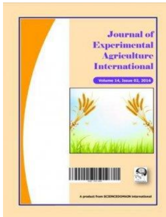

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Irrigation Levels and Potassium Doses in the Growth of Sunflower Cultivated in Soil of the Brazilian Cerrado

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Authors' contributions

This work was carried out in collaboration between all authors. Authors MK, EMBS and TJAS designed the study and wrote the protocol. The author LGAD were responsible for conducting the experiment, statistical analysis and scientific writing. The authors VMR and MK corrected and improved the writing of the manuscript in. All authors read and approved the final manuscript.

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ABSTRACT

The chief limiting factor in sunflower (*Helianthus annuus* L.) development is water deficit. Besides the dearth of water, large amounts of mainly potassium (K) are essential for the favourable development and bountiful harvest of the culture. This study aimed to evaluate the growth of sunflower plants cv. SYN 042 cultivated in red Cerrado Oxisol with controlled irrigation levels and K doses. Randomized block design was selected in a 5x4 factorial scheme, administering 5 K doses (0, 40, 80, 160 and 240 mg dm^{-3} of K_2O) and 4 different water replacement levels in the soil (75, 100, 125 and 150% of field capacity (FC)), with 4 replications. The following characteristics were evaluated: Plant height, stem diameter, Chlorophyll index, inner and outer diameters of the chapter,

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and dry mass of the stem. When 150% water replacement level of field capacity was utilised, it induced an increase in the plant growth as observed in terms of stem diameter, inner and outer diameters of the chapter, plant height and stem dry mass. The K added as fertiliser significantly affected the plant height, inner and outer diameters of the chapter, SPAD (direct index chlorophyll content), and stem dry mass, during the assessment performed at 60 days post emergence. The sunflower plants displayed improved development when the irrigation levels and K doses were estimated in isolation. The 150% water replacement level of field capacity provided the best results of development and growth of sunflower in Oxisol of the Cerrado.

Keywords: Sunflower; irrigation management; Oxisol; potassium concentration.

1. INTRODUCTION

Sunflower (*Helianthus annuus* L.) falls into the category of plant species that have the highest potential to produce renewable energy in Brazil. It is cultivated mainly for oil production for human consumption as well as for biofuel [1] and its by-product also finds use as an animal feed supplement.

From an agricultural perspective, sunflower cultivation is valued as a profitable alternative compared with other crops, because of its desirable features including its short cycle, production of good quality and quantity of oil, drought tolerance, high level of adaptability and lower production costs than any other oil [2]. Brazilian producers, thus, regard sunflower production as a viable option for additional income [3,4].

Drought is the prime limiting factor on plant growth [5]. It has become common for most farmers to regard irrigation supplemented with mineral fertilisers as advantageous to crops. K is the second most absorbed element by plants, and according to Embrapa [6] is an abundant cation, most often in its water-soluble form, observed in the tissues. It is considered one of the more mobile among the nutrients in the soil-water-plant system and especially so within the plant [6].

The low and insufficient concentration of K reserves found in a large part of the Cerrado soils have contributed towards limiting the productivity of the cultivations [7]. To boost this naturally occurring low concentration of nutrient, supplementation with fertilisers becomes necessary for the plants to flourish [8].

Beginning with the hypothesis that the combined effect of irrigation levels and K doses affects the plant growth, development and nutrition of the sunflower crop, this study aimed at assessing the growth patterns of sunflower plants cv. SYN 042 cultivated with different of water replacement levels in the soil and K doses in the Cerrado Oxisol.

2. MATERIALS AND METHODS

The experiment was performed in a greenhouse from April to August of 2015 at the Federal University of Mato Grosso, Campus of Rondonópolis - MT. The used greenhouse in the experiment had a metal frame, covered with polyethylene film and an adiabatic cooling system. It was in the north-south direction, extending across a total area of 450 m^2. The geographic location was latitude 16º27'49 '' South, longitude 54º34'47 '' West at an altitude of 284 m.

For the experiment, a sandy loam Oxisol [6], was collected from a depth of 0.0 - 0.2 m layer, used to fill the experimental plots, after passing it through a 4 mm mesh size sieve. One soil sample was sieved through a 2 mm mesh to study chemical properties and particle-size composition.

After analyses the soil, following chemical and textural characteristics were recorded: pH ($CaCl_2$ 0,01M) = 4.1; P (Mehlich-1,) = 2.4 mg dm^{-3}; K (Mehlich-1)= 28 mg dm^{-3}; Ca (Extraction KCl 1M) = 0.3 cmolc dm^{-3}; Mg (Extraction KCl 1M) = 0.2 cmolc dm^{-3}; Al (Extraction KCl 1M) = 1.1 cmolc dm^{-3}, atomic Absorption Readings were performed for Ca and Mg and acid titration for Al; H = 4.2 cmolc dm^{-3}; Organic Matter (OM) = 22.7 g dm^{-3} by titration - Walkley Black; Sand = 549 g kg^{-1}; silt = 84 g kg^{-1}; and clay = 367 g kg^{-1}; sum total of the bases cmolc 0.6 dm^{-3}; Cation Exchange Capacity (CEC) = 65.9 cmolc dm^{-3}; Base Saturation (V) = 9.8%.

The randomized block design was selected for the experiment in which a total of 80 experimental plots represented by 20 dm^3 capacity plastic pots were arranged in a 5x4 factorial scheme. It involved 20 treatments and 4 replications. The treatments consisted of 5 K doses (0, 40, 80, 160 and 240 mg dm^{-3} of K_2O) and 4 irrigation water replacement levels in the soil (75, 100, 125 and 150% of field capacity (FC)). The experimental units were organised into 4 blocks each having 20 treatments units.

Sunflower (*Helianthus annuus* L.) cultivar SYN 042 was the plant species used, having a short cycle, equal to 90-100 days of cultivation after sowing. The sunflower sowing was accompanied simultaneously by the addition of fertiliser. All the treatments were fertilised with N, P_2O_5 and micronutrients, the sources were urea, superphosphate and formulated FTE BR-12, respectively.

The recommended P dosage was 150 mg dm^{-3} of P_2O_5 single superphosphate (0-20-0) applied in solid, granular form. N fertilisation was performed into 2 installments, applying 20 mg dm^{-3} at sowing time and 80 mg dm^{-3} coverage at 30 days after sowing (DAS), both in solution form. A top dressing of 40 mg dm^{-3} of formulated FTE BR-12 (Sulfur: 3.9%, Boron: 1.8%, Manganese: 2.0% and Zinc: 9.0%).was also applied. Potassium chloride (KCl) was the potassium source added to the soil at planting, corresponding to the treatment doses (0, 40, 80, 160 and 240 mg dm^{-3} K_2O).

The irrigation management used was based on the tensiometer. Therefore, to correlate the soil moisture assessed by water consumption of the crop throughout the cycle with the matrix potential, the soil water retention curve in equation 1 was determined.

The Soil Water Retention Curve - SWRC computer program [9] was employed to mathematically adjust the results to the non-linear model proposed by Dourado [10], who explained the action of moisture as a function of the water tension from the soil.

$$\Theta = \frac{0.468}{[1 + (0.0537|\Psi m|)^{0.3545}]^{0.5724}} \quad (1)$$

In which:

θ - Volumetric soil water content in cm^3 cm^{-3};
ψm - water potential in the soil, in cm;

To estimate the water tension levels in the soil puncture tensiometers were installed in the vessels, one per block, totaling to 4 tensiometers. Irrigation management was then performed from the average reading of the tensions observed in the 4 tensiometers installed in the experimental units with 100% water replacement in the soil and a reference dose of 80 mg dm^{-3} of K.

The water tension in the soil was monitored with a digital tensiometer having a precision of 0.1 kPa. Irrigation time indicated the average stress attained by the four tensiometers to reach the next value of 10 kPa.

Manual irrigation was performed using a graduated and calibrated cylinder to raise the tension values to the field capacity of 6 kPa for all the treatments at the 100% water replacement level in the soil when the established tension of 10 kPa was achieved. Van [11] reported that field capacity values up to 5 kPa in typical Cerrado soil were a common occurrence.

Using the tensions observed the corresponding humidity values were calculated from the water retention curves in the soil. Thus, the volume of water replacement in the soil was calculated with these humidities and the values corresponding to the field capacity, by the equation given below.

$$V = (\theta_{FC} - \theta_{actual}) * 20000 \quad (2)$$

In which:

V - Water volume in cm^3;
θFC - moisture at field capacity in cm^3 cm^{-3};
θactual - moisture retention curve according to the tension observed in cm^3 cm^3;
20,000 - Volume of soil inside the pot, in cm^3;

Water replacement levels utilised in each experimental unit were set according to the percentages for each treatment.

Growth and development of sunflower plants were assessed and analysed at 60 days after plant emergence, evaluating the following aspects:

Plant height was measured by measuring the distance between the plant collar (soil surface) and the upper end of the main stem, with the help of a ruler.

Leaf number: the counting of the leaves present in each experimental plot was performed, in which the ones with a minimum length of 4 cm were considered.

Stem diameter: was obtained from a reading average of the two plants contained in the pot, at a height of 5 cm from the soil surface, with the aid of a digital caliper.

Direct index chlorophyll content reading: obtained from the average of five readings performed in random sheets in the middle third of the plants, with the aid of the chlorophyll meter chlorophyll meter Minolta SPAD-502.

Inner and outer diameters of the chapter: were measured using a tape measure.

Dry mass and stems: the stems were packed in paper bags, identified and transferred to a greenhouse at 65°C for 72 hours, and then weighed.

The results were statistically analysed using the statistical program SISVAR [12] with the analysis of variance and regression tests performed for a significance level at 5% of probability.

3. RESULTS AND DISCUSSION

The analysis of variance revealed a significant effect for the interaction between irrigation levels and potassium doses 60 days after plant emergence, only for the stem dry mass variable. However, there was a significant effect, in isolation, of factors irrigation levels and doses of potassium, for the other variables analysed.

The height of sunflower plants was influenced by irrigation levels, in isolation. It is observed that this variable, according to the levels of irrigation, adjusted to the linear regression model, with increasing water levels up to 150% of field capacity, providing the highest plant height (151.52 cm) at 60 days after emergence (Fig. 1).

One explanation for the influence of water levels on the vegetative growth of the sunflower plant is that the water stimulates a higher amount of carbohydrate assimilation, a significant factor which stimulates photosynthesis and increases the leaf surface. [13] proposed that the leaf expansion rate and photosynthetic contribution are linked to the vegetative growth rate and increased leaf area which involves a heightened production of assimilates essential for good quality production.

Variations in the availability of water in the soil, probably caused the reduction in the water potential in the stem cells of the sunflower plants, producing a smaller cell elongation and internodes, culminating in smaller growth in these plants [14].

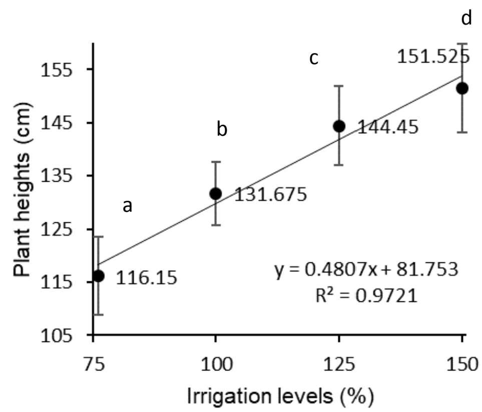


Fig. 1. Plants height submitted to irrigation levels in red Cerrado Oxisol. Averages followed by the same letter do not differ statistically from each other by with post hoc test from Tukey at 5% probability
****Significant regression test at the 0.1% probability level*

The water replacement levels in the soil revealed an isolated significant effect in setting the linear regression model for stem diameter; the greatest diameter found was 11.28 mm showing a 20% increase with the highest water replacement level in the soil (150% FC) when compared with the level that induced the least diameter (75% FC) (Fig. 2A).

With respect to the chlorophyll index, a significant effect of the K concentration in the soil was noted. The K fertiliser positively influenced the chlorophyll concentration in the sunflower leaves adjusting the quadratic regression model, and thus reiterating that the quantity of K_2O 155.93 mg dm^{-3} was responsible for the higher chlorophyll content (42.10) (Fig. 2B).

The results from this study corroborates with [15] who noted that the decrease in the water storage in the soil resulted in the development of a smaller stem diameter.

The stem diameter increase can be correlated to the production of ethylene; this is because in the presence of excess water, larger amounts of this hormone are produced, resulting in lesser root growth. This in turn causes an increase in the lateral roots and underarm and is visible as greater stem diameter. Stem diameter is

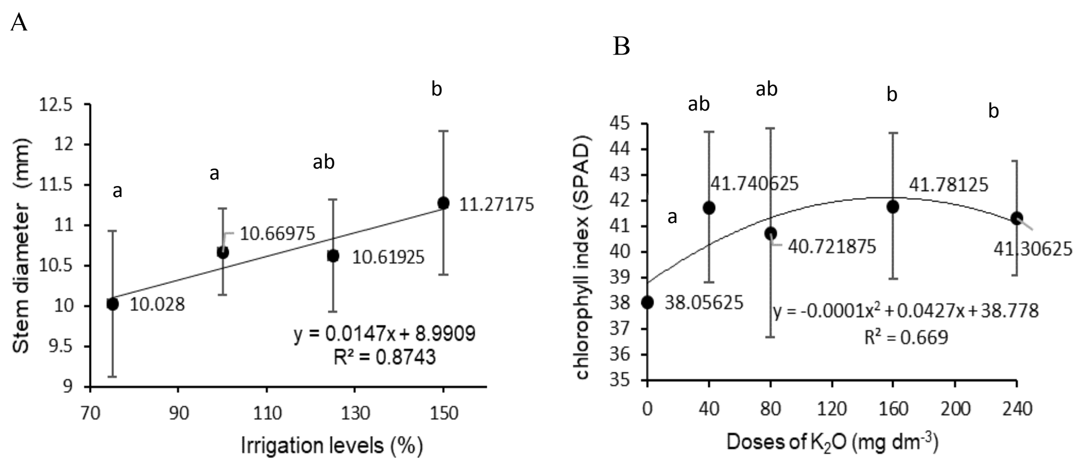


Fig. 2. Diameter of the stem as a function of irrigation levels (A) and chlorophyll index in response to K_2O (B) doses in Red Cerrado Oxisol. Averages followed by the same letter do not differ statistically from each other by with post hoc test from tukey at 5% probability

****, * significant regression test at the 0.1 and 5% respectively probability level*

significant in sunflower, because it decreases the layering of the culture, enhancing their management, cultivation and harvesting [16].

The rise in the chlorophyll content is because the chloroplasts possess about one-half of the K nutrients of the leaf. This stimulates greater diffusivity of the CO_2 in the mesophyll cells, thus raising the degree of photosynthetic activity [17].

It is also now possible to understand that the addition of the K fertiliser positively influences the SPAD index, if administered accurately. It also increases the N uptake and transport, the stomatal movement occurs by the entrance and exit of potassium ions (K^+) from the guard cells, regulating the entry of CO_2 that serves as fuel for photosynthesis according to Prado [18]. K deficiency induces irregular stomatal functions, which may decrease the CO_2 assimilation and consequently the photosynthetic rate [19], thus negatively affecting the production.

At 60 days post emergence a linear increase was observed in the internal and external diameters of the sunflower chapter as the water replacement levels increased. For the highest water replacement level in the soil, a diameter of 10.44 cm and 23.29 cm, respectively, was recorded, showing a 28% increase when the highest water replacement level in the ground (150% of FC) was compared with the least degree of irrigation applied (75% of FC) (Figs. 3A and 3B).

The application of K fertiliser was found to influence the inner diameter of chapter, with lower diameter for absence of K_2O no significant difference is reported in between doses of 40 to 240 mg dm^{-3} of nutrient, setting the quadratic regression model with the higher value (10.33 cm) induced by the K dose of 183.72 mg dm^{-3} (Fig. 3C).

Similar results were reported by Cecílio and Grangeiro [20] with the larger diameter of 11.9 cm observed in response to doses above 60 kg ha^{-1} K_2O.

In their study, Silva et al. [4] compared the growth and productivity of the sunflower plants under various irrigation levels, reporting a significant difference between the inner and outer diameters of the sunflower chapters, depending on the water replacement levels applied. They also suggested the possibility of achieving a higher grain production because of the larger sizes, on average, of the chapters. According to Gomes et al. [21] water availability is an important factor that limits the sunflower crop, and its production is greatly affected by the irrigation levels.

The F test showed that the stem dry mass was significantly influenced at the 5% level of probability, the interaction between the irrigation levels and K doses. The regression analysis for the averages of the K fertiliser levels, considering the water replacement levels in the soil, revealed a quadratic response to the 100 and 150% levels. For the 75 and 125% levels the linear behavior for K dosages was observed.

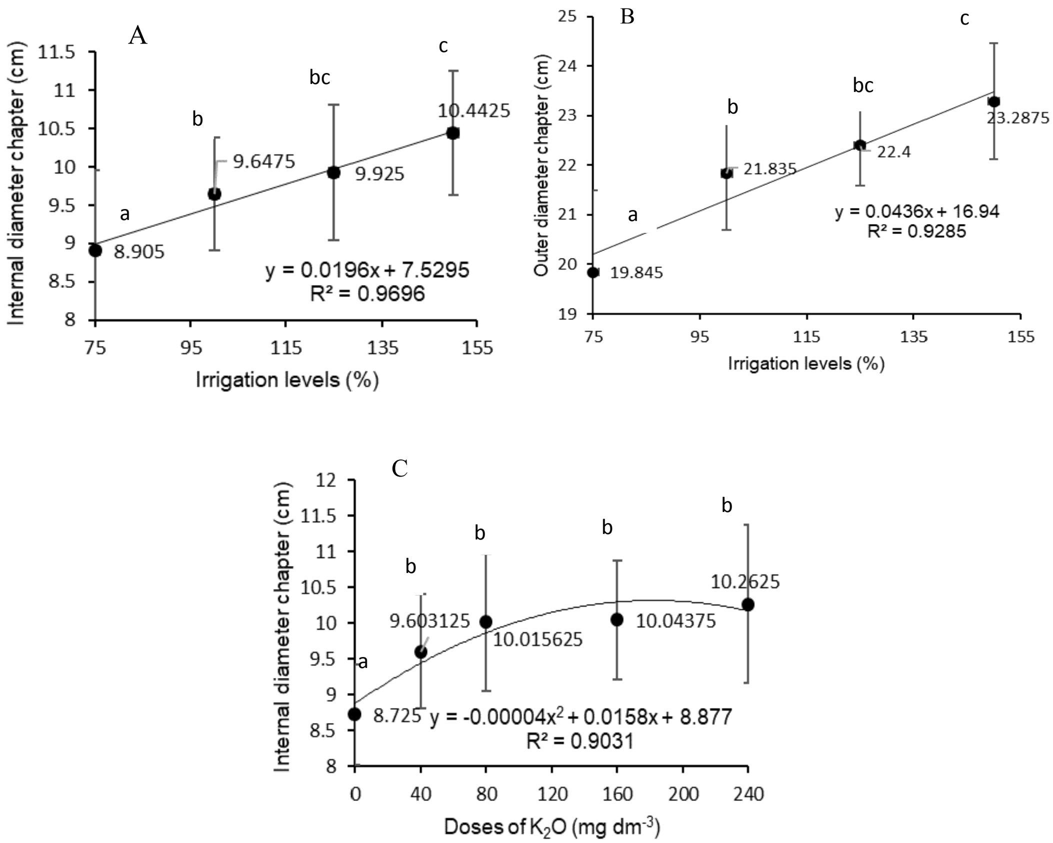
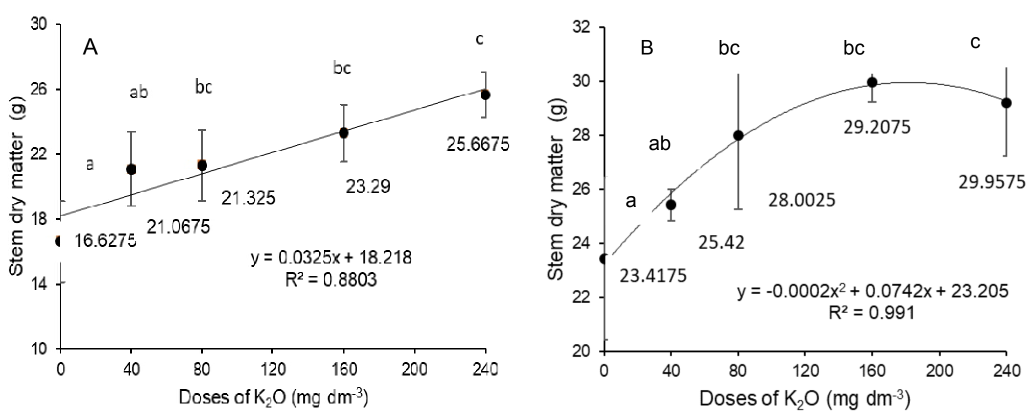


Fig. 3. Internal and external diameter of the chapter of the sunflower based on the water replacement levels (A) and (B) and the K2O doses (C) in Red Cerrado Oxisol. Averages followed by the same letter do not differ statistically from each other by with post hoc test from tukey at 5% probability

****,** significant regression test at the 0.1 and 1% probability level respectively.*

At the 75 and 125% levels of field capacity a linear increase in stem dry mas was reported in response to the 240 mg dm^{-3} dose of K (Fig. 4), corresponding to 25.66 and 37.67 g, respectively. For 100 and 150% irrigation levels of field capacity the K doses induced higher degrees of stem dry mass (30.09 and 47.29 g) which were 186.75 and 232.37 mg dm^{-3}, respectively (Fig. 4).



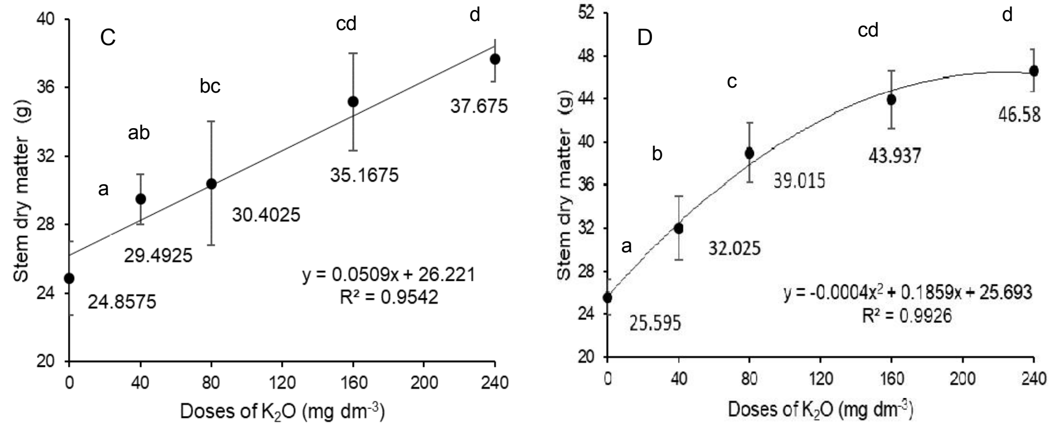


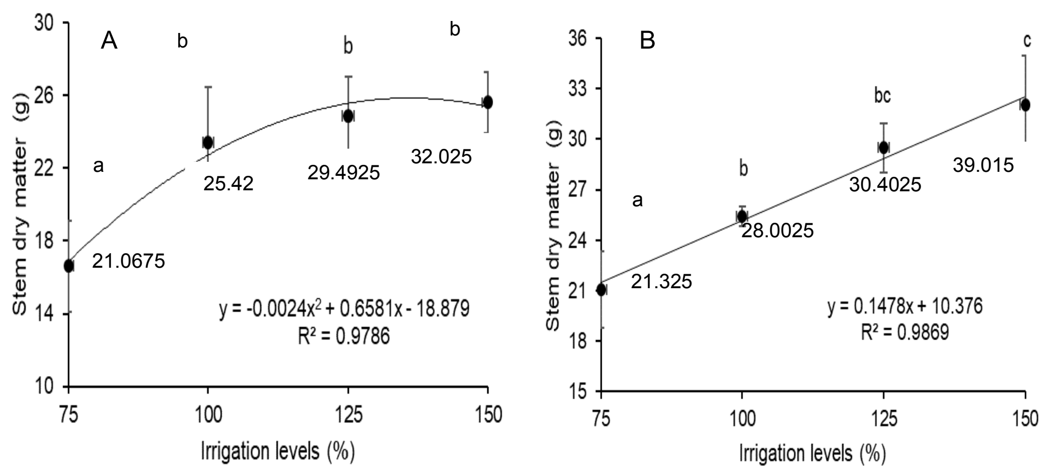
Fig. 4. Dry mass of the stem due to combinations of K_2O doses and soil irrigation levels of 75 (A), 100 (B), 125 (C) and 150% (D) of CF in Red Cerrado Oxisol. Averages followed by the same letter do not differ statistically from each other by with post hoc test from tukey at 5% probability

*** significant regression test at the 1% probability level.*

Regression analysis performed for the medium levels of water availability, considering the K levels, revealed a quadratic response to the 0 mg dm^{-3} dose. For the 40, 80 and160 mg dm^{-3} doses of K_2O the linear behavior was evident for the irrigation levels (Fig. 5). For the 0 mg dm^{-3} dose of K_2O, the irrigation level induced a greater stem dry mass in the sunflower plants (25.84 g) which was 135.91% of FC.

For the 40, 80 and 160 mg dm^{-3} doses of K_2O a linear increase in the stem dry mass was noted (32.02, 39.01 and 43.93 g, respectively) in response to the increase in the water levels, an increase of 68.11, 87.57 and 93.35 %, respectively, compared with the highest water replacement level in the soil (150% of FC) with the lowest water replacement level applied (75% of FC).

Nobre et al. [1], reported a linear growth in the shoot (leaves, stems and roots) dry mass of the sunflower with an increase in the water depth; the increase recorded was 280.88% compared with the treatment under hypoxic conditions and 40% water requirement.



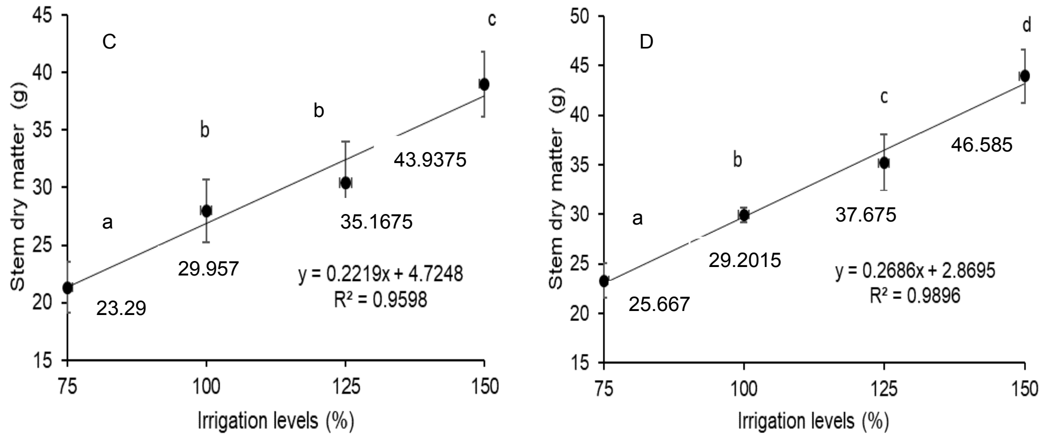


Fig. 5. Dry mass of the stem due to combinations of irrigation levels and potassium doses of 0 (A), 40 (B), 80 (C) and 160 mg dm^{-3} (D) in Red Cerrado Oxisol. Averages followed by the same letter do not differ statistically from each other by with post hoc test from tukey at 5% probability

** significant regression test at the 5% probability level*

Optimal and well distributed amounts of water supply during the plant cycle are crucial for growth. According to Farahvash et al. [22] any decrease in the total dry mass of the sunflower plants is the direct result of drought during the growth and development period of the plants, which would show reduced leaf area and thus slower photosynthetic process. This results in the low production of assimilates and poor development of the leaves, stem and chapters.

4. CONCLUSION

The more water available for the sunflower plants, the higher their output in terms of the quantitative growth parameters, plant height, stem diameter and inner and outer diameters of the chapter.

The most favourable range of doses of K as fertiliser required to maximise the growth and development of sunflower plants was 133.5 to 240 mg dm^{-3}.

Decreases in the water available in the soil negatively influence the growth and biomass accumulation in sunflower plants SYN 042.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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