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Productive characteristics of quinoa (*Chenopodium quinoa* Willd.) under irrigation and potassium fertilization

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Abstract

Quinoa (*Chenopodium quinoa* Willd.) quickly adapts to different climatic conditions; however, low soil fertility conditions and inadequate soil water levels may reduce yield. The objective of this study was to evaluate the effect of irrigation levels and potassium fertilization for quinoa production in the Cerrado Oxisol. The experiment was performed in a greenhouse, located at the Federal University of Mato Grosso (UFMT), Campus of Rondonópolis - Brazil, using soil collected from a Cerrado Oxisol. The experimental design was a randomized complete block design in a 5x5 factorial scheme with four replicates, corresponding to five potassium doses (0, 100, 200, 400 and 600 mg dm^{-3}) and five irrigation levels (50, 75, 100, 125 and 150% of field capacity). The variables of dry mass of shoot, dry mass of roots, water use efficiency, mass of 100 grains, production and number of grains were analyzed. The dry mass of the aerial part and the roots are influenced by the potassium fertilization in the doses between 530 and 600 mg dm^{-3}. All the vegetative and productive characteristics were affected by the treatments. The highest water use efficiency was observed at the potassium (K_2O) dose of 375 mg dm^{-3} and a 50% irrigation level.

Keywords: Brs piabiru, Cerrado, water use efficiency, pseudocereal, latosol.

Abbreviatiosn: MCG_mass of 100 grains, MDS_shoot dry mass, DAS_days after sowing, DAE_days after emergence, MDR_root dry mass, PG_grain production, NG_number of quinoa grains, WUE_water use efficiency, NI_Irrigation Levels, EMBRAPA_Empresa Brasileira de Pesquisa Agropecuária.

Introduction

The Cerrado extending roughly across one-fourth of the Brazil, is regarded as one of the most conducive biomes for agriculture; however, the soils show poor fertility and long dry intervals. Therefore, the low soil fertility strongly affects the production of several crops, despite providing adequate irrigation management (Kluthcouski and Aidar, 2003).

Quinoa (*Chenopodium quinoa* Willd.) raised in Peru and Bolivia for over 7000 years is high in nutrition, and suitable for both the human consumption and animal fodder. Both the grain and the entire plant are well accepted as animal fodder for its protein rich content and high energy value (Spehar and Souza, 1993).Quinoa is extremely water deficit resistant and had been introduced in Brazil with the intention of diversifying the Cerrado production system (Spehar and Souza, 1993). Nevertheless, despite its water deficit resistant nature, its physiological functions reveal their greatest performance in terms of productivity under ideal water supply conditions (Geerts et al., 2008). However, even when irrigation techniques are implemented, poor soil fertility can severely reduce productivity; therefore, the nutrient richness of the soil should also be rectified (Lopes et al., 2004). Hence, both irrigation levels and sufficient soil fertilization are mandatory for a bumper quinoa crop, as they boost productivity and grain quality. Thus, the aim of this study was to assess the response of quinoa production under the effect of varying irrigation levels and potassium fertilizer doses in the Cerrado Oxisol.

Results

Shoot dry mass and root dry mass

The variables analyzed were influenced significantly by the irrigation levels (IL) and potassium fertilization doses. For the shoot dry mass of the quinoa (Fig. 1), a significant effect was noted with adjustment to the quadratic regression model, showing a maximum shoot dry mass (MDS) of 33.1 g per plant, for potassium dose of (K_2O) 535.2 mg dm^{-3}.

The root dry mass (MDR) revealed an isolated effect in response to the potassium doses (Fig. 2), adjusting to the linear regression model. The highest yield of root dry mass (8.8 g per plant) was reported at the most concentrated dose of the experimental range (600 mg dm^{-3} of K_2O); on comparison with the treatment lacking fertilization, it registered a 44.05% rise.

Mass of 100 grains and grain production

In the case of the mass of 100 grains (MCG) an isolated effect was recorded for the potassium doses, adjusting the linear regression model (MCG = 2.803887-0.000537 * K, $R^2 = 0.436$). It was confirmed that the mass of 100 grains dropped as the potassium dosage was increased. Thus, the treatment lacking any addition of potassium showed the highest mass of 100 grains (2.8 g per plant), whereas the treatment experiencing the highest experimental dose showed the lowest mass of 100 grains (2.48 g per plant). With respect to grain production (PG), an isolated effect was observed for potassium fertilization (Fig. 3A) and irrigation levels (Fig. 3B), adjusted to the quadratic regression model. In terms of the potassium treatments, the 350.3 mg dm^{-3} dose induced the maximum grain yield (16.3 g per plant) (Fig. 3A). Irrigation levels also affect productivity as the maximum grain yield (14.7 g per plant) was recorded when the irrigation level was 103.4% (Fig. 3B). The results from the present study were almost similar to the findings of Locatelli (2014), who confirmed maximum grain yield at 94% irrigation levels in cowpea (*Vigna unguiculata*).

With respect to the number of quinoa grains, an isolated effect was recorded for both potassium fertilization (Fig. 4A) and irrigation levels (Fig. 4B), adjusted to the quadratic regression model, respectively.

Number of grains

In response to the potassium doses (K_2O), the most number of grains (NG) (5.9 grains per plant) was reported at the 371.9 mg dm^{-3} dose (Fig. 4A). Potassium strongly influences quinoa and rice development (Zaratin et al., 2004), due to panicle formation and subsequently to the formation, number and weight of the grains. From the different irrigation levels employed in the experiment, at the 99.6% level higher NG (5.4 grains per plant) were observed to be produced (Fig. 4B). These results bear close similarity to those of Torres et al. (2013) and Locatelli (2014) who recorded the highest NG when the water supplied was 115 and 108% of field capacity, respectively. At the 150% irrigation level the water consumption was observed to reach its peak (38.5 L per pot). A significant effect was noted when an analysis was done, in isolation, of the water use efficiency (WUE) for the different potassium doses (Fig. 5A) as well as irrigation levels (Fig. 5B), and adjusting the results to a quadratic and linear regression model.

Water use of efficiency

The maximum water use of efficiency (1.41 g L^{-1}) was observed when potassium fertilization with K_2O was applied at the dosage of 375.1 mg dm^{-3} (Fig. 5A). The highest water use of efficiency (WUA) was recorded at the 50% irrigation level (1.61 g L^{-1}), slowly declining as the water availability increased (Fig. 5B). In their work on lettuce cultivation, Araújo et al. (2010) reported a linear reduction in the efficiency of water use with increased irrigation.

Discussion

Rosolem et al. (2012) reported a rise in the shoot dry mass of *Brachiaria ruziziensis*, at 150 to 300 mg dm^{-3} doses, while contribution of potassium fertilizer towards the production of the shoot dry mass was analyzed. An increased MDS value was identified as a function of potassium fertilization, as also observed by Coutinho et al. (2014).

Souza et al. (2010) reported that potassium increased the stomatal open and close control. This closure enabled the CO_2 flow to be blocked, significantly influencing the photoassimilate accumulation, and possibly decreasing the production. However, under favorable conditions of sufficient soil water, the well-nourished plant reacted positively by maintaining an increase in its photosynthetic rates, thus guaranteeing higher output.

According to Eshel and Waisel (1996) the nutritional status of the plant, potassium fertilization in particular, profoundly influences root development, as noted in this study. Hence, sufficient fertilization induces greater root production and, therefore, a more abundant growth of the aerial portions, resulting from the improved absorption of the soil water.

For soybean, another C3 crop like quinoa, a different result was observed. The mass of 100 grains increased when potassium was added to the soil; however, these results do not concur with the ones reported in the current study. This result could be linked to the huge variations in grain size, noticed in the course of the analyses.

The linear decreasing response may also be connected with the toxicity produced on addition of potassium to the soil; this is due to the fact that the nutrients absorbed tend to touch a critical level, at which point a slight response is seen in the production; but beyond these limits, only negative consequences are observed (Malavolta et al., 1997).

In a study on rice cultivars (*Oryza sativa*) Zaratin et al. (2004) confirmed that potassium greatly influences grain filling because of its various functions, including minimizing the number of pimples and boosting production. The results of this study concur with that of Rezende et al. (2010), who reported that potassium induced a higher production of full grains.

Irrigation was thus noted to exert a positive impact on increased grain yield in quinoa cultivation, resulting in a 73% increase in the treatment without irrigation (Casas, 2012). Arf et al. (2004) stated that the hydric deficit during the vegetative period can diminish the growth and, thereby, the grain production.

The provision of sufficient amounts of water is one of the fundamental aspects of crop production, because both excess and deficit can hamper the crop development and productivity (Arf et al., 2004); however, excess water supplied as irrigation to levels higher than 120% can produce soil oxygen deficiency (Torres et al., 2013). In their work on lettuce cultivation, Koetz et al. (2006) also reported the positive influence of potassium doses and irrigation frequency on the efficiency of water use. Melo et al. (2010) reported that potassium greatly affected the efficiency of water use, because the nutrient strongly controls the water maintenance in the plant by monitoring the stomatal actions of opening and closing, thereby minimizing transpiration and permitting minimum water loss during CO_2 absorption during photosynthesis.

In light of these results quinoa can be termed drought resistant, with the understanding that such resistance is linked with high WUE. Another study on C3 culture, like coffee (*Coffea canephora*) reported that the greater efficiency of water use with heightened drought resistance was linked to a deeper root system, presumably as efficient as the quinoa root system, and presumably like that of the WUE (Pinheiro et al., 2005).

Table 1. Results of the chemical and granulometric analyses of the soil taken from 0-0.20 m depth prior to the installation of the experiment on the Oxisol, Rondonópolis / MT.

pH	P	K	Ca	Mg	Al	H	BS	CTC	V	O.M.	Sand	Tags	Clay
$CaCl_2$	--mg dm^{-3}--		--------------------$cmol_c$ dm^{-3}--------------						%	g dm^{-3}	------------g kg^{-1}-----------		
4.0	1.7	24	0.2	0.2	0.8	4.4	0.5	5.6	8.2	20.6	546	54	400

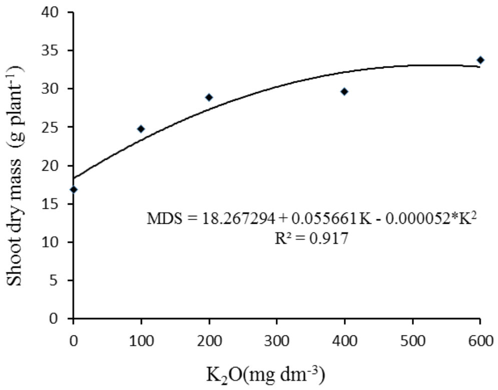

Fig 1. Quadratic regression of shoot dry mass as a function of the potassium (K_2O) doses in *Chenopodium quinoa* (Rondonópolis, MT, 2015), MDS - Shoot dry mass and K - Potassium, * Significant at 5%.

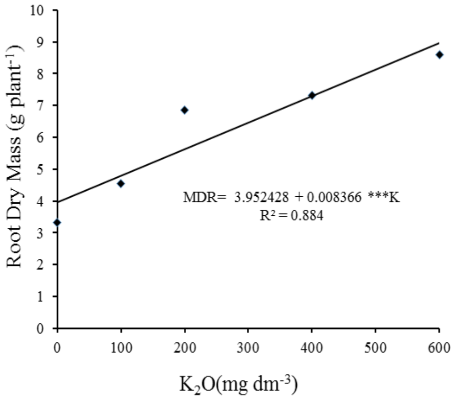

Fig 2. Linear regression of root dry mass, as a function of potassium (K_2O) doses in *Chenopodium quinoa* (Rondonópolis, MT, 2015), MDR -Root Dry Mass and K - Potassium,*** Significant at 0.1%.

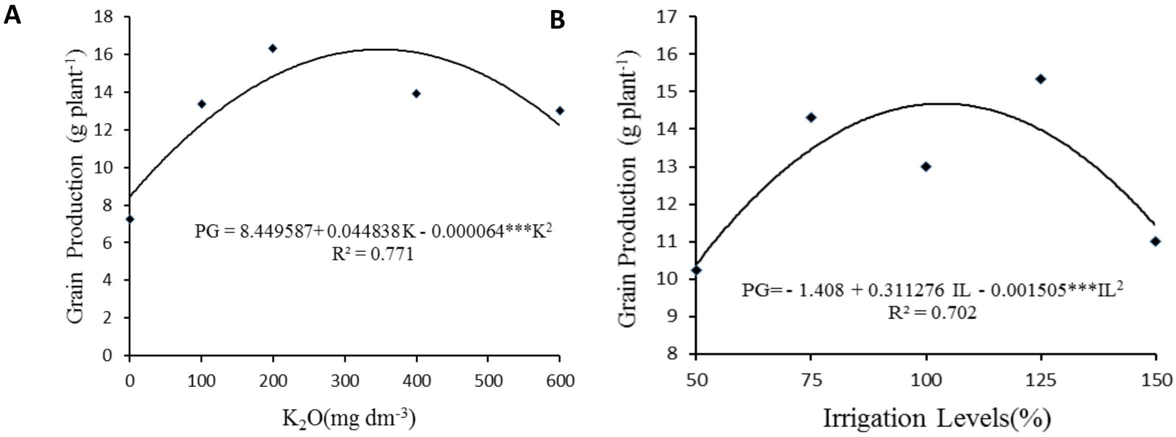

Fig 3. Quadratic regression of grain production, as a function of the potassium (K_2O) rates in *Chenopodium quinoa* (Rondonópolis, MT, 2015), PG- Grain production; K - Potassium (A) and based on the irrigation levels (%), IL - Irrigation Levels (B) *** Significant at 0.1%.

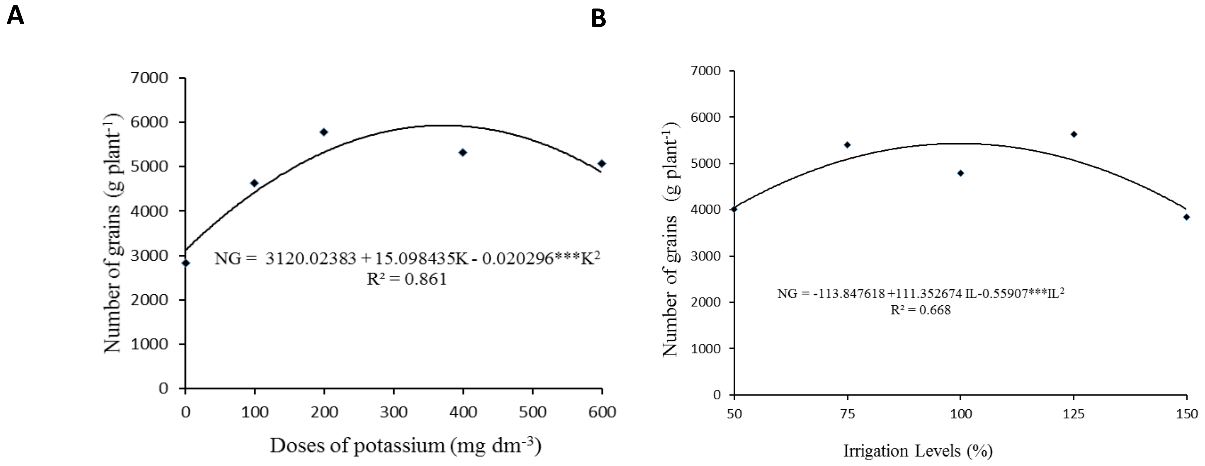

Fig 4. Quadratic regression of number of grains, as a function of the potassium (K_2O) rates in *Chenopodium quinoa* (Rondonópolis, MT, 2015), NG - Number of grains e K - Potassium (A) and based on the irrigation levels (%), IL - Irrigation Levels (B) *** Significant at 0.1%.

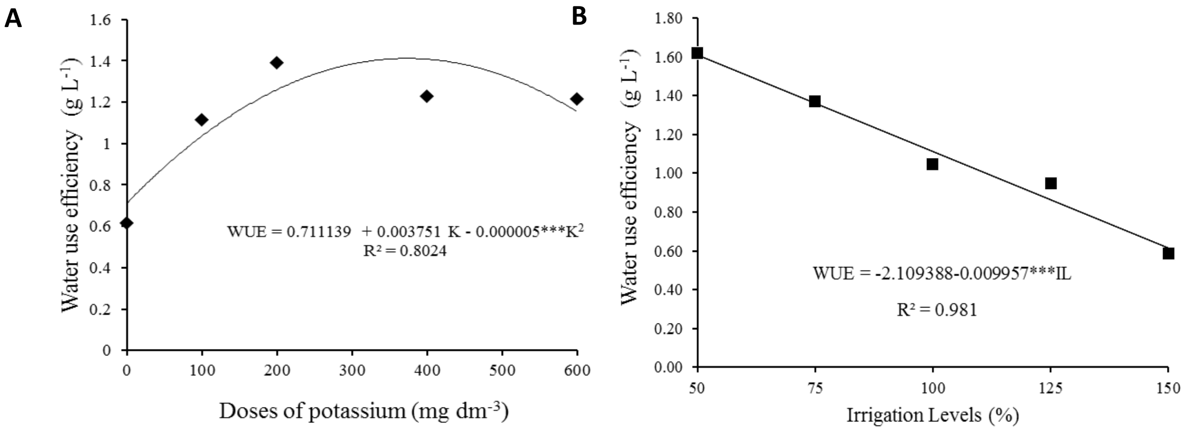

Fig 5. Water use efficiency, quadratic regression as a function of potassium (K_2O) doses in *Chenopodium quinoa* (Rondonópolis, MT, 2015), K - Potassium (A) and linear regression based on the irrigation levels, IL - Irrigation Levels (B) *** Significant at 0.1%.

Materials and Methods

Description of the area and installation of experiment

Between February and August 2015, the experiment was performed in a greenhouse, at the Federal University of Mato Grosso (UFMT), University Campus of Rondonópolis, having the geographic coordinates of 16º28 'South Latitude, 50º34' West Longitude and altitude of 284 m.

Oxisol (soil) was collected from 0-0.20 m depth below the Cerrado vegetation. The soil was then sieved though a 2 mm mesh and sent for chemical and granulometric analysis based on the methodology proposed by EMBRAPA (1997) (Table 1). Liming was done based on the outcome of the chemical analysis of the soil, increasing the saturation to 60% by adding bases.

Experimental design and description of treatments

Employing the randomized block experimental design, a 5x5 factorial arrangement was selected, involving 25 treatments, with four replications and 100 experimental plots. The treatments included adding potassium in five dosages (0, 100, 200, 400 and 600 mg dm^{-3}) and water at five irrigation levels (50, 75, 100, 125 and 150% of field capacity). Each plot comprised a plastic container with 22 dm^{-3} soil capacity.

Fertilization at planting

At the time of sowing the soil was fertilized by adding 250 mg dm^{-3} of phosphorus (P_2O_5) as single superphosphate, 40 mg dm^{-3} of micronutrients as FTE BR-12 (9.20% of Zn, 2.17% of B, 0.80% of Cu, 3.82% of Fe, 3.4% of Mn and 0.132% of Mo), and potassium (K_2O) which was supplied at the specified treatment doses.

Nitrogen fertilization was given at 200 mg dm^{-3}, in three applications, using urea as the source. The *BRS Piabiru quinoa* cultivar was sowed, and the plants were thinned at 15 and 20 days after emergence (DAE), keeping on only three and two plants per pot, respectively.

Water retention curve in the soil and irrigation

To ascertain the relationship between the soil water content and the energy of its retention in the soil, the Soil Water Retention Curve was analyzed and the results of the retention were interpolated using the Van Genuchten equation through Regression; the value of the water content was volumetric.

Using the Soil Water Retention Curve (version 3.0) proposed by Dourado-Neto et al. (2000), soil moisture was explained as a function of tension.

The soil water tension was monitored on a daily basis employing a digital tensiometer with 0.1 kPa sensitivity; it was installed in the experimental units with 100% water replacement in the soil to which was added the reference dose of 100 mg dm^{-3} of potassium (K_2O), based on the methodology of Koetz (2006). Water management was performed depending upon the estimated soil water tension, defined as the point at which the average tension achieved a value close to 10 kPa; the water volume applied to each experimental unit was defined in terms of percentage for each treatment. The soil water tension, equivalent to the moisture capacity of the field, was identified as 6 kPa. For the first 15 days after sowing (DAS), the same volume of water was used to irrigate all the treatments, to the time when the average tension approached values around 10 kPa, in order to ensure the plant development.

Measured characteristics

At 129 days after sowing, the plants were cut and fractionated into stems, leaves, roots and panicles. After packing them in paper bags they were placed in a greenhouse and subjected to forced air circulation at 65º C until constant mass was reached.

The production was determined by weighing in an analytical balance (g per plant) with moisture corrected to 13%. The mass of 100 grains was obtained by weighing four 100 grain samples and the grain number estimation was performed through the correlation between the results obtained in the MCG and the total weight of the sample.
Determination of the variables was done including shoot dry mass, root dry mass, efficiency of water usage, mass of 100 grains, production and number of grains.

Statistical analysis

The results were submitted to the analysis of variance at 0.05 probability; when the differences found were significant, they were submitted to regression analysis using the SISVAR program (Ferreira, 2008).

Conclusion

Potassium (K_2O) in the 530 to 600 mg dm^{-3} range is necessary for the aerial parts and MDR to achieve maximum production. The required potassium (K_2O) dose range is 350 to 372 mg dm^{-3} to achieve the most productive characteristics (100 grain mass, grain yield, number of grains); irrigation levels are necessary in the range of 50 to 104%. For quinoa cultivation the highest water efficiency is evident at the potassium (K_2O) dose of 375 mg dm^{-3} and an irrigation level of 50%.

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