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PRODUCTIVITY AND EFFICIENCY IN THE USE OF WATER IN DIFFERENT IRRIGATION DEPTHS IN FORAGE SORGHUM IN DYNAMIC OF CUTS

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1 ABSTRACT

The availability of pasture during the year is essential to the development of animals. In the period between spring and summer, pasture quality is impaired due to the irregularity of rainfall, needing the establishment of cultivated and irrigated pastures. Thus, sorghum is a culture propitious for implementation in the Brazilian state of Rio Grande do Sul due to its adaptation to this time of the year and the supply of mass produced. However, it needs adequate water availability to achieve its potential. The objective of this work was to evaluate the dry matter yield of the forage sorghum in six irrigation depths (0, 60, 80, 100, 120 and 140% of the reference evapotranspiration) and the water use efficiency for four cut periods of the crop (50, 80, 110 and 140 days after sowing). The experiment was conducted in the Brazilian city of Santiago, RS. Sowing was held on November 18, 2014. A conventional sprinkler irrigation system was used with a main row and six side rows in PVC and the irrigation levels were differentiated by the sprinkler nozzle diameter of each lateral row. Statistically significant differences were found for the dry matter yield variation for the four cut periods evaluated, as well as for the water use efficiency of each cut, linear equations were adjusted for 3 cuts and quadratic for 1 cut for both productivity and water use efficiency. Therefore, it is clear that irrigation can have influence in the increase of forage sorghum crop production, and adequate water supply and proper management are extremely import to obtain higher crop yield.

Keywords: *Sorghum bicolor L.(Moench)*, irrigation management, pasture irrigation, productivity of cuts.

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PRODUTIVIDADE E EFICIÊNCIA NO USO DA ÁGUA EM SORGO FORRAGEIRO IRRIGADO EM DINÂMICA DE CORTES

2 RESUMO

A disponibilidade de pastagem durante o ano é essencial para o desenvolvimento dos animais em pastejo. No período compreendido entre a primavera e o verão, a qualidade das pastagens é prejudicada devido à irregularidade das chuvas, necessitando o cultivo de pastagens cultivadas e irrigadas. Assim, o sorgo é uma cultura propícia à sua implantação no Rio Grande do Sul devido à sua adaptação nesta época do ano e à oferta de massa produzida. No entanto, precisa de uma disponibilidade de água adequada para atingir seu potencial. O objetivo deste trabalho foi avaliar o rendimento de massa seca do sorgo forrageiro em seis lâminas de irrigação (0, 60, 80, 100, 120 e 140% da evapotranspiração de referência) e a eficiência no uso da água, em quatro períodos de corte (50, 80, 110 e 140 dias após a semeadura). O experimento foi conduzido na cidade brasileira de Santiago, RS. A semeadura foi realizada em 18 de novembro de 2014. Utilizou-se um sistema convencional de irrigação por aspersão com uma linha principal e seis linhas laterais em PVC sendo os níveis de irrigação diferenciados pelo diâmetro de bocal dos aspersores de cada linha lateral. Foram encontradas diferenças estatisticamente significantes para a variação da produção de massa seca nos quatro períodos de corte avaliados, bem como, para a eficiência no uso da água de cada corte, sendo ajustadas equações lineares para 3 cortes e quadrática para 1 corte tanto para produtividade quanto para a eficiência no uso da água. Assim, a irrigação apresentou uma grande influência no aumento da produção de sorgo forrageiro, onde, atrelada a um uso eficiente da água, proporcionou ganhos elevados de rendimento forrageiro na cultura.

Palavras-chave: *Sorghum bicolor L.(Moench)*, manejo da irrigação, irrigação de pastagem, produtividade dos cortes.

3 INTRODUCTION

The use of cultivated pasture has become an essential tool in a beef production system. However, to reduce the seasonality of the production, it is indispensable to use the necessary evapotranspiration demand replacement technologies carried out by irrigation, thus enabling an increase in the growth characteristics of plants and consequently better food quality for the animals (MAGALHÃES et al., 2013).

In this context, sorghum (*Sorghum bicolor L. (Moench*)) crops have great potential due to their adaptability to the spring-summer weather of Brazilian state Rio Grande do Sul, in which, through proper water supply, nutritional quality of food and high production of green and dry matters are enabled, taking into account the animal's, nutritional needs and allowing fattening in a short period of time (CUNHA & LIMA, 2010). The increase in the forage sorghum crop has been gaining prominence nationally in the recent years due to its importance in the production chain of beef cattle because it is easy to deploy and manage, and has excellent nutritional qualities (PORTUGAL et al., 2003; BASSO et al., 2011; MONTANARI et al., 2013; PARENTE et al., 2014; COSTA et al, 2014).

Worldwide, the yield obtained with the practice of irrigated agriculture is 2.7 times higher than that obtained with flood based farming systems due to dependence of the distribution and frequency of rainfall. Thus, the practice of irrigation allows to improve production management through of the availability of water in right quantity and at the right time, playing an increasing and important role in agricultural production and animal husbandry (CHRISTOFIDIS, 2013). Water is the main component necessary for the development of any forage species, its availability is of utmost importance for the correct growth and development of crops and it may define the viability of any agricultural activity (FAGGION et al., 2009).

Irrigation of pastures has been identified as one of the main regulatory strategies of production. They are considered an essential management technique to soften the effect of seasonality in the production of pastures (VITOR et al., 2009). Thus, irrigation management becomes a determinative tool in the success of cultivation and it may be performed by various methods, either by the soil or climate conditions and crops (CARVALHO et al., 2014).

Despite the existence of numerous irrigation management methods, many farmers empirically carry out the replacement of water only by their practical experience as producers, without adopting any water rational use and management strategies. The inefficiency of the management adopted in irrigated farms has been identified as one of the main aspects contributing to the shortage of water resources. It is estimated that between 40% and 60% of the water applied to irrigation is actually exploited in agriculture. The remainder is lost by surface runoff, evaporation and seepage. Because of this, it becomes extremely important to determine the proper irrigation level for the crops in order to increase irrigation efficiency and reduce water loss (NASCIMENTO, 2008).

Therefore, the objective of this work was to evaluate the influence of different levels of complementary irrigation on dry matter production and water use efficiency during sorghum (*Sorghum bicolor L. (Moench*)) periods in the Midwest State of Rio Grande do Sul the municipality of Santiago.

4 MATERIALS AND METHODS

The work was conducted in agricultural year 2014/2015 in an experimental area located on the farm Fazenda Liberdade,municipality of Santiago, in the state of Rio Grande do Sul. The area is located in latitude 29º 09’ 50’’ S, longitude 54º 51’ 32’’ O and altitude of 439 meters.

Cultivar Nutribem Elite was submitted to six treatments of irrigation level. They were 0, 60, 80, 100, 120 and 140 % of the reference evapotranspiration (ETo). To determine ETo, the Penman-Monteith/FAO equation was used (ALLEN et al., 2006). The meteorological data were collected through an automatic meteorological station, located on the farm itself, about 200 meters from the experiment.

For irrigation management a fixed irrigation shift of seven days was adopted. Irrigations would be held whenever the actual rainfall during the irrigation period would not attend the crop evapotranspiration demand. To determine the effective precipitation, a methodology proposed by Millar (1978) was adopted. This function of the lost precipitation can be estimated in accordance with the type of soil, soil slope and the cultivation condition. For the site of the work, the part of precipitation lost by runoff used is 30% of the total precipitation.

A conventional spray system was used for irrigation, comprising a main row and six fixed lateral row, with all pipes of the PVC system. The spacing of the laterals rows were 12 m, connected with a quick coupling. The sprinklers were connected to these laterals rows with spacing of 12 m and an elevation of 1.5 m above the ground. The sprinklers used were the NaanDanJain brand, model 427 ½'', full circle.

The establishment of irrigation levels was performed by overlapping spray nozzles with different diameters, where each of the six laterals rows received a nozzle diameter, as follows: 4.0 mm x 3.5 mm; 3.2 mm x 3.0 mm and 2.8 mm. For the definition and calibration of different irrigation levels, the Christiansen uniformity coefficient test was performed.

The sowing of forage sorghum was held on November 18, 2014 with approximately 15 seeds per linear meter, objectifying at a final population of 330,000 plants.ha^{-1}. To carry out the sowing of sorghum, a mechanical seeder was used, with rows spaced 0.36 m. The experimental design was a randomized block design with four replicates, making up twenty-four experimental units.

According to climate classification proposed by Köppen (Moreno, 1961) the climate of this study region is classified as humid subtropical (Cfa) with an average temperature of 17.9 ºC during the year and average annual rainfall is 1769 mm. However, periods of irregularity occur during the interval between spring and summer, causing water deficiency to the crops, due to the high evapotranspiration of the period, at where the precipitations become insufficient to supply the water to the plants (NIED et al., 2005).

The experiment site has a soil classified as typical Dystrophic Gray Latosol, which has a textural gradient in the profile, with horizontem B more clayey than horizon A, besides being deep to very deep. (STRECK et al., 2008).

The Basic fertilization was done at moment with sowing the sorghum crop through, with a fertilizer seeder, following the interpretation of the soil chemical analysis. Two hundred and fifty kg.ha-1 of fertilizer with a commercial formulation of 5-20-20 of nitrogen (N), phosphorus (P) and potassium (K) were applied, respectively (COMISSÃO DE QUÍMICA E FERTILIDADE DOS SOLOS, 2004).

Nitrogen fertilization (N) was carried out fractionally, folowed on the content of the soil organic matter, where 150 kg.ha-1 of urea were applied in each of the applications in tillering and after each of the cuts made. Cropping practices relating to applications of fungicides, insecticides and herbicides were evenly performed for all treatments, covering the whole experimental area.

Four dry matter (DM) productivity assessments were performed through four cuts made at 50, 80, 110 and 140 days after sowing (DAS), respectively. The cuts were made in accordance with the seed manufacturer's recommendations. The first cut was in a wider range of days due to the fact of the sorghum crop presents toxicity to animals in the early stages of development and presenting in its composition high levels of tannin and hydrocyanic acid.

For the first uniform cut, i.e., at 50 days after sowing (DAS), the yield obtained was transformed to thirty days, where the output found was divided by fifty and multiplied by thirty, in order to standardize the range of days with the other cuts made.

Three samples of 0.5 linear meters per portion were collected, totaling 72 samples per cut. The cuts were made at 15 cm height from the ground with a sickle. They were manually separated and individually assessed in three fractions of the sample: leaf (leaf blade), stalk (leaf sheath + stalk) and dead material. All samples were dried in an oven with forced air circulation at 65 °C for 72 hours and their mass was recorded on a precision scale. From this, the percentage participation and the mass of each component were calculated in $kg.ha^{-1}$ of DM.

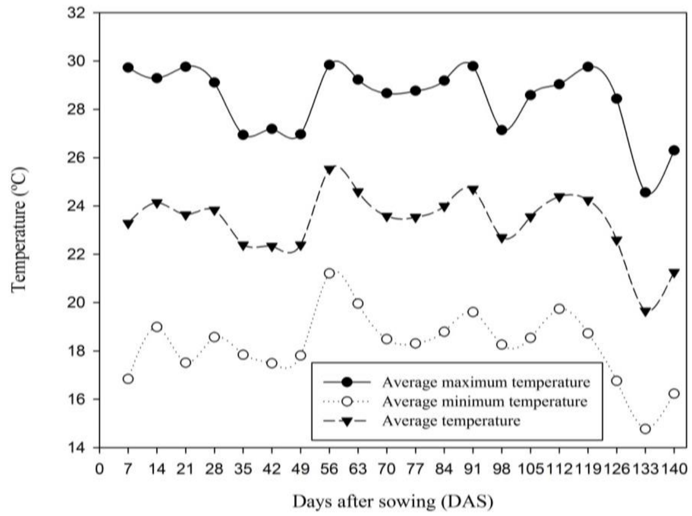
The water use efficiency of each of the cuts was performed through the relation between the total amount of water (summation between the effective precipitation and the irrigation depths of each of the treatments) and its relation with the dry mass produced for each of the cuts, for determine which irrigation depths provided the most efficient use of water, as a function of the dry mass of forage production along the four cuts of uniformity.

The data obtained on the production of dry mass throughout the days after sowing (DAS) were statistically evaluated through analysis of variance and, later, the individual effects of the treatments were evaluated through the regression analysis at 5% probability error message. The SIGMAPLOT 11.0 software was used for the elaboration of graphic images.

5 RESULTS AND DISCUSSION

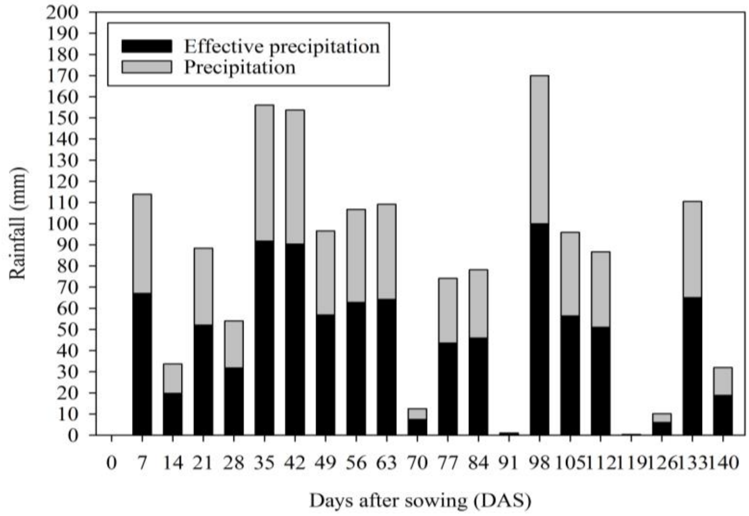
While conducting the experiment, there was great variation in the daily minimum, maximum and average temperatures because of the scope of the experiment period. The average temperature in the range from November to April of agricultural year 2014/2015 was 22.6 ºC. The relative humidity showed an overall average of 82.3%. The temperatures and the relative humidity are represented in Figure 1.

Figure 1. Weekly means of relative humidity and maximum and minimum temperatures observed during the experiment period.



The rainfall and effective precipitation occurred during the experiment at 7 day intervals are shown in figure 2.

Figure 2 . The rainfall and effective precipitation occurred during the experiment.



During the 140 days of conducting the experiment, the total precipitation sum occurred and collected was 883 mm. However, adopting Millar's (1978) methodology to determine the effective precipitation, effective rainfall considered was 618 mm. Table 1 shows the effective precipitation (EP), the reference evapotranspiration (ETo) and the total water applied at each irrigation level on each cut made at seven day time intervals due to the irrigation schedule.

Table 1. Effective precipitation, reference evapotranspiration (ETo) and irrigation depth applied.

	DAS	PE (mm)	ETo (mm)	Irrigation depths (mm) – % ETo 60	80	100	120	140
1st cut	7	46,9	35,3	0,0	0,0	0,0	0,0	0,0
	14	13,9	30,4	8,1	13,2	16,5	19,8	23,1
	21	16,4	43,1	16,0	21,3	26,7	32,0	37,4
	28	12,3	31,0	11,2	14,9	18,7	22,4	26,2
	35	64,3	31,8	0,0	0,0	0,0	0,0	0,0
	42	63,3	22,1	0,0	0,0	0,0	0,0	0,0
	49	39,8	32,8	0,0	0,0	0,0	0,0	0,0
		256,9	**226,5**	**35,3**	**49,4**	**61,9**	**74,2**	**86,7**
2nd cut	56	43,0	21,8	0,0	0,0	0,0	0,0	0,0
	63	44,9	22,6	0,0	0,0	0,0	0,0	0,0
	70	5,2	33,1	16,7	22,3	27,9	33,5	39,0
	DAS	**PE (mm)**	**ETo (mm)**	**Irrigation depths (mm) – % ETo 60**	**80**	**100**	**120**	**140**
	77	30,5	29,1	0,0	0,0	0,0	0,0	0,0
		123,6	**106,5**	**16,7**	**22,3**	**27,9**	**33,5**	**39,0**
3rd cut	84	32,2	32,2	0,0	0,0	0,0	0,0	0,0
	91	0,4	32,5	19,2	25,7	32,1	38,5	44,9
	98	70,0	21,1	0,0	0,0	0,0	0,0	0,0
	105	39,5	28,4	0,0	0,0	0,0	0,0	0,0
		142,1	**114,1**	**19,2**	**25,7**	**32,1**	**38,5**	**44,9**
4th cut	112	35,7	27,0	0,0	0,0	0,0	0,0	0,0
	119	0,1	29,9	17,9	23,8	29,8	35,8	41,7
	126	1,2	28,9	16,6	22,2	27,7	33,2	38,8
	133	45,5	13,9	0,0	0,0	0,0	0,0	0,0
	140	13,2	16,9	0,0	0,0	0,0	0,0	0,0
Total		**95,7**	**116,6**	**34,5**	**46,0**	**57,5**	**69,0**	**80,5**
	140	**618,3**	**563,7**	**105,7**	**143,4**	**179,4**	**215,2**	**251,1**

Von Pinho et al. (2007), affirm the water demand needed to obtain good yields in sorghum crops is 380 a 600 mm. Therefore, the effective precipitation of 618 mm would be enough to meet the crop water needs. However, the rainfall distribution scheme was very variable over the experiment implementation period, when precipitations were often very high in the seven-day irrigation period. At other times, the lack of rainfall caused short “Indian summers,” making essential to achieve the replacement of the evapotranspiration demand through irrigation.

During the experiment were required seven supplemental irrigations, being that three in consecutive weeks in the period between seeding and the first cut, one between the first and second cuts, one between the second and third cuts, and two in consecutive weeks, between the third and fourth cuts.

Although the experiment has been conducted in a year agricultural with above average rainfall for the period and some irrigations were performed in an interleaved way with the rainfall, there was influence of the irrigation on the dry matter production. The dry matter (DM) yield found in each of the irrigation levels in each of the four cuts made is shown in Table 2.

Table 2. Average dry matter yield (kg.ha^{-1}) found in each of the irrigation depths in each of the four cuts made.

Irrigation depths (%ETo)	Dry matter (kg.ha^{-1})					
	Cut 1* (50 DAS)	**Cut 2* (80 DAS)**	**Cut 3* (110 DAS)**	**Cut4* (140 DAS)**	**Media**	**Standard deviation**
Without irrigation	2258	2389	1552	1391	1897	437
60	2371	2953	2174	1915	2353	382
80	2468	4028	2373	2694	2890	667
100	2660	4398	2688	2997	3185	712
120	2677	4457	2788	3137	3265	709
140	2907	4534	2855	3385	3420	675

*Significative at 5% of probability by test F.

Studies already carried out in the same experiment site point to the occurrence of Indian summers in previous years and the responses of dry matter production increase in corn, beans and soybeans due to different irrigation levels (PARIZI et al., 2009; GOMES, 2011).

It is possible to see in Table 2 that there was an influence of different irrigation levels on the dry matter production in the sorghum crop, as well as variation in productivity according to the standardization cuts made. There was also dry matter.ha^{-1} production increase through the use of irrigation in all irrigation levels used.

Thus, statistical analysis of the production increase of the different levels and the additional analysis by regression analysis were performed. In Table 3 shows the ANOVA for the influence of irrigation depths on dry mass production in each of the four cuts made in forage sorghum at 50,80,110 and 140 days after sowing.

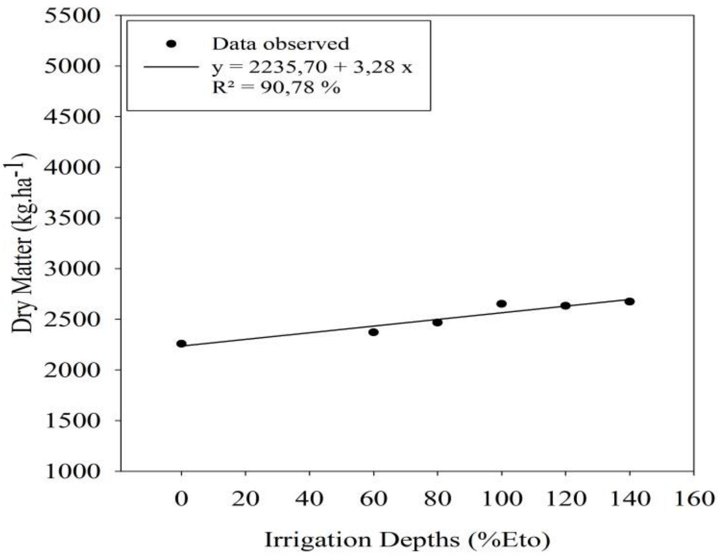
Table 3. ANOVA for the influence of irrigation depths on dry mass production in each of the four cuts made in forage sorghum at 50, 80, 110 and 140 days after sowing.

Days After Sowing (DAS)	Sum of Square (SQ)	Mean Squared error (MSE)	Fc	Pr>Fc
50	586857.058	117371.411	12.840	0.0001*
80	19199279.173	3839855.834	94.623	0.0000*
110	7094017.383	1418803.476	20.649	0.0000*
140	12573193.093	2514638.618	40.638	0.0000*

*Significative at 5% of probability by test F.

Figure 3 depicts the adjusted equation of the increment of dry matter kg.ha^{-1} of each irrigation level used in relation to treatment non-irrigated of the first cut at 50 DAS.

Figure 3. Dry matter yield (kg.ha^{-1}) in different irrigation depths in the first cut of the crop to 50 DAS.



As can be seen in Figure 3, in the first cut there was a statistically significant difference for the influence of different irrigation levels for dry matter yield per hectare in the sorghum crop, where the equation behavior increased dry matter productivity according to the increasing irrigation level in relation to the non-irrigated control.

The first cut was the one that had the lowest increase in production in comparison to the higher production level (140% of ETo) and non-irrigated control. The increase was of 648.2 in kg.ha^{-1} and in percentage the increase was of 28.7% of dry matter per hectare. These results are attributed to the fact of the occurrence of weeks with high rainfall in the period alternating with weeks when irrigation was needed. The effect of irrigation was small compared to other cuts where rainfall was not so high.

These results are attributed to the influence of different irrigation depths which enabled the sorghum crop to the suitable water conditions for growth and development. Neumann et al. (2010), in a study of sorghum crops in cuts in flood based farming systems, in an experiment conducted in the Brazilian city of Santa Maria, RS, for sowing also held in November, have obtained dry matter yield in the first cut, at 45 days after emergence, of 2259 kg.ha^{-1} for hybrid BR 800, being very close to the 2258 kg.ha^{-1}, found in the non-irrigated portion of this work. As for the portion with irrigation level of 140% of ETo, yield found was 2906 kg.ha^{-1}, showing an increase of 648 kg.ha^{-1} and the importance of irrigation for increased dry matter yield in the first cut of the sorghum crop.

Tomich et al. (2004), assessing the production of dry matter.ha^{-1} in 23 genotypes of sorghum harvested at 57 days after emergence of the plants, notice productions of dry matter ranging between 3.5 and 5.8 t.ha^{-1} in one cut management. The authors indicate that this variation is due to genetic variability factors, different requirements of soil fertility, water availability, time of planting, and plant growth stage. Also, they note that the productivity would have been higher if more uniform cuts had been made, indicating that in handling a higher number of cuts the productivity of the first cut would be lower. However, the total would be higher, a fact evidenced in this work.

Figure 4 depicts the adjusted equation of the increment of dry matter kg.ha^{-1} of each irrigation level used in relation to the non-irrigated portion of the second cut at 80 DAS.

Figure 4. Dry matter yield (kg.ha^{-1}) in different irrigation depths in the second cut of the crop to 80 DAS.

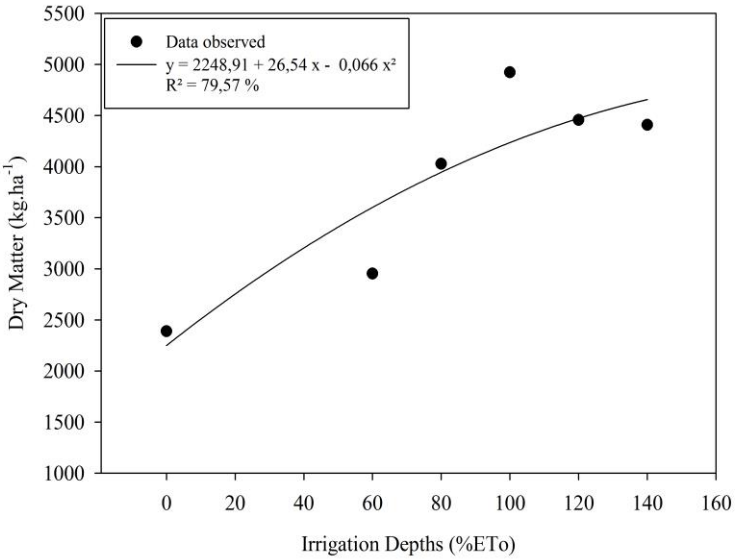


Figure 4 show it is observed that in the second cut made at 80 DAS a statistically significant difference was also found for the influence of different irrigation levels on the increasing dry matter yield per hectare. Thus, it was observed that there was a high increase in productivity of all irrigation levels in the second cut relative to the first one. However, for the second cut, the adjusted equation was the second degree, with productivity increase up to the 100 % irrigation depths, and after, a decline of the production in the 125 % of ETo.

The second cut was the time at which the highest production increases were found in kg.ha^{-1} of dry matter, with an increase of 2144 kg.ha^{-1} obtained in the irrigation level of 140% of ETo in relation to the non-irrigated control. However, when the comparison between the cuts is held in percentage, the second cut was not that in which the irrigation provided the highest increase. In this comparison it is the second highest one, with 89.7% dry matter increment per hectare.

These results are attributed to a high irrigation that was required. It was carried out at the time taken in this period, where replacements of about 30 mm in the irrigation level of 100% and 39 mm in the level of 140% were required. This fact showed water stress for the control (non-irrigated) portion, water stress for replacements below the crop needs, i.e., lower levels, and normal developmental conditions for higher levels, a fact that enabled the highest increases. Furthermore, according to the seeds manufacturer, this is the moment with greater production trend in kg.ha^{-1}, when water availability is properly provided, as for seedings in November this period joins the higher temperatures and the photoperiod, favoring the growth of sorghum leaves and stalks.

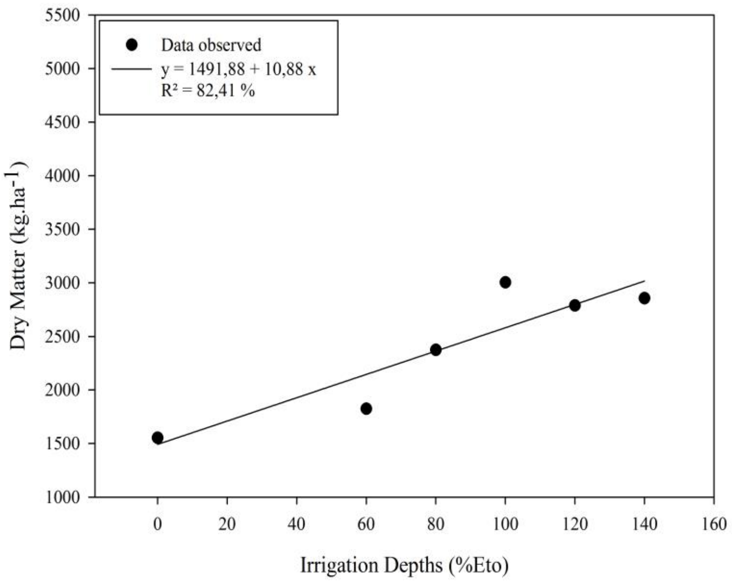
Corroborating the results found, Neumann et al. (2010) have also found higher dry matter production for the second cut in relation to the first one in flood based farming systems for the four hybrids, indicating that this increase is a result of the high tillering of the plants after the first cut and also the solar radiation and temperature conditions were conducive to the crop development.

As for the difference in production between the irrigation levels, where the highest ones produced better results, this could be explained by the occurrence of water stress provided by the lack of water in the lower depths, since the evapotranspiration demand was not sufficiently replenished. At the time the plants were restarting regrowth, there was lack of water, resulting in decreased productivity (TARDIN et al., 2013). It is also possible to observe that the range of variation among treatments was higher in the second cut in relation to the first one.

Neumann et al. (2010), in flood based farming systems, in an experiment conducted in the Brazilian city of Santa Maria, RS, for sowing also held in November, they have obtained dry matter yield in the second cut, at 75 days after emergence, of 3111 kg.ha^{-1} for hybrid AG 2501, being above the 2389 kg.ha^{-1} found in the non-irrigated portion of this work. However, the production increase results in all tested irrigation levels ranged from 563 kg.ha^{-1} in the irrigation level of 60 % of the ETo at 2144 kg.ha^{-1} in the portion with an irrigation level of 140 % of the ETo, i.e., producing 89% more than the non-irrigated portion, showing the importance of the irrigation technique to increase dry matter production in the second cut of the sorghum crop.

Figure 5 depicts the adjusted equation of the increment of dry matter kg.ha^{-1} of each irrigation level used in relation to the non-irrigated portion of the third cut at 110 DAS.

Figure 5. Dry matter yield (kg.ha^{-1}) in different irrigation depths in the third cut of the crop to 110 DAS.



As for the third cut, as can be seen in Figure 5 a statistically significant difference was also verified for the influence of the different irrigation levels on dry matter yield per hectare. The highest increase in production was found in the portion with 140% of ETo with 1303 $kg.ha^{-1}$ more than in the non-irrigated control, being the third highest increase in $kg.ha^{-1}$ when comparing the four cuts made. As for the comparison in percentage, it was also the third in increasing production with 83.9%.

These results are attributed to a high irrigation that was required. It was carried out at the time taken in this period, where replacements of about 32 mm in the irrigation level of 100% and 44 mm in the level of 140% were required. By this fact, water stress was shown for the control (non-irrigated) portion and for replacements below the crop needs, besides normal developmental conditions for higher levels, a fact that enabled significant increases.

Through the results found for the variation of dry matter according to the irrigation level applied to the third cut made at 110 DAS it is possible to see that the behavior of the dry matter yield was of production increase in higher levels, i.e., levels of 140% and 120% of ETo obtained the highest yields in relation to the others. This shows how the increased irrigation provided increased productivity in sorghum. It also shows how water influences plants growth and development. And the fact that the year was quite rainy causes shallow roots and even short periods of time show decreased productivity when in drought situations (SANTOS & CARLESSO, 1998).

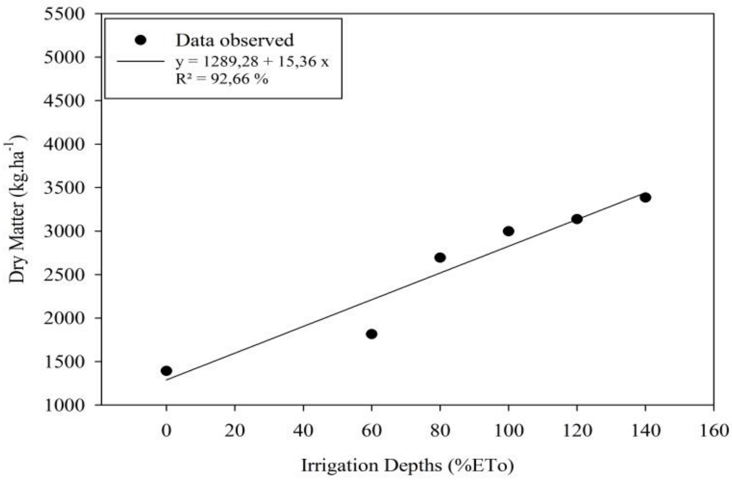
It was also observed that the lower increase in production of dry matter was obtained in the lowest level tested, with a wide range of production compared to the highest yields. This was far below the level with increased productivity, with a decrease of 52% in relation to the level of 140% of the ETo. Thus it shows the importance of an adequate water supply for the plant development.

Another important aspect to be mentioned is the decline in productivity of all the levels in relation to the previous cut. This drop in productivity is the result of the natural fall of potential crop yield, due to the fact that two previous cuts have already been carried out and also the time of year, with less solar radiation and therefore less plant growth and development. However, it is important to emphasize that the effect of different irrigation levels have remained despite the lower yields obtained.

For the third cut, Neumann et al. (2010) have found in flood based farming systems, in a cut made at 110 days after emergence, a productivity of 3301 kg.ha-1 for hybrid AG 2501, a productivity that was higher than that found in this study, where in the non-irrigated portion the production obtained was 1552 kg.ha-1, being the cut less productive among the four ones made. Despite the low productivity, there was a high increase in dry matter production due to irrigation in all levels tested, where the level of 60% of the ETo showed the lowest increase in production with 2173 $kg.ha^{-1}$, while the level of 140% of ETo had the highest increase with 2855 $kg.ha^{-1}$ in relation to the non-irrigated portion.

Figure 6 depicts the adjusted equation of the increment of dry matter $kg.ha^{-1}$ of each irrigation level used in relation to the non-irrigated portion of the fourth cut at 140 DAS.

Figure 6. Dry matter yield (kg.ha^{-1}) in different irrigation depths in the fourth cut of the crop to 140 DAS.



It can also be seen from the results apresented in Figure 6, that in the fourth cut made at 140 DAS a statistically significant difference was also found for the influence of the different irrigation levels on the increasing dry matter yield per hectare.

Additionally, the dry matter yield increase per hectare found in terms of kg.ha^{-1} for the fourth cut was the second among all the cuts evaluated, being obtained in the portion with 140% of ETo with 1993 kg.ha^{-1} more than in the non-irrigated control. However, it is extremely important to emphasize that in the evaluation and comparison of the production increase in percentage among the four evaluated cuts, the fourth cut was the first in production increase, with 143% increase in comparison with the level with the highest increase found in the replacement of 140% of the ETo in relation to the non-irrigated control portion.

These results are attributed to two high irrigations that were required, being carried out at moments included in this time period in consecutive weeks, where replacements of about 30 mm were necessary in one week and 28 in the following level of 100% of the ETo, 33 mm in a week and 39 mm in the following week on the level of 140% of the ETo.

Although the fourth cut was not the one with higher production increase in kg.ha^{-1}, the irrigation was characterized as determinant for the increment, where two consecutive irrigations characterized a favorable growth environment for higher levels and unfavorable environments for the control non-irrigated portions, and for the lower replacement levels. Even the fourth cut not being indicated as the one with the highest production by the seeds producer for sowing in November in the Brazilian state of Rio Grande do Sul due to the occurrence of lower temperatures and smaller radiation compared to previous cuts, the production was highly influenced by irrigation, demonstrating that water is one of the limiting factors responsible for the low productivities found for the fourth cut in the literature.

Neumann et al. (2010) have found dry matter production for hybrid AG 2501 in the fourth cut, held at 145 days after emergence in flood based farming systems of 1421 kg.ha^{-1}, while in this work the non-irrigated portion obtained an average of 1391 kg.ha^{-1}. The same authors point out that the drop in productivity in the fourth cut occurs due to the decrease of solar radiation because of the time of the year in Rio Grande do Sul, the potential drop of the crop and the time of decline in temperatures and the occurrence of frosts.

In this way, it was possible to characterize the water applied through irrigation as a determining factor for this variation of dry matter production because the same, showing that one of the alternatives for the increase in the production rates of pastures planted with sorghum is through the use of irrigation (ALENCAR et al., 2009).

The results found followed the same trend as the ones obtained in the preceding cuts, in which a possible explanation for the higher increments of dry matter per hectare found in greater irrigation levels is attributed to the stoppage or reduction in plant growth with water stress caused by the replacement of irrigation below the crop needs.

According to Antoniel et al. (2016), the increase of dry mass production in pastures when irrigated in relation to rainfed pastures is unquestionable. For Wagner et al. (2012), the growth and development of agricultural crops influenced by several factors, including soil-plant-atmosphere dynamics, soil water availability, evapotranspiration, and plant water utilization.

For Pimentel et al. (2016), the adequate water supply is an essential factor for the development of leaves and stems in forage species. Only with the adequate availability of water in the plant metabolism does the necessary changes occur between plant and atmosphere, reaching high levels of photosynthesis, which, consequently, lead to growth and development of plants, a fact verified in the present work through Differences found in the production of dry mass per hectare in the different water conditions imposed on the plants through the different irrigation levels in the cuts made.

For Bengough et al. (2006) the occurrence of periods of water deficiency inhibits the normal functioning and wellbeing of any species. According to the same authors, with the water deficit, the cells receiving signals from the root system trigger responses in an attempt to remain productive, and the first measure is to reduce or even paralyze the photosynthetic activity, causing damage to the productivity of Cultures. The severity of these measures adopted by the plants under water deficit depends on the ability of the species to adapt to this new condition, and damages are usually caused by productivity (SILVA et al., 2012), a fact that is observed in the irrigation depths with lower replenishments of water for the four evaluation moments of the present study.

Mahajan & Tuteja (2005) through a review study, point out that several physiological changes occur in plants when in water stress. The first measure is usually to prevent the loss of water by transpiration through the closure of the stomata, be it by hydropassive or metabolic activation. Metabolically, this process is regulated by the ABA (abscisic acid), which promotes efflux of K + ions from the guard cells, leading to losses of turgor in the structures of the cells of the plants. The water lack signal is emitted by the roots, being intermediated by the ABA up to the leaves, and the process of closing the pores of the stomata is then triggered, reducing aspects essential to plants, such as: the growth and development, and, consequently, decreasing the productivity.

Ferrari et al. (2015) attribute the occurrence of water stress changes such as reduction of leaf water potential, stomatal closure, reduction of photosynthetic rate, reduction of aerial part, acceleration of senescence, leaf abscission, among others. Ferraz et al. (2012), corroborate by affirming that through the greater availability of water, the plants high the gas exchange between plant and atmosphere, causing plant tissue expansion and development of the aerial part, mainly leaves, essential when the subject is pasture dry mass.

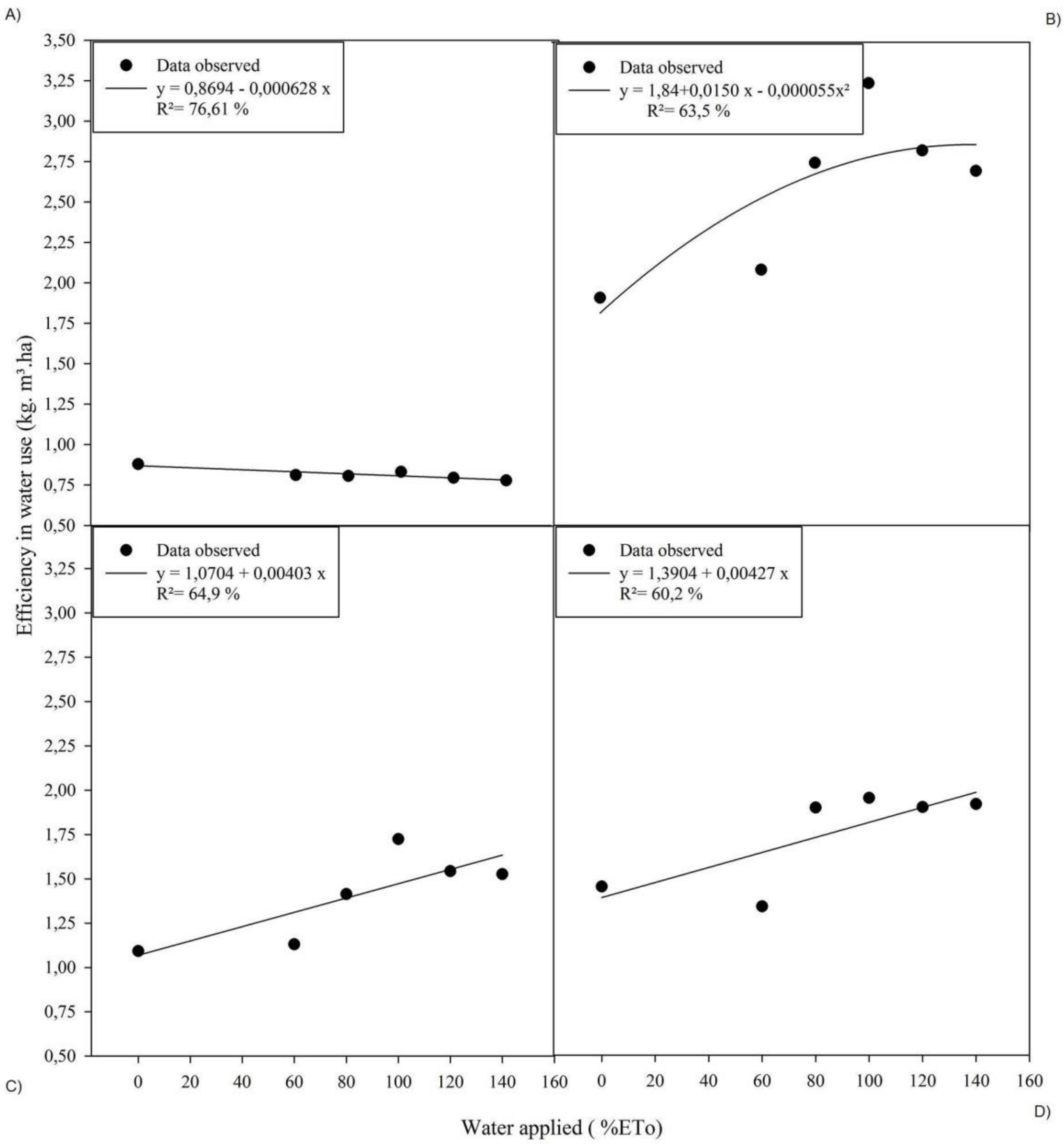
Also contributing with the results found in the present work studies by Bergamaschi et al. (2004), who attributed the occurrence of water deficiency to the fall of dry mass production in maize. Lopes et al. (1986), state that when subjected to water deficiency, the foliar expansion of the crops is reduced, and this process is affected by the reduction of metabolic activity and photosynthesis.

However, although it is extremely important to increase forage yield in the culture of forage sorghum with the use of irrigation, it is essential to adapt to the blade that provides the efficient use of water, since it is an increasingly scarce resource. A rational use of the water is necessary, calibrating the irrigation blade with the necessity and avoiding the waste of a natural good essential to life (NASCIMENTO et al., 2012).

Irrigation when properly used and calibrated, with a rational management, can promote an economy of approximately 20% of water and 30% of the energy consumed. Of the energy value, the savings of 20% would be due to not excessive water application and 10% due to the resizing and optimization of the equipment used (LIMA; FERREIRA; CHRISTOFIDIS, 1999). It is estimated that 2500 km³ of agricultural water is lost annually by the inadequate use of water, which is much higher than the industry (117 km³) and the domestic use (64.5 km³) loses (LEMOS, 2003).

In this way, the water use efficiency (WUE) was evaluated for each of the cut-off periods at 50, 80, 110 and 140 days after sowing, since this information is scarce in the literature regarding water use efficiency In a dynamic of cuts and indispensable for the correct management of the irrigation. The water use efficiency for each of the cut-offs is shown in Figure 7.

Figure 7. Efficiency in water use (EUW) for each of the 4 cuts realized at 50, 80, 110 and 140 days after sowing in forage sorghum.



As can be seen in Figure 7 (A), the first cut of the crop, at 50 DAS, showed the lowest efficiency in the use of water compared to the others, due to the high rainfall verified in the period and the lower irrigation volume applied, where, linear equation was adjusted for the different treatments. The highest efficiency in water use was found in the non-irrigated plot with 0.87 $kg.m^{-3}.ha^{-1}$, while the lowest was found in the 140% ETo blade with 0.77 $kg.m^{-3}. ha^{-1}$.

These results are in line with those obtained by Melo (2006), who studied sorghum and millet under different soil water levels, it was found that greater efficiency in the use of the larger water for the smaller irrigation levels. The following slides were tested: 0, 25, 50, 75 and 100% of the soil field capacity. The highest efficiency was found in the 25% field capacity blade with 4.50 $g.kg^{-1}$, while the lowest value of the water use efficiency was obtained in the blade of 100% field capacity with 3.00 $g.kg^{-1}$.

For the second cut (Figure 7 (B)), performed at 80 DAS, where rainfall was lower than the first one, the water use efficiency had a quadratic behavior, with a maximum technical efficiency point in the 136.3 mm, thus characterizing that upper irrigation levels to this, can characterize increments of production that do not correspond to the objectives traced, with inadequate water expenditure. In addition, it can be observed that in the second cut the greatest values of WUE were found among the cuts, due to the fact that the second cut was the one with the highest yield among the four cuts evaluated.

The results found are in line with those found by Parizi et al. (2009), that working with five irrigation strategies 0%, 60%, 80%, 100% and 120% of the ETo, also in Santiago-RS, with the maize crop, observed that water higher values of 3.41 kg $m^{-3}.ha^{-1}$ and 3,46 $kg.m^{-3}.ha^{-1}$ in the treatments of 80% and 100% of ETo and the lowest value, 3.0 $kg.m^{-3}$. ha^{-1} was obtained with 120% of the ETo, that is, irrigation levels greater than 100% decreased to the WUE.

For the third and fourth cuts (Figure 7 C and D), performed at 110 and 140 DAS respectively, the results obtained for the water use efficiency were very close, and linear equations were adjusted for both, where the highest WUE values were found in the 100% with about 1.75 $kg.m^{-3}$ ha^{-1}.

The results are similar to those of Souza et al. (2011), who worked with five different irrigation depths: 0%, 50%, 75%, 100% and 125% of ETo for the intercropping of maize and cowpea in the Petrolina-PE region. Linear behavior for maize water efficiency in exclusive sowing.

The values found for the different irrigation depths were 0.46 $kg.m^{-3}$, 0.58 $kg.m^{-3}$, 0.67 $kg.m^{-3}$, 0.72 $kg.m^{-3}$ and 0.77 kg. m^{-3} as a function of the treatments mentioned, thus characterizing that the increase in the irrigation levels brought the increase of the WUE, as well as in the third and fourth cuts in the present study, where there was also an increase in the a WUE as the irrigation levels increment.

5 CONCLUSIONS

Sorghum crop has shown great production response of dry $matter.ha^{-1}$ when irrigated, where, with the increase of irrigation level, there was a higher production.

Irrigation levels of 140% and 120% of the ETo were the ones that showed the highest production increases in relation to the non-irrigated portion in the four cuts, showing the crop response to water increase provided through irrigation.

There was variation in production and dry matter increase per hectare among the cuts made, where it was possible to determine the importance of water for crop growth at different times, where the second cut was the most productive in $kg.ha^{-1}$ and the fourth cut in percentage with 143% of production increase.

Crop management in dynamics of cuts was characterized as efficient when irrigated, as it made possible a better pasture offer distributed throughout the cycle, with high production.

Sorghum crops showed high dry matter yield/ha when irrigated, characterized as an alternative to farmers and cattle breeders in the central-west region of the Brazilian state of Rio Grande do Sul.

The water use efficiency presented variation for the different cuts, where the 100% ETo blade showed the highest efficiencies in three of the four evaluated cuts, being an extremely important parameter for the irrigated forage production.

Irrigation by conventional sprinklers is presented as an alternative for producers of forage species of the central-west area of Rio Grande do Sul, since its use provided high increase in dry matter production in sorghum crops.

The use of supplemental irrigation can be an alternative to increase the productivity of sorghum in the central-west portion of the RS, because its use has influenced the total dry matter production and the four cuts.

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7 REFERENCES

ALENCAR, C. A. B.; CUNHA, F. F.; MARTINS, C. E.; CÓSER, A. C.; ROCHA, W. S. D.; ARAÚJO, R. A. S. Irrigação de pastagem: atualidade e recomendações para uso e manejo, **Revista Brasileira de Zootecnia,** Piracicaba, v. 38, p. 98-108, 2009.

ALLEN, R.G.; PEREIRA, L.S.; RAES, D.; SMITH, M.. **Evapotranspiration del cultivo**: guias para la determinación de los requerimientos de agua de los cultivos. FAO- Irrigation and Drainage Paper 56, Roma: FAO, 2006. 298 p.

ANTONIEL, L. S.; PRADO, G.; ROCHA, T.; BOMBARDELLI, W. W. A.; BELTRAME, G. A.; BUENO, J. I. Irrigação no teor de proteína bruta de duas espécies de pastagens. **Irriga**, Botucatu, Edição Especial, Grandes Culturas, p. 248-259, 2016.

BASSO, F. C.; ANDREOTTI, M.; CARVALHO, M. P.; LODO, B. N. Relações entre produtividade de sorgo forrageiro e atributos físicos e teor de matéria orgânica de um latossolo do cerrado. **Pesquisa Agropecuária Tropical**, Goiânia, v. 41, n. 1, p. 135-144, 2011.

BENGOUGH, A. G.; BRANSBY, M. F.; HANS, J.; MCKENNA, S. J.; ROBERTS, T. J.; VALENTINE, T. A.. Root responses to soil physical conditions; growth dynamics from field to cell. **Journal of Experimental Botany**, Oxford, v. 57, p. 437- 447, 2006.

BERGAMASCHI, H.; DALMAGO, G. A.; BERGONCI, J. I.; BIANCHI, C. A.M.; MÜLLER, A. G.; COMIRAN, F.; HECKLER, B. M. M. Distribuição hídrica no período crítico do milho e produção de grãos. **Pesquisa Agropecuária Brasileira**, Brasília, v. 39, n. 9, p. 831-839, 2004.

CARVALHO, J. J.; SILVA, N. F.; ALVES, D. M.; MORAIS, W. A.; CUNHA, F. N.; TEIXEIRA, M. B. Produtividade e teores de nutrientes em grãos de feijão sob diferentes manejo do solo e da irrigação. **Revista brasileira de agricultura irrigada**, Fortaleza, v. 8, n. 3, p. 297-307, 2014.

CHRISTOFIDIS, D. Água, irrigação e agropecuária sustentável. **Revista de política agrícola**, Brasília, v. 22, n. 1, p. 115-136, 2013.

COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO- CQFSRS/SC (2004). **Manual de adubação e calagem para os Estados do Rio Grande do Sul e de Santa Catarina**. 10. ed. Porto Alegre, SBCS - Núcleo Regional Sul/UFRGS, 400 p.

COSTA, P. D. S.; PINTO, M. S. C.; SILVA, K. B.; RECH, E. G.; PINTO, M. G. C. Zoneamento das forrageiras cultivadas nos estabelecimentos rurais do município de Catolé do Rocha, PB. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, Pombal, v. 9, n. 3, p. 236-243, 2014.

CUNHA, E. E.; LIMA, J. M. P. D. Caracterização de genótipos e estimativa de parâmetros genéticos de características produtivas de sorgo forrageiro. **Revista Brasileira de Zootecnia**, Piracicaba, v. 39, n. 4, p. 701-706, 2010.

FAGGION, F.; OLIVEIRA, C. A. S.; DEMÉTRIOS, C. Uso eficiente da água: uma contribuição para o desenvolvimento sustentável da agropecuária. **Pesquisa Aplicada & Agrotecnologia**, Guarapuava, v. 2, n . 1, p. 187-190, 2009.

FERRARI, E.; PAZ, A.; SILVA, A.C. Déficit hídrico no metabolismo da soja em semeaduras antecipadas no Mato Grosso. **Revista Nativa**, Sinop, v.3, n. 1, p. 67-77, 2015.

FERRAZ, R. D. S.; MELO, A. S.; SUASSUNA, J. F.; BRITO, M. E. B.; FERNANDES, P. D.; NUNES JÚNIOR, E. S. Trocas gasosas e eficiência fotossintética em ecótipos de feijoeiro cultivados no semiárido. **Revista Pesquisa Agropecuária Tropical**, Goiânia, v. 42, n. 2, p. 181-188, 2012.

FERREIRA, D. F. **Sisvar** - Sistema de análise de variância para dados balanceados. Lavras: UFLA, 19 p. 1998.

GOMES, A. C. S. **Estudo experimental e simulado da cultura da soja em função de diferentes níveis de irrigação**. 166 p. Tese (Doutorado em Engenharia Agrícola) – Universidade Federal de Santa Maria, Santa Maria, RS, 2011.

LEMOS, H. M.; Instituto Brasil Pnuma; Autos do Comitê Brasileiro do Programa das Nações Unidas para o Meio Ambiente; 2003.

LIMA, J. E. F. W.; FERREIRA, R. S. A.; CHRISTOFIDIS, D. Uso da irrigação no Brasil. O estado das águas no Brasil. Agência Nacional de Energia Elétrica. 1999. CD-Rom.

LOPES, N. T.; OLIVA, M. A.; CARDOSO, M. I.; COMES, M. S. S.; SOUZA, V. F. Crescimento e conversão da energia solar em Phaseolus vulgaris L. submetido a três densidades de fluxo radiante e dois regimes hídricos. **Revista Ceres**, Viçosa, v. 33, n. 186, p. 142-164, 1986.

MAGALHÃES, J. A.; CARNEIRO, M. S. S.; ANDRADE, A. C.; PEREIRA, E. S.; ANDRADE, A. P.; BAKKE, A. O.; RODRIGUES, B. H. N.; MOCHEL FILHO, W. J. E.;

COSTA, N. L. Características morfogênicas e estruturais do capim-andropogon sob irrigação e adubação. **Semina: Ciências Agrárias**, Londrina, v. 34, n. 5, p. 2427-2436, 2013.

MAHAJAN, S.; TUTEJA, N. Cold, salinity and drought stresses: an overview. **Arch. Biochem. Biophys**. New York, v. 444, n. 2, p. 139-158, 2005.

MELO, D. **Avaliação de sorgo (Sorghum bicolor L. Moench) e milheto (Pennisetum glaucum (L.) B. R.) sob diferentes níveis de água no solo**. 59f. Dissertação (Mestrado em Zootecnia) – Curso de Pós-Graduação em Zootecnia, Universidade Federal de Campina Grande, Patos, 2006.

MILLAR, A. A. **Drenagem de terras agrícolas**: bases agronômicas. São Paulo: McGraw-Hill do Brasil, LTDA., 276 p, 1978.

MONTANARI, R.; PANACHUKI, E.; LOVERA, L. H.; OLIVEIRA, I. S.; BONINI, C. S. B. Variabilidade espacial da produtividade da forragem de sorgo e atributos físicos num Planossolo. **Agro@mbiente On-line**, Boa Vista, v.7, n. 3, p. 252-261, 2013.

MORENO, J. A. Clima do Rio Grande do Sul. Porto Alegre, Secretaria da Agricultura, 1961.

NASCIMENTO, P. S.; BASSOI, L. H.; PAZ, V. P. S. Planilha eletrônica para auxílio à tomada de decisão em manejo da irrigação. **Irriga**, Botucatu, v. 17, n. 1, p. 1-15, 2012.

NASCIMENTO, R. Crescimento de plantas de sorgo sob diferentes disponibilidades de água no solo. **Revista Educação Agrícola Superior**, Brasília, v. 23, n. 1, p. 53-54, 2008.

NEUMANN, M.; RESTLE, J; SOUZA, A. N. M.; PELLEGRINI, L. G.; ZANETTE, P. M.; NORNBERG, J. L.; SANDINI, I. E. Desempenho vegetativo e qualitativo do sorgo forrageiro (Sorghum bicolor x Sorghum sudanense) em manejo de cortes. **Revista Brasileira de Milho e Sorgo**, Sete Lagoas, v. 9, n.3, p. 10-15, 2010.

NIED, A. H.; HELDWEIN, A. B.; ESTEFANEL, V.; SILVA, J. C.; ALBERTO, C. M. Épocas de semeadura do milho com menor risco de ocorrência de deficiência hídrica no município de santa maria, Rs, Brasil. **Ciência rural**, Santa Maria, v. 35, n. 5, p. 995-1002, 2005.

PARENTE, H. N.; SILVA JÚNIOR, O. R.; BANDEIRA, J. R.; PARENTE, M. O. M.; RODRIGUES, R. C.; ROCHA, K. S. Produtividade do sorgo forrageiro em função de quantidades crescentes de adubação fosfatada e nitrogenada. **Revista Trópica - Ciências Agrárias e Biológicas**, Chapadinha, v. 8, n. 1, p. 1-10, 2014.

PARIZI, A. R. C.; ROBAINA, A. D.; GOMES, A. C. S.; SOARES, F. C.; RAMAO, C.; CALEGARO, I.; PEITER, M. X. Efeito de diferentes estratégias de irrigação sobre a produção de grãos e seus componentes na cultura do milho. **Irriga**, Botucatu, v. 14, s.n, p. 254- 269, 2009.

PIMENTEL, R. M.; BAYÃO, G. F. V.; LELIS, D. L.; SILVA, A. J. C.; SALDARRIAGA, F V.; MELO, C. C. V.; MIRANDA, D. Ecofisiologia de plantas forrageiras. **PUBVET**, Maringá, v. 10, n. 9, p. 666-679, 2016.

PORTUGAL, A. F.; ROCHA, V. S.; PINTO, G. H. F.; PINA FILHO, O. C.; SILVA, A. G. Fenologia de cultivares de sorgo no período de verão e rebrota na safrinha. **Revista Ceres**, Viçosa, v. 50, n. 289, p. 325-336, 2003.

SANTOS, R. F.; CARLESSO, R. Déficit hídrico e os processos morfológicos e fisiológico das plantas. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 2, n. 3, p. 287-294, 1998.

SIGMAPLOT. For Windows, version 11.0. Systat software, 2008.
SILVA, W. L.; BASSO, F. C.; RUGGIERI, A. C.; VIEIRA, B. R.; ALVES, P. L.; RODRIGUES, J. A. Características morfogênicas e estruturais de híbridos de sorgo submetidos à adubação nitrogenada. **Revista Brasileira Ciências Agrárias**, Recife, v. 7, n. 4, p. 691-696, 2012.

STRECK, E. V.; KÄMPF, N.; DALMOLIN, R. S. D.; KLAMT, E.; NASCIMENTO, P. C.; SCHNEIDER, P.; GIASSON, E.; PINTO, L. F. S. **Solos do Rio Grande do Sul**, 2.ed., Porto Alegre, Emater/RS-Ascar, 222 p, 2008.

SOUZA, L. S. B; MOURA, M. S. B.; SEDIYAMA, G. C.; SILVA, T. G. F. Eficiência do uso da água das culturas do milho e do feijão-caupi sob sistemas de plantio exclusivo e consorciado no semiárido brasileiro. **Bragantia**, Campinas, v.70, p.715-721, 2011.

TARDIN, F. D.; ALMEIDA FILHO, J. E.; LEITE, C. E. P.; MENEZES, C. B.; MAGALHÃES, P. C.; RODRIGUES, J. A. S.; SCHAFFERT, R. E. Avaliação Agronômica de Híbridos de Sorgo Granífero Cultivados Sob Irrigação e Estresse Hídrico. **Revista Brasileira de Milho e Sorgo**, Sete lagoas, v. 12, n. 2, p. 102-117, 2013.

TOMICH, H. R. G. P.; GONÇALVES, L. C.; BORGES, I. Potencial forrageiro de híbridos de sorgo com capim-sudão. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, Belo Horizonte, v. 56, n. 2, p. 258–263, 2004.

VITOR, C. M. T.; FONSECA, D. M.; CÓSER, A. C.; MARTINS, C. E.; NASCIMENTO JÚNIOR, D.; RIBEIRO JÚNIOR, J. I. Produção de matéria seca e valor nutritivo de pastagem de capim-elefante sob irrigação e adubação nitrogenada. **Revista Brasileira de Zootecnia**, Piracicaba, v. 38, n. 3, p. 435-442, 2009.

VON PINHO, R. G.; VASCONCELOS, R. C.; BORGES, I. D.; RESENDE, A. V. Produtividade e qualidade da silagem de milho e sorgo em função da época de semeadura. **Bragantia**, Campinas, v. 66, n. 2, p. 235-245, 2007.

WAGNER, M.; JADOSKI, S. O.; MAGGI, M. F.; SAITO, L. R.; LIMA, A. S. Estimativa da produtividade do milho em função da disponibilidade hídrica em Guarapuava, PR, Brasil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.17, n.2, p. 170-179, 2013.