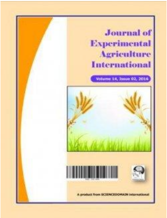

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Sources of Potassic Fertilization in Soybean Production under Different Irrigation Blades

Hudson Carvalho Bianchini[1*] and Douglas Jose Marques[1]

[1]Department of Agronomy, University Jose do Rosario Vellano-UNIFENAS, Minas Gerais, Brazil.

Authors' contributions

This work was carried out in collaboration between both authors. Author HCB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author DJM managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: The objective of this research was to evaluate the physiological and biometric parameters of the soybean crop in potassic fertilization sources under different irrigation blades. Two potassium sources (ground rock, "phonolite", with 9% K2O and potassium chloride with 60% K2O) and five irrigation blades (30, 70, 100, 130 and 160% of the recommended blade) were used.

Study Design: The experimental design was in randomized blocks, with ten treatments and four replications, in a 2 x 5 factorial scheme, totaling 40 vessels.

Place and Duration of Study: Sample: Department of Agronomy, UNIFENAS, between March 2018 and November 2018.

Methodology: Soil moisture was determined through tensiometers, using a water potential of -30kPa, considered adequate for the soybean crop. At the end of the crop cycle, the weight of shoot dry matter, weight of 1000 seeds, weight of seeds standardized to 13% moisture, total chlorophyll, chlorophyll a, chlorophyll b and carotenoids, besides nutrient content of the leaf tissue, were evaluated.

Conclusion: KCl favors the accumulation of dry matter, weight of 1000 grains and grain production in the soybean crop in the different irrigation blades. Phonolite increases calcium and magnesium contents in the leaves, independently of the irrigation blade used, also favoring the increase in phosphorus and sulfur contents when soil moisture increases.

**Corresponding author: E-mail: hudson.bianchini@unifenas.br;*

Keywords: Glycine max (L.); drought stress; potassium; phonolite rock; KCl.

1. INTRODUCTION

Soybean, *Glycine max* (L.) Merrill, is a crop of great social and economic importance. The area under cultivation in the world is over 58 million hectares, with an average yield of 3,593 kg ha^{-1}. Brazil is the second largest soybean producer in the world, with possibilities for linear growth in production, both by increasing yield and territorial expansion [1]. In the 2017/2018 harvest season, production was 119.3 million tons in an area of 35.15 million hectares [2].

Potassium demand for the soybean crop is approximately 38 kg K_2O for each ton of grain produced, with approximately 20 kg of potassium exported per tonne [3]. Due to the high production of soybeans in Brazil, the demand for imported potassic fertilizers has increased continuously, since the internal production of these fertilizers is small, when compared to the great domestic demand for the product. Brazil is located in the world context as a major importer of potassic fertilizers, which represents 95% of the total consumed. In 2017, almost 6 million tons of K_2O were imported into Brazil [4].

Rockdust is a fertilization technique based on the addition of dust of certain types of rocks or minerals with the capacity to positively alter the fertility of the soil, without affecting environmental balance [5]. In Poços de Caldas, MG, Brazil, Curimbaba Mining extracts an alkaline volcanic rock as a by-product in bauxite mining, called “phonolite”, with about 8.5% K_2O, 1.5% CaO, 3.4% Fe_2O_3 and 7% Na_2O. In a technical report on the use of phonolite in field experiments, the possibility of phonolite to totally replace the use of KCl in planting fertilization was verified [6].

Water is an essential factor for plant development due to its direct involvement in the transport of nutrients and metabolites. Approximately 33% of the world’s land area has been found to be drought-prone, which is a serious threat to agriculture and crop production in the near future [7]. The reduction in water availability and/or the increase in transpiration rate induce water stress in plants and negatively influence various physiological processes. When the plant is subjected to adverse conditions, a series of internal protection mechanisms are activated, and the osmotic adjustment is one of the most efficient physiological mechanisms to maintain cellular turgescence, under conditions of low soil water potential [8]. In plants submitted to water stress, the K^+ ion efflux of guard cells, which lose water to neighboring cells, leads to a decrease in turgescence and stomatal closure [9].

Water constitutes approximately 90% of the weight of the soybean plant, acting in practically all the physiological and biochemical processes, in addition to performing the solvent function, transporting gases, minerals and other solutes in the plant [10]. The occurrence of water deficit causes premature loss of leaves, flowers and pod abortion, resulting in a lower grain yield [11]. The water requirement for soybean cultivation increases with plant development and reaches the maximum during flowering and grain filling (7.0-8.0 mm per day), decreasing after this period. The amount of water required by the crop for maximum yield ranges between 450 and 800 mm per cycle [12]. It is important to evaluate alternative sources of potassic fertilizers, such as phonolite rock dust, considering the behavior of physiological parameters in situations where the available water for the plants is a limiting factor.

Therefore, the objective of this research was to evaluate the physiological and biometric parameters of the soybean crop in potassic fertilization sources under different irrigation blades.

2. MATERIALS AND METHODS

All stages of the research were conducted in a greenhouse, covered with agrofilm, using two protective structures, with 225 m each (9 m wide/25 m long) and 4 m headroom. Each experimental unit consisted of a polyethylene vessel, with a volume of 19 dm^3, filled with medium-textured Oxisol [13]. The experimental design was in randomized blocks, with 10 treatments and 4 replications in a 2 x 5 factorial scheme, using two potassium sources (phololite 9% K_2O and potassium chloride 60% K_2O) and five irrigation blades (30, 70, 100, 130 and 160 % of the recommended water blade), totaling 40 vessels.

The soil used has the following characteristics: organic matter, 19 g dm^{-3}; pH ($CaCl_2$), 6.1; pH (H_2O), 6.6; Ca, 34 mmolc dm^{-3}; Mg, 24 mmolc dm^{-3}; Al, 0.0 cmolc dm^{-3}; K, 3 mmolc dm^{-3}; P (Mehlich), 5 mg dm^{-3}; and base saturation of 73%. Before sowing, the soil was fertilized with

300 mg dm^{-3} of P_2O_5 (single superphosphate) and 200 mg dm^{-3} of K_2O (phonolite and potassium chloride) [14]. In order to favor symbiotic nitrogen fixation, bacteria of the genus *Bradyrhizobium* were inoculated to the seeds. During plant development, the necessary phytosanitary treatments were made.

The soybean cultivar 'AS 3730 IPRO' was used, with 4 seeds in each vessel so that, after thinning, 2 plants were well distributed. After plant germination and thinning, the soil of the vessels was covered with a layer of dry grass, to limit water losses. The following parameters were evaluated: weight of shoot dry matter, weight of 1000 seeds, weight of grains standardized to 13 % moisture, total chlorophyll, chlorophyll *a*, chlorophyll *b* and carotenoids, besides nutrient content of leaf tissue. Soil chemical analyses were also performed at the beginning and at the end of the experiment.

Soil moisture was determined through tensiometers, using a water potential of -30kPa, considered adequate for crop development [15].

Irrigation was performed by drip irrigation, and self-compensating emitters were manually inserted in polyethylene hoses. The calculation of the operating time of the irrigation system was made based on the moisture sensors (tensiometers) installed at a depth of 0.15 m. With the observed tensions, the corresponding moisture values were estimated from the water retention curve in the soil. With these moisture values and that corresponding to -30 kPa, and considering the effective depth of the root system (0.15 m), the net and gross replacement blades were calculated for the treatments. The irrigation system operating time was calculated for water replenishment in the 5 blades studied (30, 70, 100, 130 and 160 % of the recommended water blade), according to [16]. Aiming at soil water replacement, two readings were performed daily in the tensiometers, one in the morning (8.00 a.m.) and one in the afternoon (2.00 p.m.).

To determine the dry matter weight of the plants, the shoot was collected (including the stem), and the material was then dried in greenhouses at 60º C, with forced ventilation until reaching a constant mass. Material was also collected for the determination of the contents of N, P, K, Ca, Mg and S [17]. A self-calibrating chlorophyll meter (SPAD 502, Spectrum Technologies Plaineld, IL) was used to measure chlorophyll content based on SPAD values in the determination of photosynthetic pigments, evaluating the middle third of the central leaves of the plants in the useful plots; the mean was used to represent the treatments. The evaluations were performed in the morning. The results were submitted to analysis of variance and the means were submitted to the Scott-Knott test using the SISVAR software [18].

3. RESULTS AND DISCUSSION

The leaf contents of N, P, K, Ca, Mg and S are shown in Fig. 1. The highest levels of N in the leaves of soybean plants were obtained with the use of KCl for all the irrigation blades. This is due to the fact that KCl is a more soluble source than phonolite. Considering that K is required as a co-factor of more than 40 enzymes, being the main cation in the establishment of cellular turgor and maintenance of cellular electroneutrality [19], this may have favored an increase in N metabolism in plants fertilized with KCl. A characteristic of leguminous plants is the nitrogen fixing capacity of the air, due to the high N requirement of the crop (estimated at 80 kg N to produce 1000 kg of soybeans) to obtain high yields, N_2 fixation should work with maximum efficiency [20].

The leaf content of P was higher for the treatment with KCl in the blades of 30 and 100% and the use of phonolite favored higher levels of P in the blades 70, 130 and 160%. In all irrigation blades, KCl increased the leaf content of K, due to its higher solubility. The leaf content of S was higher until the 100% blade for the use of KCl and in the blades of 130 and 160%, the content was higher for phonolite. The interactions between nutrients at different moisture levels probably explain the results obtained. The soybean crop is very demanding in nutrients, being highly responsive to fertilization, mainly nitrogen, phosphorus, potassium and sulfur, which are exported in greater quantity. After nitrogen, potassium is the second most absorbed nutrient by soybeans. The soybean crop absorbs from the soil about 81 kg of N and 54 kg of K for every 1,000 kg of harvested grains, which result in an annual export of 51 kg of N and 14.4 kg of K per ton of grain [21].

The leaf contents of Ca and Mg showed an increasing trend, in all the irrigation blades with the use of phonolite, due to the presence of these nutrients in the rock dust used. The highest levels of Ca and Mg can be explained by the competition between K, Ca and Mg cations by the same root absorption site. The imbalance between these nutrients affects plant nutrition, causing the antagonism between them. This imbalance causes reciprocal influences in terms of soil availability, uptake and translocation in the plant [19]. In the treatments fertilized with KCl, which is more soluble than phonolite, K was released faster, which may have favored competitive inhibition, reducing Ca and Mg leaf contents.

Fertilization with KCl yielded the highest levels of chlorophyll a, except in the 100% blade (Fig. 2A). Chlorophyll b contents were higher for blades 30, 70 and 130% with the use of KCl and, in blades of 100 and 160%, the contents were higher for phonolite (Fig. 2B). The treatment with KCl yielded higher total chlorophyll content, with an increase in irrigation levels (Fig. 2C). For the 30, 70 and 130% blades, the carotenoid contents were higher with KCl and, in the blades of 100 and 160%, they were higher for phonolite (Fig. 2D). There seems to be no direct relationship between chlorophyll a and b levels and plant water stress, even in very negative xylem water potentials (between -0.70 and -2.0 MPa), there was little variation in chlorophyll a and b levels due to degradation of chlorophylls occurring throughout crop development [22]. Other factors may also have contributed to the results obtained, since it is important to emphasize that the photosynthetic activity, soluble protein content and macro- and micronutrients in the leaves vary greatly and may affect the chlorophyll content in the leaf tissue [23].

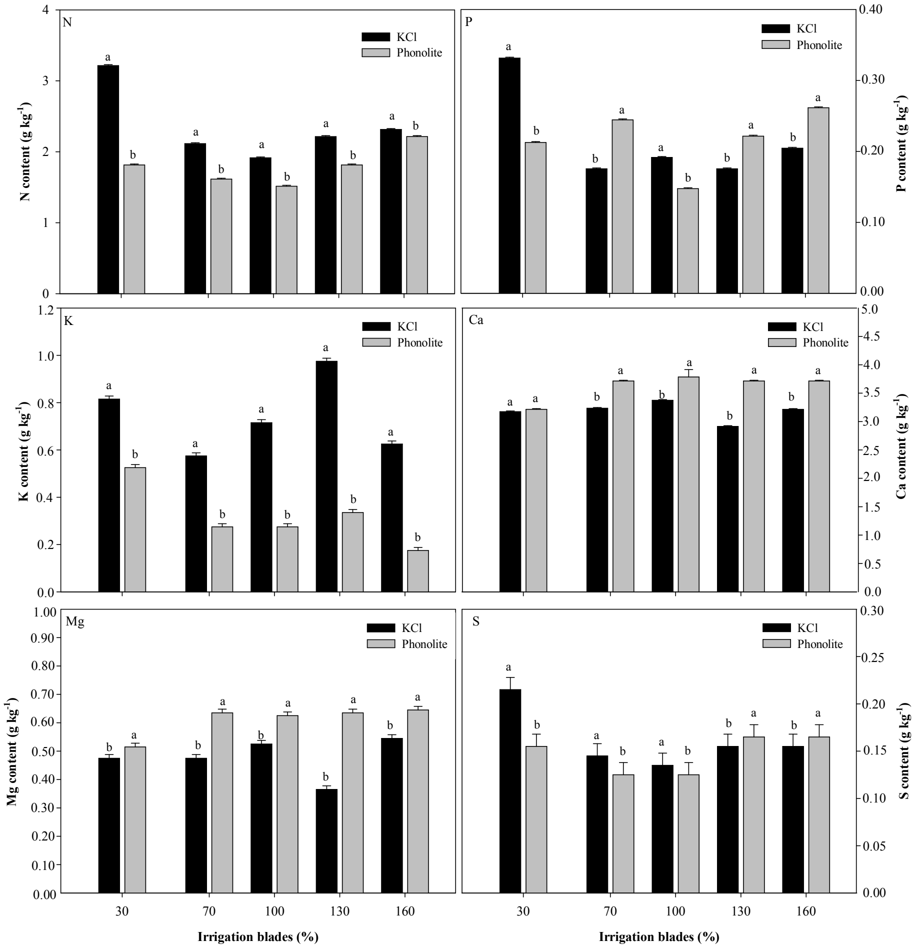

Fig. 1. Nutrient content in soybean leaves as a function of fertilization with KCl and phonolite in relation to irrigation blades (%). Means followed by the same letter are not significantly different by the Scott-Knott test at 5 % of probability. The bars represent the mean standard error

The carotenoid content presents an increasing trend in the plants that were fertilized with phonolite in the treatments with greater moisture content. On the other hand, in the treatments with the irrigation blades with 30% and 70% KCl, which is a more soluble fertilizer, higher levels of carotenoids were obtained, due to the greater release of K^+ and Cl^- ions. Considering that the osmoregulation of guard cells is due to the entrance of K^+ and Cl^- ions and to the synthesis of malate^{2-} within these cells [9], stomatal closure is one of the first responses to water stress, reducing photosynthesis activity, due to a smaller CO_2 assimilation and increased photorespiration [24]. Regardless of the source used, the potassium fertilization that was used in this experiment is in agreement with that recommended for the crop, which favored the adequate functioning of stomatal opening and closing mechanism in the guard cells and tissue turgidity, which is regulated by K. K-deficient plants are less able to absorb water and are more subject to stress when the water content is below the critical for the crop [11]. The greater stomatal density favors greater CO_2 assimilation and, consequently, increases the potential photosynthesis. This increase depends on the availability of Mg and Ca [14].

Dry matter weight, weight of 1000 grains and soybean production were higher with the use of KCl in all studied irrigation blades (Fig. 3A, B and C). This can be explained by the high solubility of KCl, favoring the release of K in the soil solution from the initial plant development stage. Since K is the ion responsible for osmotic regulation, control of stomatal opening and closing, energy regulation, assimilate translocation, N absorption and protein and starch synthesis, it is important for grain filling [19]. Good K nutrition ensures ATPase activity, which is essential for the transformation of light energy into chemical energy by photosynthesis [25]. The production of dry matter is dependent on water

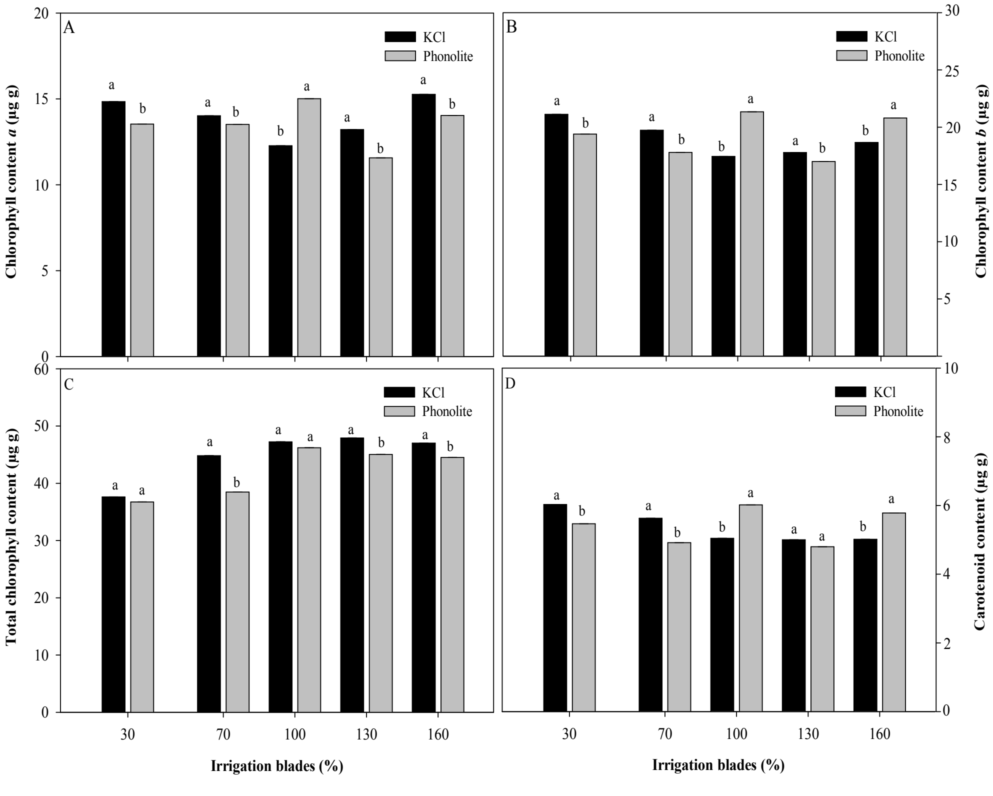

Fig. 2. Contents of chlorophyll a and b (A and B), total chlorophyl (C) and carotenoids (D) as a function of fertilization with KCl and phonolite in relation to irrigation blades (%). Means followed by the same letter are not significantly different by the Scott-KNOTT test at 5 % of probability. The bars represent the mean standard error

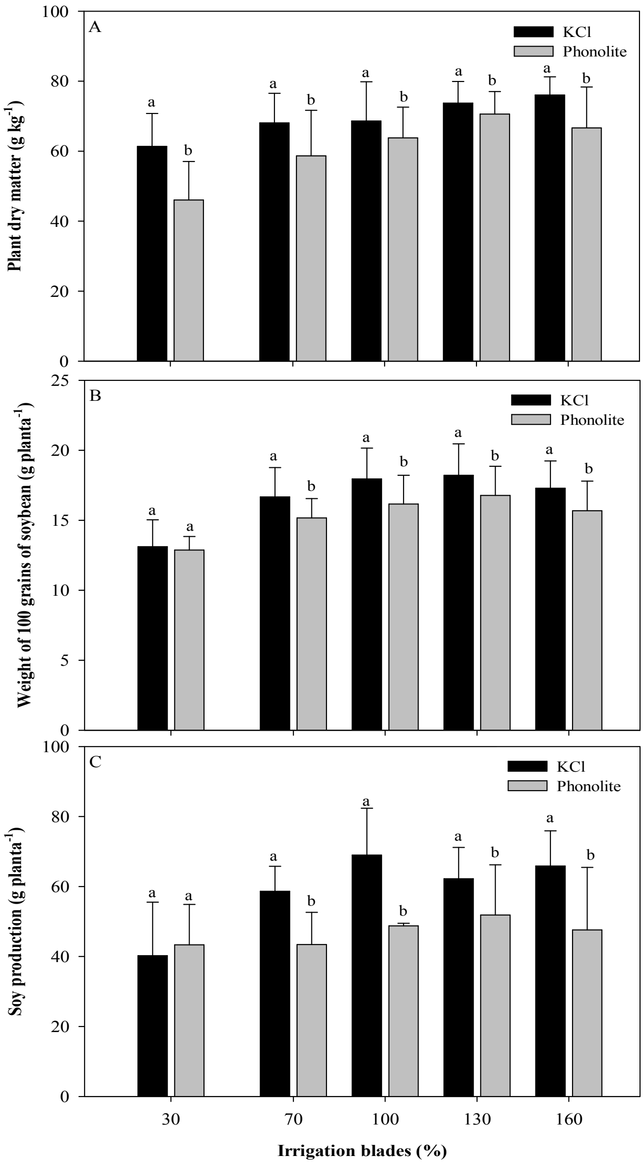

Fig. 3. Plant dry matter weight (A), weight of 1000 seeds (B) and soybean production (C) as a function of fertilization with KCl and phonolite in relation to irrigation blades (%). Means followed by the same letter are not significantly different by the Scott-Knott test at 5 % of probability. The bars represent the mean standard error

absorption, since all the plant metabolism is reduced with the low water potential. The gain in weight is the result of carbon assimilation, which is lower in wilted tissues. Drought-induced suppression in photosynthesis and growth induce significant changes in important biochemical processes of plants [26]; in addition, the decrease in photosynthesis due to water stress is associated with interrupted enzyme activities, loss of membrane integrity and stomatal closure. In the 30 % blade, the situation of higher water deficit faced by plants, grain yield, dry matter weight and weight of 1000 grains had lower values. Crop development is affected by water deficit, which reduces plant height, relative growth rate, leaf area index and photosynthetic rate with a negative impact on grain production. In the early stage of soybean development, the dry weight of the plant is reduced after 1 day of stress exposure [7]. During the soybean development phase, if the water stress period persists for a long time, several physiological changes occur, among them flower abortion, which reflects in a smaller number of grains, and the water requirement for the soybean crop increases with plant development and reaches the maximum during flowering and grain filling stages. The compensatory effect of K and soil moisture, where one factor tends to reduce the effect of deficiency on the other, has an effect on grain yield [27]. The application of higher levels of potassium fertilizer under drought stress condition improves plant water status, as well as soybean yield [28].

During the soybean development phase, if the water stress period persists for a long time, several physiological changes occur, among them flower abortion, which reflects in a smaller number of grains, and the water requirement for the soybean crop increases with plant development and reaches the maximum during flowering and grain filling stages [29].

4. CONCLUSION

KCl favors the accumulation of dry matter, weight of 1000 grains and grain production in the soybean crop in the different irrigation blades. Phonolite increases the calcium and magnesium content in the leaves, independently of the irrigation blade used, also favoring the increase in phosphorus and sulfur contents when soil moisture increases.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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