystrophic Red Argisol, and they were maintained with automatic irrigation. The leaf temperature (TF) was analyzed daily, and at the end of the cycle, the plants' height, aerial and root fresh and dry matter, the number of grains per plant, the number of grains per pod, the number of pods per plant, pod length, and grain fresh and dry matter were determined. After water deficit stress, the percentage of absolute integrity and relative water capacity were determined. The water condition reflected differences in plant height, grain dry matter, number of grains per plant, pods per plant, and the foliar temperature. The silicon doses did not influence the development and tolerance to water deficit for the bean culture.
**Keywords:** *Phaseolus vulgaris* L., abiotic stress, sustainability.

# *SILÍCIO VIA FOLIAR NO DESENVOLVIMENTO E TOLERÂNCIA DO FEIJOEIRO À DEFICIÊNCIA HÍDRICA*

**RESUMO -** A produtividade do feijão está abaixo do seu potencial produtivo, e entre os fatores relacionados, está a sensibilidade à deficiência hídrica. A fertilização com silicato pode ajudar a tolerar melhor esse estresse abiótico. Portanto, o objetivo deste trabalho foi avaliar os efeitos de doses foliares de silício (Si) no desenvolvimento e tolerância à deficiência hídrica para o cultivo do feijão. O experimento foi conduzido em casa de vegetação, com delineamento de blocos inteiramente casualizados em esquema fatorial 6x2, com quatro repetições. Foram utilizadas seis doses de silício (0; 0,5; 1,0; 1,5; 2,0; 2,5 kg Si $ha^{-1}$) com e sem deficiência hídrica na floração. Os vasos com capacidade de 2 L foram preenchidos com Argissolo Vermelho distrófico e mantidos com irrigação automática. A temperatura foliar (TF) foi analisada diariamente, e ao final do ciclo, a altura das plantas, fitomassa fresca e seca da parte aérea e das raízes, o número de grãos da $planta^{-1}$, o número de grãos da $vagem^{-1}$, foram determinados o número de $vagens^{-1}$ da planta, o comprimento das vagens e a massa fresca e seca dos grãos. Após o estresse, foram determinados o percentual de integridade absoluta e a capacidade relativa de água. A condição da água refletiu na diferença na altura das plantas, na massa seca dos grãos, no número de grãos da $planta^{-1}$, no número de frutos da $planta^{-1}$ e na temperatura foliar. As doses de silício não influenciaram no desenvolvimento e tolerância ao deficit hídrico na cultura do feijão.
**Palavras- clave:** *Phaseolus vulgaris* L., estresse abiótico, sustentabilidade.

## INTRODUCTION

Common bean is a legume that belongs to the Leguminosae family, a native to America while its exact place of origin is not yet known (CHACÓN et al., 2005). It is one of the oldest crops cultivated and because of its easy availability and nutritional properties, has now become one of the utmost essential crops consumed worldwide (RATHNA PRIYA; MANICKAVASAGAN, 2020). In the 2019/2020 harvest, 2,926 million hectares were sown in Brazil, generating a production of 3,229 million tons (CONAB, 2020). Moreover, it stands out due to its high cultural and social importance, because, together with rice, makes the most typical Brazilian dish, besides being an important source of protein (CARVALHO et al., 2013).

Notwithstanding its great importance, the national average productivity is below potential productivity awarding 1104 kg $ha^{-1}$, however, with a potential of 3000 kg $ha^{-1}$ under irrigation (CONAB, 2020). The greatest part of the Brazilian production comes from small family producers, which use reduced inputs and resulting in lower productivities (CARVALHO et al., 2013). In a study with different genotypes of common beans, Guimarães et al. (2011) observed that plants under water stress showed a reduction of 58.6% in productivity, averaging between

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862 and 2084 kg $ha^{-1}$ for plants with and without water deficit, respectively. The low yields of this crop are attributed to biotic stresses such as pests, low yielding cultivars, but mostly to different edaphoclimatic conditions where the bean is cultivated, standing out the climatic oscillations (temperature and precipitation) (LAGO et al., 2009).

Beans are considered to be less tolerant to water stress. In Latin America, water deficit is one of the main factors that limit bean production (ROSALES et al., 2012). Due to global warming, the condition of water deficiency is increasing on the planet (YANG et al., 2010). In the Rio Grande do Sul state, drought seasons and uneven with frequencies rounding 7 out of every 10 years (SEAPDR, 2014). Several studies proved that water deficit negatively affects crop development during its entire cycle (GUIMARÃES et al., 2011); still, there are three critical phenological stages, which are the germination, flowering, and grain filling (SORATTO et al., 2003). Consequently, there is a need to seek sustainable alternatives to proceed with this cultivation.

Silicate fertilization has been studied and used for its benefits to plants. While silicon (Si) is not considered an essential element for most plants, some of them can accumulate Si in their cell walls and take advantage of its effects. Among the positive effects, it is possible to measure plant architecture improvement and lodging reduction, facilitating mechanization and increasing plants' photosynthetic potential (MARTINS JÚNIOR et al., 2008). Also help reduce phytotoxicity caused by metals such as aluminum, manganese, arsenic, cadmium, and zinc (PINTO et al., 2009), increase pathogens resistance (SANTOS et al., 2014) and herbivores (PINTO et al., 2014), increase legumes nodulation (KINTSCHEV et al., 2012), and reduce plant transpiration (AGARIE et al., 1998).

After being absorbed, mono silicic acid is deposited in the form of amorphous silica on cell walls of the leaf epidermis, stem, and peels, forming a double layer of Si-cuticle (RAVEN, 2003). The lowest transpiration is due to the deposition of Si on plants cuticle and stomata, which reduce water loss, assisting to water tolerance deficiency, as evidenced in several studies with monocotyledons such as corn (SOUZA et al., 2014), rice (MORO et al, 2015), and dicotyledons such as sunflower (NEVES et al., 2019), soybean (TEODORO et al., 2015), and cowpea (ARAÚJO, 2017).

Considering the importance of beans in economic, social, and cultural context, and their sensitivity to water deficit, this work aims to evaluate the effects of silicon foliar applications on the development and water deficit tolerance of common beans.

## MATERIAL AND METHODS

The experiment was conducted in a greenhouse in Cachoeira do Sul, State of Rio Grande do Sul, Brazil, from August to November 2017. EMBRAPA BRS Expedito, which belongs to the commercial group of black grains, widely cultivated by the farmers of the region, was utilized. The experimental design used was a completely randomized block design in a 6x2 factorial scheme with four repetitions. The plots were conducted with foliar application of six doses: 0.0, 0.5, 1.0, 1.5, 2.0, and 2.5 kg Si $ha^{-1}$, with and without water deficit in the flowering. Si doses were scattered in three applications, every week before flowering. As a source of Si, a commercial product containing Si (68.1%), Ca (6.0%), P (5.7%), K (5.2%), Mg (4.4%), Fe (4.0%), Mb (2.0%), Zi (2.0%), and Co (1.0%) was used. The concentration of the other nutrients present in the product was corrected in each plot. For the effect of Si to be expressed only in the water deficit variable, four biweekly fungicide applications (a.i), and one insecticide (a.i) were performed.

The substrate used was the Dystrophic Red Argisol, whose characteristics were determined by chemical analysis, presenting 6.11 mg $kg^{-1}$ of P, 42.0 mg $kg^{-1}$ of K, 0.0 cmolc $L^{-1}$ of Al, 5.2 cmolc $L^{-1}$ of Ca, 2.8 cmolc $L^{-1}$ of Mg, 1.9 cmolc $L^{-1}$ of H+Al, 9.9 cmolc $L^{-1}$ of CTC pH 7, 8.1 cmolc $L^{-1}$ of CTC effective, 2.3% of organic matter, 28 % of clay, pH 6.3, and 6.7 of SMP, and corrected following the fertilization and liming manual recommendations (CQFS RS/SC, 2016). The soil was removed in the 0-25 cm layer, air dried, sieved in a 5 cm mesh, and placed with a 2 L capacity bottle, coated with black paint, which constituted a plot.

The irrigation was automatic, controlled with soil moisture sensors. Irrigation control was defined by the tension curve of the water in the soil, used by Ribas et al. (2015). The plots corresponding to non-water deficit were irrigated according to the crop needs throughout the cycle. On the other hand, plots corresponding to water deficit were irrigated according to the crop needs until the flowering (R6), when the water deficit was imposed up to 42.81 mm of accumulated reference evapotranspiration (ETo), calculated daily through hourly data from the A813 Automatic Station of the Brazilian National Institute of Meteorology (Inmet) with the help of the software SMAI. After this period, irrigation was resumed according to the crop needs until the end of the cycle.

The foliar temperature was measured daily at noon (±1 h) using an infrared thermometer. Protoplasmic tolerance and water retention capacity were analyzed on the last day of the water deficiency condition, which was at the beginning of stage R7 (pod formation). The determination of water retention capacity (WRC) followed the methodology described by Barrs and Weatherley (1962), and the determination of protoplasmic tolerance followed the methodology described by Vasquez-Tello et al. (1990). At the end of the cycle; height, fresh and dry matter of the aerial part, roots and grains, number of grains $plant^{-1}$, number of grains $pod^{-1}$, pods $plant^{-1}$, and pod length were measured.

Pearson's linear correlation (HOSMER et al., 1997) was determined using the Excel 2007 version program. The results were submitted to analysis of variance (ANOVA), and the interaction between the doses and the water condition was performed, when significant. The effects of the doses were submitted to the regression analysis, testing the linear and quadratic models, and the effects of the water deficit were submitted to Tukey test at 5% of probability, using the statistic software Sisvar (FERREIRA, 2011).

## RESULTS AND DISCUSSION

Water deficit condition (WDC) reflected in lower plant height average (Table 1). The water scarcity also resulted in a decrease in plant height, as in corn (DANTAS JÚNIOR et al., 2011) and wheat (SANTOS et al., 2012). The Si doses did not influence the vegetative parameters (Table 1). In sunflower, the Si doses did not influence the plant height and aerial part of plant dry matter (OLIVEIRA et al., 2013). For sugar cane, increasing doses of Si showed no significant difference in the growth and physiological characteristics (MEDEIROS et al., 2009). However, the results disagree with Silva et al. (2019) wherein genotypes of cowpea, Si promoted gain in a fresh matter of plants under water shortage.

**TABLE 1 -** Plant's height, roots length (RL), fresh matter aerial part (FMA) and roots (FMR), and dry matter aerial part (DMA) and roots (DMR) at the end of the cycle.

| Water condition | Dose of Si | Height | RL | FMA | DMA | FMR | DMR |
|---|---|---|---|---|---|---|---|
| | kg ha $^{-1}$ | cm | cm | g | g | g | g |
| Without WD | 0.0 | 73.00 | 32.25 | 12.50 | 3.15 | 7.75 | 4.13 |
| | 0.5 | 87.75 | 30.00 | 13.25 | 3.15 | 8.25 | 3.85 |
| | 1.0 | 72.75 | 31.75 | 10.75 | 2.75 | 6.75 | 3.50 |
| | 1.5 | 82.50 | 31.75 | 11.50 | 2.92 | 7.25 | 3.69 |
| | 2.5 | 93.25 | 29.75 | 12.00 | 3.02 | 9.00 | 4.70 |
| | 2.5 | 94.75 | 32.50 | 15.25 | 3.55 | 9.75 | 5.66 |
| Average | | 84.00 A | 31.33 | 12.54 | 3.09 | 8.13 | 4.26 |
| With WD | 0.0 | 45.00 | 29.38 | 15.25 | 3.63 | 9.75 | 5.41 |
| | 0.5 | 46.75 | 27.50 | 12.75 | 3.15 | 11.00 | 6.53 |
| | 1.0 | 43.50 | 28.63 | 15.00 | 4.02 | 12.25 | 7.36 |
| | 1.5 | 57.75 | 27.50 | 14.88 | 3.50 | 7.50 | 3.86 |
| | 2.0 | 52.25 | 31.00 | 12.25 | 2.96 | 7.75 | 4.10 |
| | 2.5 | 41.50 | 31.13 | 12.00 | 2.88 | 9.25 | 5.05 |
| Average | | 49.46 B | 29.19 | 13.69 | 3.36 | 9.58 | 5.39 |
| CH | | * | ns | ns | ns | ns | ns |
| D | | ns | ns | ns | ns | ns | ns |
| CH*D | | ns | ns | ns | ns | ns | ns |
| CV(%) | | 22.37 | 13.62 | 21.37 | 23.11 | 35.8 | 48.28 |

WD = water deficiency, F-test for: water condition (WC), doses (D), and their interaction (WC*D). Averages followed by the same letter do not differ by the Tukey test, being lowercase for interaction between water condition and doses and uppercase for doses in columns. Uppercase letters in the averages mean the significant difference between the water conditions NS: not significative at the level of 5% of probability. *,** significative to 5% and 1% of probability.

WDC did not influence the number of grains plant$^{-1}$, grain fresh matter, and the number of pods plant$^{-1}$ (Table 2). Other studies with beans match the results found. In a study by Carvalho et al. (2013) with calcium silicate applications, via soil, with and without water deficit, the stress resulted in a difference in the number of pods plant$^{-1}$ and the number of grains plant$^{-1}$; yet, Si application did not reflect significative difference. In research with bean cultivars in dry and rainy seasons, the application of three sources of Si (Rocksil, 30 g L$^{-1}$; Saborsil AC77, 20 g L$^{-1}$, and potassium silicate, 30 g L$^{-1}$) via leaf did not influence the number of pods plant$^{-1}$, several grains pod$^{-1}$ and the weight of one hundred grains (TEIXEIRA et al., 2008).

Guimarães et al. (2011), evaluating different genotypes of common bean concerning water deficit, concluded that the number of pods per plant$^{-1}$ was the most sensitive component, followed by the number of grains pod$^{-1}$, understanding that the water deficiency acts with more intensity on the abscission of flowers and pods than on the sterility of the pollen grain. Ramirez-Vallejo and Kelly (1998) also observed that the number of pods and grains embody the productivity components with higher response to the water state of plants. The plants with water deficiency increase the synthesis of abscisic acid and ethylene in the floral peduncle, causing them to fall at the slightest movement and preventing the formation of pods and grains (CALVACHE et al., 1997).

The doses of Si did not influence the production of beans, where only 1.5 kg Si ha$^{-1}$ dose influenced the length of the pods. This data does not match with the results found in the literature, which found an increase in productivity with silica fertilization via leaf in soybean (TEODORO et al., 2015), soybean, bean and sunflower (CRUSCIOL et al., 2013).

Correlating the plants' height with the number of grains produced by them, in those not stressed there was a positive correlation of $R^2$ = 0.65. Like this, the taller the plants, the greater the production since the photosynthetic area has the necessary water resources to expand and produce its photoassimilates. In research with coffee plants, Assis et al. (2014) and Carvalho et al. (2010) observed a positive correlation of 0.92 between the height and the production of plants. On the other hand, the plants stressed presented a negative correlation of -0.69, that is, the shorter the plant, the higher the number of grains produced per plant because plants under water stress have to choose where to handle their available resources. Probably because plants submitted to water stress seek to maintain the turgor in regions of growth and reserve (CHAVES, 1991), as a way of survival.

Si doses and the water regime did not influence WRC and PIA (Table 3) of plants. This data disagrees with Araújo (2017) in which genotypes of cowpea beans, the Si in plants with water deficit, reduced its deleterious effects on WRC. During the water scarcity, the plants presented higher leaf temperature than plants in a normal water regime. This difference remained after the water deficit was suspended, except in the first week.

**TABLE 2 -** Pod's length (PL), grains plant$^{-1}$ (G/P), grains pod$^{-1}$ (G/P), fresh (FM) and dry matter (DM) of grains and pods plant$^{-1}$ (P/P).

| Water condition | Dose of Si | PL | G/P | G/P | FM | DM | PP |
|---|---|---|---|---|---|---|---|
| | kg ha$^{-1}$ | cm | un | un | g | g | un |
| Without WD | 0.0 | 8.75 | 40.50 | 5.21 | 11.00 | 11.02 | 8.00 |
| | 0.5 | 8.80 | 49.25 | 5.79 | 12.19 | 11.42 | 8.50 |
| | 1.0 | 8.74 | 44.25 | 5.74 | 11.17 | 11.81 | 7.75 |
| | 1.5 | 7.20 B | 51.50 | 5.43 | 13.06 | 12.21 | 10.00 |
| | 2.0 | 8.89 | 50.75 | 5.51 | 12.09 | 12.60 | 9.50 |
| | 2.5 | 8.66 | 46.50 | 5.70 | 13.45 | 13.00 | 8.50 |
| Average | | 8.51 | 47.125 A | 5.56 | 12.16 A | 12.01 | 8.71 A |
| With WD | 0.0 | 8.65 | 40.50 | 5.45 | 9.80 | 9.65 | 7.50 |
| | 0.5 | 8.94 | 41.25 | 5.69 | 10.38 | 10.23 | 7.25 |
| | 1.0 | 8.71 | 37.50 | 5.77 | 9.82 | 9.67 | 6.50 |
| | 1.5 | 8.21 A | 33.13 | 5.23 | 11.22 | 11.07 | 8.25 |
| | 2.0 | 8.37 | 36.00 | 5.33 | 9.36 | 9.21 | 7.00 |
| | 2.5 | 8.33 | 37.50 | 5.54 | 9.39 | 9.24 | 6.75 |
| Average | | 8.53 | 37.65 B | 5.50 | 10.00 B | 9.85 | 7.21 B |
| CH | | ns | * | ns | * | * | * |
| D | | ** | ns | ns | ns | ns | ns |
| CH*D | | ns | ns | ns | ns | ns | ns |
| CV(%) | | 8.92 | 20.06 | 8.28 | 13.90 | 14.09 | 16.75 |

WD = water deficiency, F-test for: water condition (WC); doses (D); and their interaction (WC*D). Averages followed by the same letter do not differ by the Tukey test, being lowercase for interaction between water condition and doses and uppercase for doses in columns. Uppercase letters in the averages mean the significant difference between the water conditions NS: not significative at the level of 5% of probability. *, ** significative to 5% and 1% of probability.

Guimarães et al. (2011) observed that the higher leaf temperature is associated with the reduction of productivity of different common bean genotypes, and they mention that the number of grains pod$^{-1}$ and the number of pods plant$^{-1}$ were also reduced with the increase of leaves temperature. The temperature of the canopy is greater as the lower the loss of energy is, which among many reasons, the transpiration is highlighted, which is reduced when the water condition of the plants is unfavorable. The plants with no water stress at the dose of 0.0 kg ha$^{-1}$ presented a higher average temperature, although there was no significant difference. Conversely, the same did not happen with stressed plants, which may be due to plants absorbing the Si available in the soil to support the water deficit.

The water deficit did not influence the vegetative characteristics since the stress was imposed in the plants flowering, affecting the productive parameters (Table 2). To support the stress, the plants' defense mechanism consists of genes that regulate its metabolism to the situation, inhibiting its growth and altering its development (BRAY, 1997). Consequently, plants without water deficiency grow more than stressed plants (Table 1). Besides, to support the stress, genes promote increased cell tolerance to dehydration (BRAY, 1997).

While there was no significant difference, the average of the WRC of stressed plants was 2.67% (Table 3) greater than non-stressed ones, which is possible because the cells retain more water to survive the unfavorable condition. The same occurred to the PIA of the cells, which, although there was no significant difference, it can be observed that in the stressed plants the values were higher with the application of Si than in the control ones, which is possible to the influence of Si in the reduction of leakage of electrolyte from leaves (AGARIE et al., 1998). The same happened in plants of corn that underwater deficit kept the turgor of their cells, but reduced their development (MICHELENA; BOYER, 1982). Therefore, it was probably a natural behavior influenced by the plant genotype, and not by Si.

**TABLE 3 -** Relative water content in leaves (RWC), absolute integrity percentage (AIP) in stage R7 in bean and leaf temperature of beans during the water deficit (WDC) and after the suspension of the water deficit (WDCS).

| Water condition | Doses of Si | RWC | AIP | 1st week WDC | 2nd week WDC | 1st week WDCS | 2nd week SDW | 3rd week WDCS |
|---|---|---|---|---|---|---|---|---|
| | kg ha -1 | % | µ S cm-1 | | | ºC | | |
| Without WD | 0.0 | 59.02 | 0.86 | 20.79 | 20,8 | 20,67 | 22.63 | 22.82 |
| | 0.5 | 58.37 | 0.89 | 19.87 | 19.31 | 19.73 | 22.52 | 21.90 |
| | 1.0 | 63.03 | 0.87 | 19.76 | 18.82 | 20.37 | 22.40 | 21.16 |
| | 1.5 | 57.28 | 0.89 | 18.49 | 18.77 | 19.73 | 21.28 | 20.71 |
| | 2.0 | 59.46 | 0.86 | 19.78 | 19.54 | 20.22 | 22.11 | 21.00 |
| | 2.5 | 59.75 | 0.86 | 19.38 | 19.11 | 20.50 | 21.77 | 21.46 |
| Average | | 59.48 | 0.87 | 19.68 B | 19.39 B | 20.20 | 22.12 B | 21.51 B |
| With WD | 0.0 | 68.42 | 0.87 | 21.84 | 21.31 | 20.41 | 23.28 | 22.44 |
| | 0.5 | 60.37 | 0.89 | 21.95 | 21.59 | 19.5 | 23.43 | 23.18 |
| | 1.0 | 57.51 | 0.88 | 21.84 | 21.47 | 19.45 | 23.53 | 22.92 |
| | 1.5 | 56.56 | 0.88 | 20.57 | 19.97 | 19.16 | 21.9 | 21.78 |
| | 2.0 | 62.75 | 0.89 | 21.33 | 20.76 | 26.59 | 23.56 | 22.6 |
| | 2.5 | 61.05 | 0.89 | 20.75 | 20.12 | 26.57 | 22.89 | 22.36 |
| Average | | 61.11 | 0.88 | 21.38 A | 20.87 A | 21.95 | 23.10 A | 22.55 A |
| CH | | ns | ns | ** | ** | ns | ** | * |
| D | | ns | ns | ns | ns | ns | ns | ns |
| CH*D | | ns | ns | ns | ns | ns | ns | ns |
| CV (%) | | 14.96 | 3.06 | 5.89 | 8.28 | 29.95 | 5.10 | 7.52 |

WD = water deficiency, F-test for water condition (WC); doses (D); and interaction between water condition and doses (WC*D). Averages followed by the same letter do not differ by the Tukey test, being lowercase for interaction between water condition and doses and uppercase for doses in columns. Uppercase letters in the averages mean the significant difference between the water conditions NS: not significative at the level of 5% of probability. *, ** significative to 5% and 1% of probability.

The study noted that the cultivar BRS Expedito did not respond to the leaf Si applied doses under water deficit during flowering. Common bean, being a dicotyledonous plant, is not considered a Si accumulator, consequently, the research was based on foliar applications, nonetheless, studies with soil fertilization are fundamental to expand the knowledge on this matter. Having in mind the importance of water deficit in current and future agricultural production, new research that assesses different bean cultivars' response to water stress for a longer period and at different phenological stages is highlighted.

## CONCLUSION

The silicon doses did not influence the development and tolerance to water deficit for the bean culture.

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