English Version

Reduced spacing for *Sorghum bicolor* in the irrigated and rainfed systems

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Abstract

The water stress in the North of Minas Gerais enabled sorghum (*Sorghum bicolor* L.) to arise as a good option for the region. This culture tolerates better the high temperatures and water deficit when compared to most of the other cereals. Due to the importance of the sorghum crop in that region, the aim of this work was to determine the best arrangement of plants in the sorghum under irrigated and rainfed system. Two experiments were conducted in adjacent areas with an irrigated and rainfed system. In each experiment, it was used the densities of 100, 150, 200 and 250 thousand plants ha^{-1}, and the spacing of 25, 50 and 75 cm. Each experiment was conducted under a randomized block design, in a 4 x 3 factorial design with four replications, with four densities and three spacing. The data were initially submitted to an analysis of variance. This was followed by an analysis of variance involving the two experiments. The reduction of spacing between rows promotes increases in grain yield, regardless of plant population adopted. Sorghum grown under irrigation has increased productivity by reducing the spacing, however, the increase in population of plants in irrigated provides increases in productivity to a point of maximum, and decreased under.

Keywords: *Sorghum bicolor* (L.); density; irrigation; grain; Semi-arid

Introduction

The North region of Minas Gerais presents remarkable physical diversities, however, the water restriction more or less pronounced is an hegemonic characteristic which makes it known as the one with highest degree of aridity of the state of Minas Gerais. This condition provided a great increase in the cultivated area with sorghum to the livestock feed, since cattle has wide influence in the economy of this region which has an effective of approximately 3 million cattle (IBGE, 2009), dependent on maize from other regions, mainly from the northwest of Minas Gerais and from the south of Goiás.

The climate conditions and other natural factors constitute situations which limit or enable to express, in higher or lower degree, the potential yield of some plantations. This fact makes the maize production unfeasible in this region, not affecting sorghum, which can substitute in nutritional terms maize in the livestock feed either as silage or as concentrated feed.

The determination of seed density in other various situations of culture management is an important factor to improve productivity (BERENGUER and FACI, 2001; HAMMER and BROAD, 2003). The use of larger planting densities has showed yield up to 20% in sorghum plantation (ALMEIDA and RODRIGUES, 1985).

When evaluating different plant densities in sorghum, LOPES et al. (2005) verified intraspecific competition between treatments, with the grain yield per plant superior in the lowest seed density (100 thousand plants ha^{-1}), compared to the highest density (220 thousand plants ha^{-1}). Still in this work, the use of smaller spacing favored higher yield.

When evaluating grain sorghum plant arrangement in conditions of rainfed and under two irrigation depths (2.5 mm d^{-1} e 5.0 mm d^{-1}), BAUHMHARDT and HOWELL (2006) verified that the plant population did not influence the grain yield in rainfed conditions and when submitted to a maximum of 2.5 mm d^{-1}. The smallest spacing increased in 7% the grain yield, considering the three water conditions. Still in this work, the authors obtained 7.5 t ha^{-1} of grains in the irrigated system

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and 1.9 t ha^{-1} in rainfed. These authors attributed the highest yields to the highest number of seeds per panicle and highest seed mass in the irrigated system.

In order to determine the ideal population of plants in a specific area, it must be considered aspects as soil fertility, genotype used and regularity of occurrence of rain. Considering the increase of areas of sorghum in the agricultural properties in the North of Minas Gerais and the scarcity of information about the culture, it is of major importance researches that aim to evaluate the performance of grain sorghum submitted to different plant arrangements, in the system of irritated plantation in rainfed.

Material and methods

The experiment was performed in the Fazenda Experimental de Mocambinho (FEMO – Experimental Farm of Mocambinho), part of the Unidade Regional EPAMIG do Norte de Minas Gerais (URENM – EPAMIG Regional Unit of the North of Minas Gerais), which belongs to the EPAMIG (Agricultural Research Corporation of the State of Minas Gerais). FEMO is located in the Irrigated perimeter of Jaíba, municipality of Jaíba – MG, at the right margin of the River São Francisco and at the left margin of the River Verde Grande. The experimental area is characterized by Latossolo Amarelo distrófico[1], with 220 g kg^{-1} of clay, 680 g kg^{-1} of sand and 100 g kg^{-1} of silt. The results of the superficial analysis of the topsoil layer (0-20 cm) presented pH in H_2O (5.2), H + Al (2.3 cmol$_c$ dm^{-3}), Al (0.2 cmol$_c$ dm^{-3}), Ca (1.8 cmol$_c$ dm^{-3}), Mg (0.7 cmol$_c$ dm^{-3}), K (99.0 mg dm^{-3}), P (4.5 mg dm^{-3}), Zn (3.1 mg dm^{-3}), Fe (15.4 mg dm^{-3}), Mn (27.1 mg dm^{-3}), Cu (0.7 mg dm^{-3}), B (0.4 mg dm^{-3}), SB (2.9 cmol$_c$ dm^{-3}), T (5.1 cmol$_c$ dm^{-3}), t (3.1 cmol$_c$ dm^{-3}), V (56.0%), m (7.0%).

The region climate is Aw, according to the classification of Köeppen (JACOMINE et al., 1979). The experimental area lies in the coordinates 48° 05' 29" of West longitude and 15° 06' 48" of South latitude, altitude of 452 m. The data about ranges in

1 Brazilian Soil classification

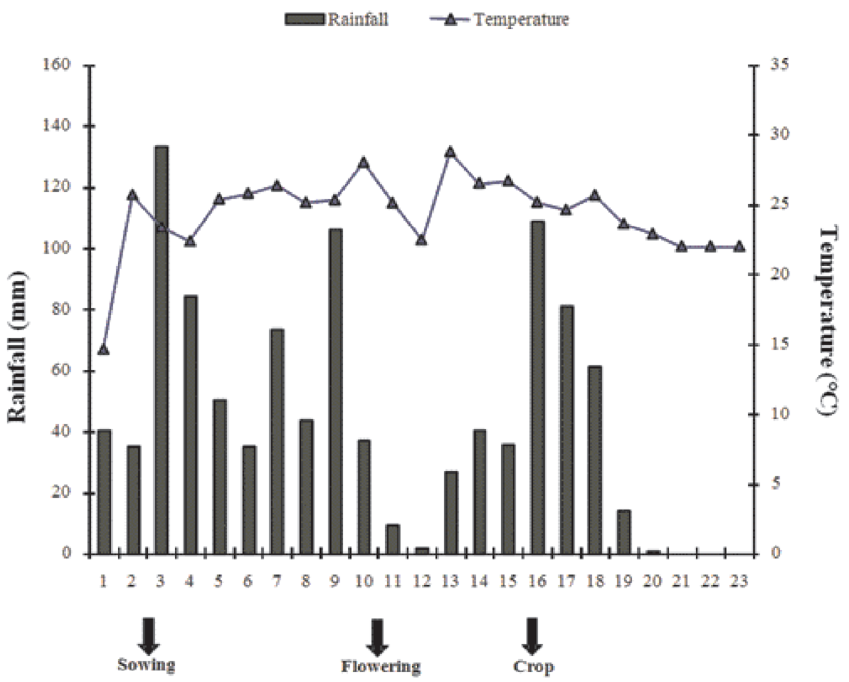


Figure 1. Average data of temperature and rainfall by sowing period, in Mocambinho, district of Jaíba, MG, from 25/11/2008 to 05/07/2009. Data obtained in the meteorological station of Inmet in Epaming in Mocambinho, district of Jaíba, MG.

rainfall and in the average temperature by sowing time, during the conduction of the experiments are presented in Figure 1.

Two experiments were conducted, being one in an irrigated area and other in rainfed area. It was used the cultivar DKB 599, which is an early grain hybrid, widely marketed in the region.

In both cultivation systems (irrigated and rainfed) it was used the density of 100, 150, 200 and 250 thousand plants per hectare and spacing between rows of 25, 50 and 75 cm, respectively.

To both experiments it was used 480 kg ha^{-1} of the formula 4 (N): 30 (P_2O_5): 10 (K_2O) plus 0.5% of Zn, based in the soil analysis. In cover fertilization it was used 60 kg of K_2O ha^{-1} (Potassium Chloride as source) and 80 kg of N ha^{-1} (Urea as source), applied 30 days after the emergence. The panicles were covered with paper bags to protection from birds.

The management of irrigation, in the irrigation plantation system, was performed with aid from tensiometers installed in the parallel lines of the plants in the depth of 20 cm. The irrigation was used only until near the end of the period of grain filling.

In order to control weeds, it was used in post-emergence the herbicide Gezaprim 500 (Atrazine) in the dosage of 4 L ha^{-1} of the commercial product. To control shoot plagues it was performed leaf spraying with insecticides when 20% of the plot plants presented symptoms of *Spodoptera frugiperda* caterpillar attack.

It was used in both experiments the random blocks design, in the factorial scheme 4 (densities) x 3 (spacing), with four replications. The experiments were conducted simultaneously in contiguous area in the irrigated and rainfed conditions. The experimental plot was constituted of 4 lines with 5 cm of length and useful area the two central lines, in which the experimental data were evaluated after and during the crop.

Plant height (m), Grain yield (t ha^{-1}), weight of a thousand grains (g) and crude grain protein (%) were the characteristics evaluated. The data obtained in each experiment were submitted to and analysis of individual variance. Later it was performed the tests of additivity of data, normality of errors and homogeneity of variances in order to perform a joint analysis of variance concerning both experiments.

All the analysis, including the study of regression in function of different spacing and densities were performed using the statistic program SISVAR® (FERREIRA, 2000). The averages were grouped by the SCOTT-KNOTT test (1974).

Results and discussion

It was observed a highly significant effect ($p \leq 0.01$) of spacing to plant height, grain yield and weight of a thousand grains. There was difference between the two cultivation systems ($p \leq 0.01$) and to the interaction system x density ($p \leq 0.05$) only in grain yield. The yield and the weight of a thousand grains were affected still by densities, interactions systems x spacing and spacing x densities.

The grain protein was not affected by the cultivation system, spacing and densities evaluated. It was also not verified effect of the interactions for the grain quality evaluated by the percentage of crude protein. Considering the average of all the studied treatments, it was observed 14.78% of crude protein in grains.

The coefficient of variation (C.V.%), which is interpreted as the variability of data in relation to the average, was 9.93 for plant height, 14.9 for grain yield, 9.38 for the weight of a thousand grains and 8.44 for the percentage of crude protein. According to PIMENTEL (1990) the values verified for plant height, grain yield and crude protein are considered low. For the weight of a thousand grains MONTAGNER et al. (1999) reported values of coefficient of variation close to those obtained in this work.

Considering both systems (irrigated and rainfed) there was no significant differences to the variable plant height. In average, it was verified 1.09 m in the rainfed system and 1.13 m in the irrigated system. These averages are below those found by ALBUQUERQUE (2009), in which it was found averages between 1.26 and 1.40 in 4 different genotypes in experiments performed in two different crops. The work conducted by this author was in a Latossolo Vermelho Eutrófico[1] with high fertility where the lowest heights were associated to the deficient water regime which prevailed in the

1 Brazilian Soil Classification

agricultural year.

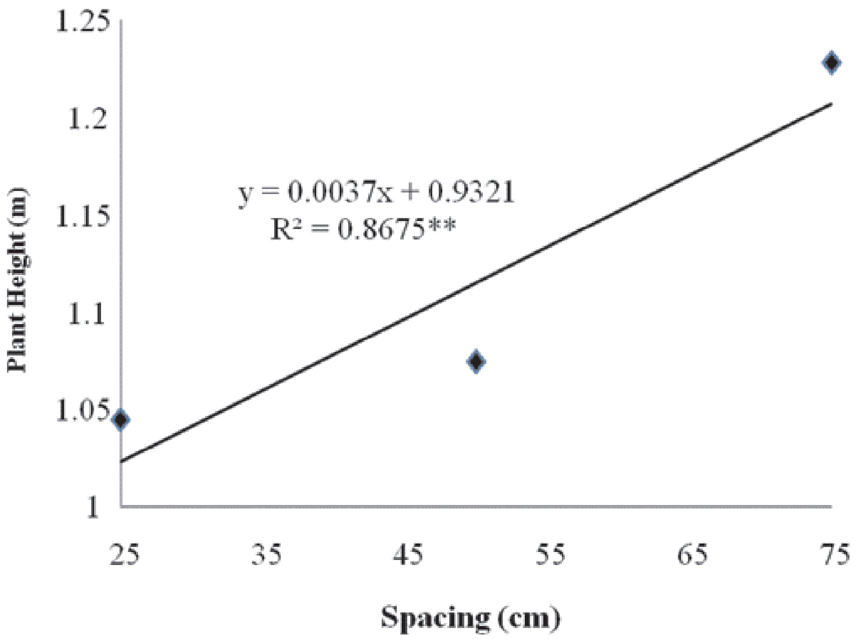
Thus, it was expected that in the irrigated system the plant heights were higher. The little availability of water is one of the most common causes of reduction in sorghum plant height due to the lower cell expansion caused by water stress (GRIMA; KRIEG, 1992). Possibly, the chemical compound of soil in the present work provided plants with the same height independent on the system. The soil is characterized by a sandy texture, with low capacity of water retention and with low content of organic matter.

The graphical representation of the regression equation for plant height in function of the spacing between rows is presented in Figure 2. It was obtained significant linear relation to plant height in function of the spacing, with the determination coefficient (R^2) of 86.8%. For each 1 cm increase in spacing it was observed an increase of 0.0037 in plant height.

These results are different from those obtained by ALBUQUERQUE (2009), who, when evaluated spacing between rows of 50, 70 and 90 cm found highest plant heights in the lowest spacing only for forage sorghum, by contrast in grain sorghum there was no effect of the spacing.

Considering the average grain yield of the experiments individually for each system, it was verified yield equivalent to 5.00 t ha^{-1} in the irrigated system, value which is superior than the national average which was 2.35 t ha^{-1} (IBGE, 2009), due to the improvement provided by irrigation. However in rainfed the yield was 1.28 t ha^{-1} - in this case, inferior to the national average. Aiming to evaluate the response of two grain sorghum hybrids in the region of Zona da Mata of the state of Alagoas, CRUZ et al. (2009) reported grain yield superior than 8.0 t ha^{-1}. The highest yield reported by these authors is justified by the different soil and climatic conditions of cultivation besides the genetic base of the material evaluated.

It was observed decrease of the rainfall in the period of flowering and grain filling (Figure 1) and consequent reduction of the availability of water in the soil profile, limiting the development of sorghum plants. The lowest yields are attributed to the water deficiency in the initial stages of plant development and maturation, which cause early senescence of the inferior leaves and reduction in grain yield (SILVA et al., 2009; MAGALHÃES et al., 2000).



***Significant at 1% of probability.*

Figure 2. Graphical representation of the linear equation for plant height in function of spacing.

It is noteworthy that the effects of water stress, in the compounds of grain sorghum yield, as weight of a thousand grains, are attributed to reductions of the leaf area and photosynthetic rates of the plant (MAGALHÃES et al. 2000).

The graphical representations of the equations of regression for grain yield in function of the spacing between rows in the irrigated and rainfed systems are presents in Figure 3.

It was verified a linear decreasing relation between the grain yield and the spacing used only in the irrigated system. It was noticed that the increase of one centimeter in the spacing between rows caused reduction of 29 kg ha^{-1} of grains. In the rainfed system there was no significance.

Different results were obtained by BAUMHARDT and HOWELL (2006) in the rainfed system. In this work the lowest spacing increased the grain yield in all the water regimes, being that these authors recommend the spacing 28 cm between rows for the grain sorghum. The different results in works of spacing and density may be attributed to the climate conditions which prevail in the agricultural year, genotype used and soil fertility (ALBUQUERQUE, 2009).

This author still emphasizes that it was not verified reduction in yield in the lowest spacing and that it must be recommended the use of reduced spacing in the grain sorghum plantation. Since this characteristic is affected by environmental factors, the yield will be assured in years with greater rainfall, being that in the years with larger water restrictions the yield will not be affected.

Considering the grain yield in function of the densities, there was an increasing linear relation in the rainfed experiment and quadratic relation in the irrigated system with R^2 values always superior to 88% (Figure 4).

In the irrigated system there was a quadratic relation with increase in grain yield, estimated by the equation, until it reached the density of 191 thousand plants ha^{-1}, obtaining 5.23 t ha^{-1} of grains. In the rainfed system, the increase of a thousand plants per hectare provided an increase of 4 kg ha^{-1} of grains.

Considering the decomposition of the interaction spacing x density, it was obtained significant linear relation to grain yield, in function of the spacing in the population 100 and 250 thousand plants ha-1 and quadratic relation in the density of 200 thousand plants ha^{-1} (Figure 5). The spacing 25

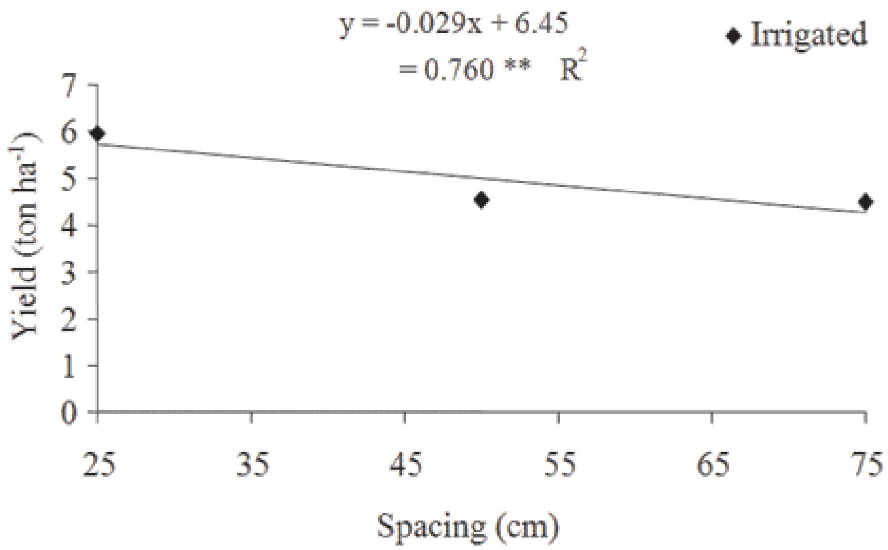


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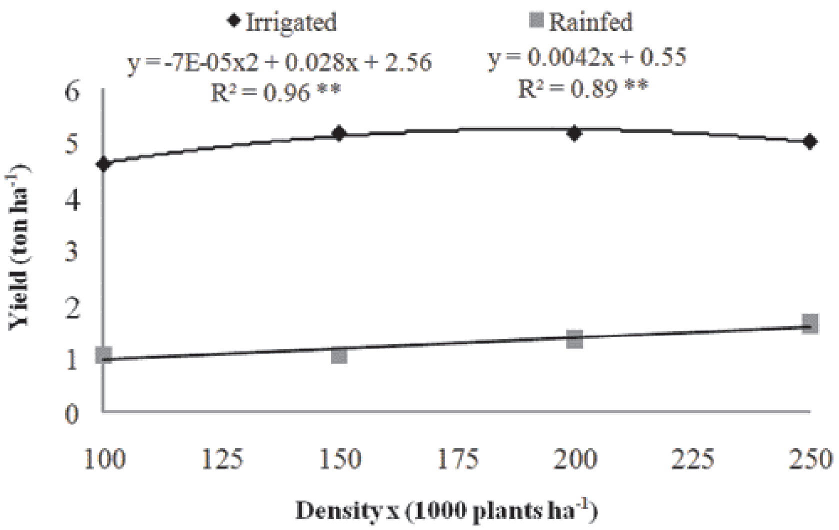
Figure 3. Graphical representation of the equation of regression for the grain yield in function of the spacing in the irrigated system and rainfed.

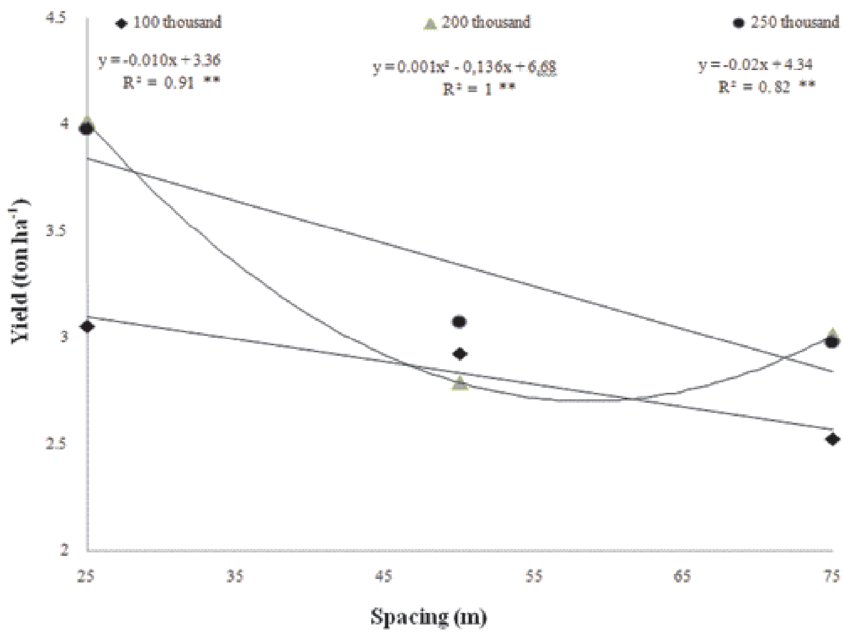


***Significant at 1% of probability.*

Figure 4. Graphical representation of the equations of regression for grain yield in function of the density in irrigated and rainfed system.

cm presented highest grain yield in all the densities evaluated.

It was verified in the population 100 thousand plants ha^{-1} that for each increase of one centimeter in the spacing between rows, there was a decrease of 10 kg ha^{-1} of grains, for a population of 250 thousand plants ha^{-1} the increase of one centimeter in the spacing provided a decrease of 20 kg ha^{-1} of grains. Considering



***,* significant, at 1% and 5% of probability.*

Figure 5. Graphical representation of the regression equation to Yield in function of the slice Spacing x Density.

the population 200 thousand plants ha^{-1} it was reported decrease until the spacing 58 cm, achieving 2.70 t ha^{-1} of grains. From this, with the increase of spacing, there was an increase in grain yield.

The graphical representation of the equations of regression in function of the slice density x spacing is found in Figure 6.

It was verified that for each increase of a thousand plants per hectare in the spacing 25 cm there was an increase of 6 kg ha^{-1} of grains. In the spacing 50 cm it was not seen significant effect of the increase of the population.

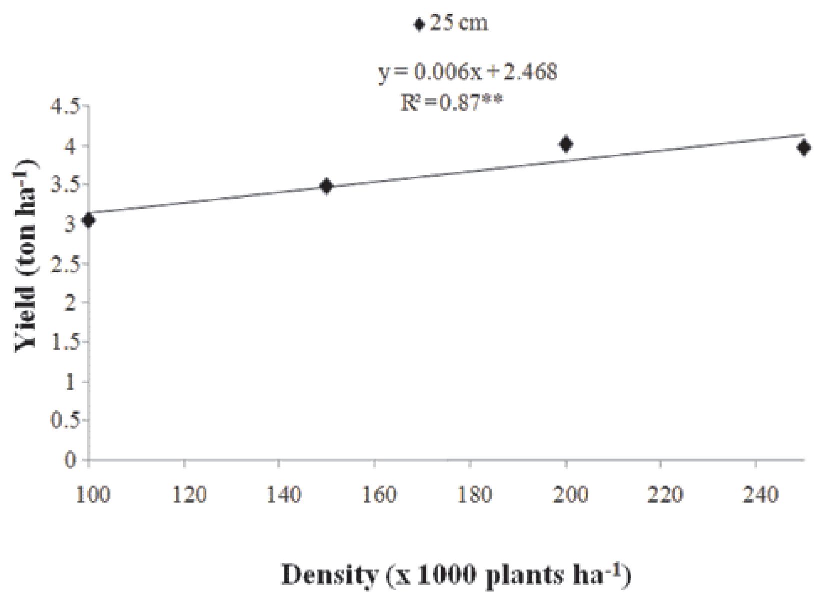
In Texas, USA, STICHLER et al. (1997) observed, in irrigated area, increases in sorghum grain yield with the reduction of spacing between rows from 90 to 70 cm and decrease in yield in populations larger than 15 plants m^2. In rainfed conditions, JONES and JOHNSON (1997) proved that the best sowing date, plant population, variety and spacing between grain sorghum rows are interdependent. Still in this work, the late cultivars presented reduction in yield when sowed with high populations.

Considering the average weight of a thousand grains it was observed differences between the irrigated and rainfed systems only in the spacing 50 cm (Table 1). In this case, it was verified values of 14.40 g for the irrigated system and 15.55 g in the rainfed. Moreover we may infer that the highest grain yield previously reported in the irrigated system occurred due to the highest spikelet filling and consequently larger amount of grains per panicle. The larger number of grains per panicle is considered the main compound of production associated to sorghum yield (MAGALHÃES et al. 2000).

The results obtained are inferior to those obtained by HACKLER (2002), which obtained average weight of a thousand grains of 27.4 g, with various sorghum cultivars planted in Mato Grosso do Sul, however, neat to the values found by SILVA et al. (2009) in Goiás, in which they obtained average of 17.97 g. In these works, it was used different genotypes, therefore the interaction genotype-environment must be considered.

The graphical representation of the equations of regression for the weight of a thousand grains in function of the spacing between rows in rainfed and irrigated system are presented in Figure 7.

It was verified that in both cultivation systems



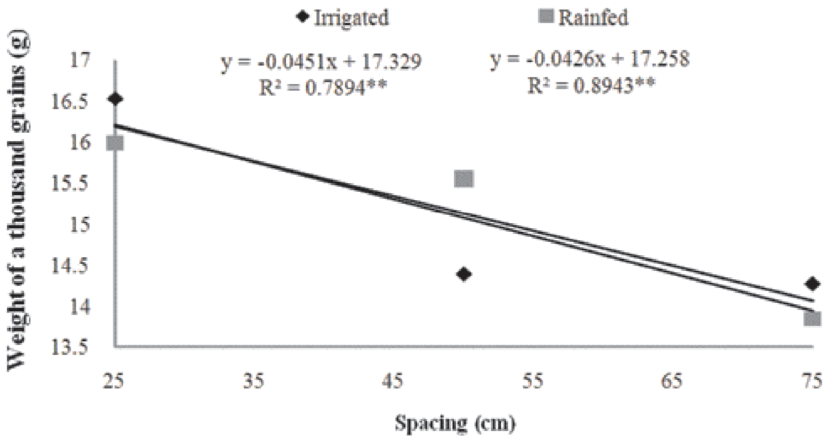
*** Significant at 1% probability; ^{ns} Non significant*

Figure 6. Graphical representation of the equation of regression for Yield in function of the slice Density x Spacing.

Table 1. Average results obtained in the evaluation of weight of a thousand grains (g) in the two systems of cultivation in different spacing.

Systems	Spacing			Average
	25 cm	50 cm	75 cm	
Irrigated	16.53 a	14.40 b	14.28 a	15.07 a
Rainfed	15.98 a	15.55 a	13.85 a	15.27 a
Average	16.25	14.98	14.07	15.10

Averages with the same lower case letter in the vertical belong to the same group, according to the test of Scott-Knott.



***Significant, at 1% probability.*

Figure 7. Graphical representation of the linear equation for the weight of 1000 grains in function of spacing in the irrigated system.

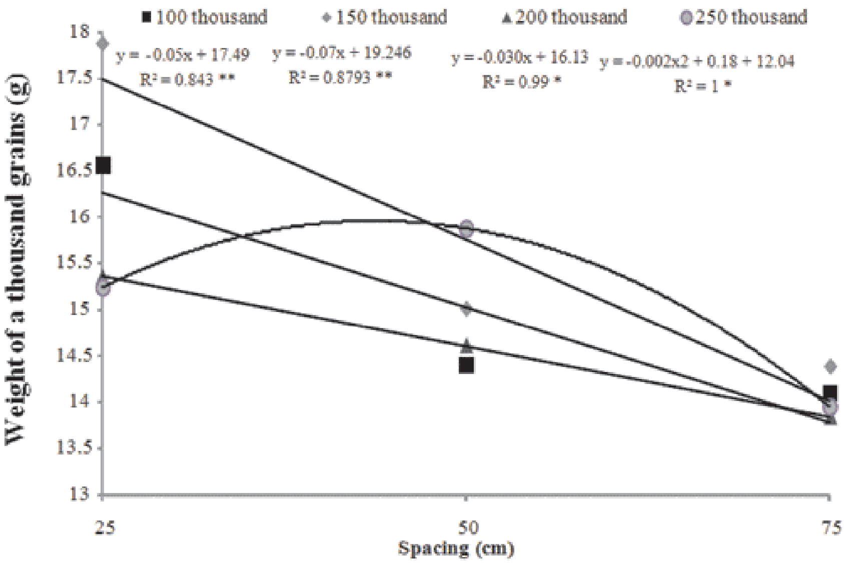
there was a decreasing linear relation between the weight of a thousand grain and the spacing, with R^2 equal to 78.9% in the irrigated and 89.4% in the rainfed.

In the irrigated experiment for each increase of 1 cm in the spacing between rows, there was a decrease of 0.045 g in the weight of a thousand grains. By contrast, in the rainfed experiment each increase of 1 cm in spacing caused a decrease of 0.043 g in the weight of a thousand grains.

It is interesting to emphasize that the smallest spacing provided smaller amount of plants per linear meter. With that one may infer that there was less competition between sorghum plants in the planting line favoring increasing translocation of photoassimilates and carbohydrates to the grains. In this sense, the highest grain yields previously emphasized for the irrigated system occurred also due to the highest grain weight, provided by the plant arrangement in the smallest spacing, independent on the system.

BAUMHARDT and HOWELL (2006) observed in the irrigated system highest grain weight. However in the rainfed system these authors did not verify effect of the spacing.

In the interaction Spacing x Density, it was obtained significant linear relation for the weight of a thousand grains, in function of the spacing in the densities 100, 150 and 200 thousand plants ha^{-1} and quadratic relation in the density of 250 thousand plants ha^{-1} (Figure 8). It was verified in the population of 100 thousand plants ha^{-1} that for each increase of one centimeter in the spacing between rows, a decrease of 0.05 g in the weight of a thousand grains. In the population of 150 thousand plants ha^{-1} the increase of one centimeter in the spacing caused a decrease of 0.07 g in the weight of a thousand grains. For the population of 200 thousand plants ha^{-1} the increase of one centimeter in the spacing caused a decrease of 0.03 g in the weight of 1000 grains. Considering the population 250 thousand plants ha^{-1} it was reported increase until the spacing



**, * *Significant, at 1% and 5% of probability respectively.*

Figure 8. Graphical representation of the equation for weight of 1000 grains in function of the slice Density x Spacing.

44 cm, reaching 15.96 g in the weight of a thousand grains. From that with the increase in spacing there was a decrease in the weight of a thousand grains.

The larger amount of plants in the area caused higher intraspecific competition and reduction in the weight of a thousand grains in the density with 250 thousand plants ha^{-1}. However this lower weight of a thousand grains was offset by the larger number of plants in the area, since it was previously found improve in the grain yield with the increase of the population.

According to LOPES et al. (2009), in modern hybrids, as DKB 599 used in this study, it can be verified higher efficiency of radiation use in the period of grain filling, in relation to the classic hybrids, due to the smaller amount of phytomass per plant, which enables to have more individuals per area, resulting in an increase in the leaf area index and favoring a most effective light interception.

In the slice of the interaction density x spacing there was no significance in the characteristics evaluated.

The weight of a thousand grains is considered stable, only being affecter by conditions of stress during its formation (MONTAGNER et al., 1999). This result is similar to the one found by HUME and KEBEDE (1981), who concluded that the population density do not influence significantly the weight of 1000 grains. Also BLUM (1970), reports that the weight of the grains is not directly affected by plant density.

Conclusions

The reduction of the spacing between rows promotes improvements in grain yield, independent in the plant population adopted.

Grain sorghum cultivated with irrigation has increased in yield with the reduction in spacing; however, the increase in plant population in irrigated cultivation provides increase in yield until it reaches a maximum point, and a decrease from it.

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