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Variation of leaf area index of the forage sorghum under different irrigation depths in dynamic of cuts

Jardel Henrique Kirchner[1]*, Adroaldo Dias Robaina[2], Marcia Xavier Peiter[1], Wellington Mezzomo[1], Rogério Ricalde Torres[1], Leonita Beatriz Girardi[1], Bruna Dalcin Pimenta[1], Ricardo Benetti Rosso[1], Anderson Crestani Pereira[1] and Marcos Vinícius Loregian[1]

[1]Postgraduate Studies Program Agricultural Engineering (PPGEA), Federal University of Santa Maria (UFSM), Brasil.
[2]Department of Rural Engineering at Federal University of Santa Maria, Santa Maria, RS, Brasil.

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The determination of leaf area index is a variable of great importance for predicting productivity, especially when it comes to forage species where the desired product is the leaves. This study aimed to determine the variation of the leaf area index of forage sorghum when subjected to different irrigation depths in four culture cuts. Treatments consisted of six irrigation depths, these being 0, 60, 80, 100, 120 and 140% of the reference evapotranspiration. Seven evaluations of leaf area index (LAI) were performed, which were in the four cuts, specifically at 50, 80, 110 and 140 days after sowing (DAS), and also 15 days after each cut to evaluate the culture's resprouting, that is, at 65, 95 and 125 DAS. The delineation was randomized blocks, with six treatments and four blocks, totaling 24 experimental units. The experiment was conducted in Santiago-RS. Sowing was done on November 18, 2014. Using an irrigation system sprinkler, with one main row and six lateral rows, of PVC, being the irrigation levels differentiated by the nozzle diameter difference of sprinkler each lateral row. Samples of 0.5 linear meters per plot were collected in each of the seven evaluations, totaling 24 samples for evaluation. The analysis of leaf area index was performed using the computer program ImageJ. Significant results were found for the influence of the different irrigation levels on the leaf area index in the four cuts (recommended periods for grazing) evaluated, as well as for resprouting evaluations in the intermediate periods between cuts. Quadratic equations were adjusted for all the evaluation dates, where the 100 and 120% reference evapotranspiration levels alternated the largest LAI for all evaluations. The results also characterize that the second cut, or second grazing period of the irrigated forage sorghum, was the most productive, being it possible to recommend an increase in the animal load, or increase in grazing period in the area in this period. In this way, irrigation by sprinkling in the sorghum culture was characterized as an alternative for producers to increase leaf area index, and, consequently, crop productivity.

Key words: *Sorghum bicolor L. (Moench)*, irrigation management, pasture irrigation, sprinkler irrigation, production estimation.

INTRODUCTION

The leaf area index (LAI) is defined as the existing ratio of leaf area occupied by a population of any plant species, with the ground area, being extremely important in defining the productivity of a particular crop (Müller et al., 2005). Through the index, it is possible a better understanding of the relationship between environmental conditions and the dry matter accumulation in forages. In general, as the LAI increases, the growth ratio of forage species follow the same trend, reaching a value considered "optimum ", point from which there is a reduction in the growth rate (Molan, 2004).

According to Carnevalli et al. (2006), the LAI is an important parameter to be measured to conduct a proper management in cultivated pastures, through it is possible to determine the occupancy rate of the pasture or cuts performed, as well as the period of occupation or cutting intervals. Pasture management is extremely important for the success of the desired results, requiring special attention as regards the need to maintain leaf area to perform photosynthesis and reconcile with harvesting a large amount of high quality plant tissues, particularly leaves by grazing or pasture cuttings (Fagundes et al., 2001). Environmental factors such as temperature, light, soil fertility, genetic characteristics, pasture management, physiological plant age, and especially water availability, are intrinsically linked to the variation of leaf area index of forage species, leading to occurrence of variations according to the region and the rainfall incurred. Moreover, they are also critical in the new leaf area reconstitution capacity after cutting or grazing conditions, and this capability is crucial to the production and sustainability of pasture (Santos Jr. et al., 2004).

When subjected to some type of storm or stress, plants exhibit responses directly related to performance loss, the main constraint being water insufficiency condition. With the lack of water in their cells, the plants lack one of the primordial elements for the vegetative development, that is to say, foliar growth, causing in a smaller IAF and, insufficient for the reach of high productivities that characterize the viability of the costs of production (Larcher, 1986; Severino et al., 2004). The first plant strategy to adapt to drought conditions is the reduction of the aerial part due to the roots, limiting their ability to compete for light, by the decrease in leaf area, with consequent reduction in productivity (Nabinger, 1997). Considering that the irregularity of rainfall restricts the development of plants and that evapotranspiration of forage species is high at this time of year, there are usually periods of water insufficiency. In this way, the distribution of water in pastures through irrigation can improve productivity and profitability indexes by expressing a high leaf area index, compatible with production expectations, since, in the case of pastures, the main animal's power supply is the leaves (Cunha et al., 2007). The occurrence of water deficit in forage sorghum may lead to a reduction in the efficiency of the conversion of solar radiation to aerial mass, leading to a lower leaf and stem development, having a high influence on LAI (Dercas and Liakatas, 2007; Garofalo et al., 2011; Rinaldi and Garofalo, 2011). In addition, the adequate water supply of the forage sorghum crop, performed with irrigation shifts established through irrigation, increases the efficient use of water, with an increase in the leaf and stem mass increment, directly influencing LAI (Garofalo and Rinaldi, 2013).

In this context, sorghum has been characterized in cattle production system as a species used in animal feed due to high dry matter produced by the high number of leaves and their expansion, which can be offered by grazing or cuttings dynamic dynamic (Silva et al., 2015). However, for the crop to express their potential and achieve high levels of dry matter productivity, LAI must be high, where the main determining factor is water availability.

The availability of water for the crop be it through the occurrence of precipitation or supplement the evapotranspiration need through irrigation, is the alternative to food production in quantity and quality (Hefny et al., 2013). Thus, irrigation has been identified as an alternative to increase production in pastures, helping to reduce the effect of their seasonality. The response of dry matter forage production is directly related to climatic conditions, being of extreme importance the increased production caused by irrigation independently of the forage species, having the LAI as the main factor in increasing productivity in irrigated pastures (Vitor et al., 2009). Therefore, the objective of this study was to determine the variation of the leaf area index of forage sorghum when subjected to different irrigation in four crop cuts.

MATERIALS AND METHODS

The experiment was conducted in the agricultural year 2014/2015, in an experimental area located at Fazenda Liberdade, District of Tupantuba, municipality of Santiago, in the state of Rio Grande do Sul-Brazil. The area is located at latitude 29°09 '50' 'S, longitude 54º51' 32” W and altitude of 439 meters. Sowing of sorghum (*Sorghum bicolor* L., Moench) performed in a direct sowing system under crop residue, using cultivar Nutribem Elite, of Atlântica Sementes, on November 18, 2014. The sowing was done using one pull type mechanical seeder with spacing of 0.36 m between rows. For the establishment of the plant population were deposited to the ground about 15 seeds per linear meter of sowing, aiming at a final population of 330,000 plants.ha^{-1}. The climate in the region, according to Koopen’s scale (Moreno, 1961), is characterized as humid subtropical (Cfa), with an average temperature of 17.9°C annually. The average long-term rainfall is 1769 mm. The maximum, minimum and average temperature conditions at 7 day intervals occurring during the experiment are shown in Figure 1.

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*Corresponding author. E-mail: jardelkirchner@hotmail.com.

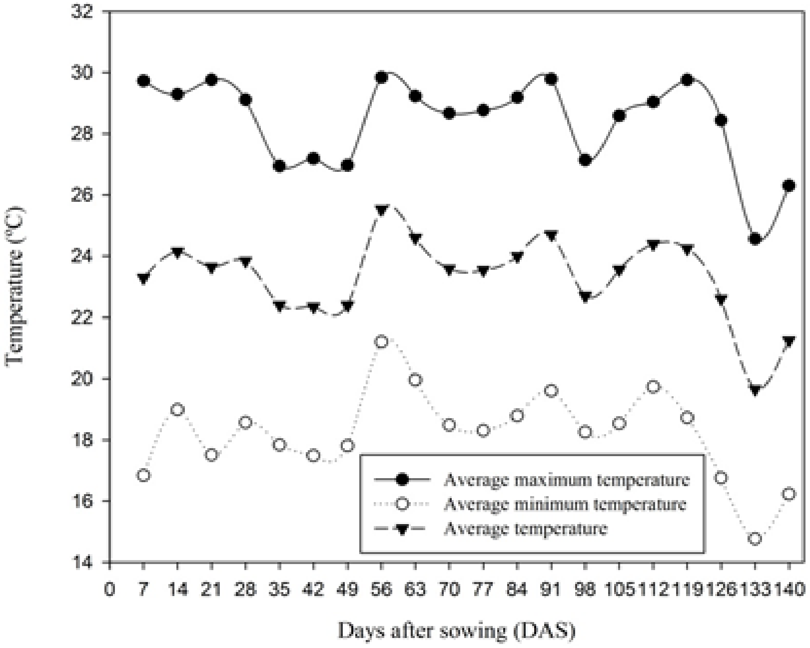

Figure 1. Average of maximum, minimum and average temperatures during the experiment.

The distribution of rainfall during the summer period is usually irregular, causing periods of drought stress to crops, because the atmospheric evaporative demand is high in the period, and the precipitations usually are not sufficient to meet crop needs (Nied et al., 2005). The rainfall and effective precipitation occurred during the experiment at 7 day intervals are shown in Figure 2. The soil used for the experiment is classified as Typical Dystrophic Red Latosol, which are deep to very deep soils and with the presence of a textural gradient profile, with horizon B (more clay) and horizon A (Streck et al., 2008).

The basic fertilization was done jointly with the sowing of the forage sorghum culture through a seeder-fertilizer, according to the interpretation of the soil chemical analysis, being deposited on the seeding row, below and beside the seeds. 250 kg.ha^{-1} fertilizers were applied with a commercial formulation of 5-20-20 nitrogen (N), phosphorus (P) and potassium (K), respectively. Nitrogen fertilization (N) or topdressing was carried out fractionally, based on the content of soil organic matter, which were applied 150 kg ha^{-1} of urea in each of the applications, which were at tillering and after each of the cuts made. Cultural practices relating to the application of fungicides, insecticides and herbicides were performed evenly for all treatments, covering the whole experimental area. Treatments consisted of six different water depths, evaluated in four blocks, totaling 24 experimental units, using a randomized block design. The irrigation depths used were 0, 60, 80, 100, 120 and 140% of the reference evapotranspiration (ETo). For the determination of ETo was used Penman-Monteith / FAO (Allen et al., 2006). Irrigation management was established with fixed irrigation shift of seven days, and irrigations were held whenever the effective rainfall during the irrigation interval of the shift did not meet the evapotranspiration demand of the crop. The determination of effective precipitation was calculated using the methodology proposed by Millar (1978).

It was used a conventional type sprinkler irrigation system comprising a main line measuring 60 meters and six fixed wings measuring 48 meters was used with all pipes of PVC system. The spacing of the wings was 12 m, connected with quick coupling. The nozzles were connected to these lines with spacing of 12 m and elevation of 1.5 m above the ground. The sprinklers used were the NAANDAINJAIN make, model 427 ½ " complete rotations. Differentiation of irrigation depths was performed by overlapping spray nozzles with different diameters where each of the six side rows received a nozzle diameter, namely: 4.0 mm × 3.5 mm; 3.2 mm × 3.0 mm and 2.8 mm.

We adopted the intermediate depth as 100% ETo, yielding after Christiansen uniformity test irrigation water and adjusted calibrated. Four crop cuts were performed at 50, 80, 110 and 140 days after sowing (DAS). For the evaluation of LAI were performed seven evaluations in fifteen day intervals, which were, at 50, 65, 80, 95, 110, 125 and 140 DAS. The first evaluation was performed 50 days after sowing (DAS), as the period recommended by the manufacturer of the seed used for the first cut of culture. The other evaluations were performed at intervals of 15 days, i.e., in the interim period between the previous and the next cut. It is noted that the cuts were made in accordance with the recommendations of the manufacturer of the seeds, the first cut in a wider range of days due to the culture of the sorghum presenting toxicity to animals in the early stages of development, having in its composition high levels of tannin and hydrocyanic acid. Therefore, it is recommended that the first cut be made 50 days after sowing, and the other cuts at intervals of 30 days.

Samples of 0.5 linear meters per plot were collected in each of the seven evaluations, totaling 24 samples for evaluation. The analysis of leaf area index was performed using the computer program ImageJ, where it analyzes photographs of leaves present in the sample, and to take photographs, the leaves were laid on a white background, where it was placed a square object of known size and photographed. The computer program ImageJ through the contrast between the paper and the white background and the knowledge of the proportion of area of the known object, determined the leaf area of the sample as Figure 3. As the row spacing was 0.36 linear meters and collections were made at 0.5 linear meters, the sample represents0.18 m2, making it possible to obtain the Leaf Area Index (LAI) existing in a square meter. The

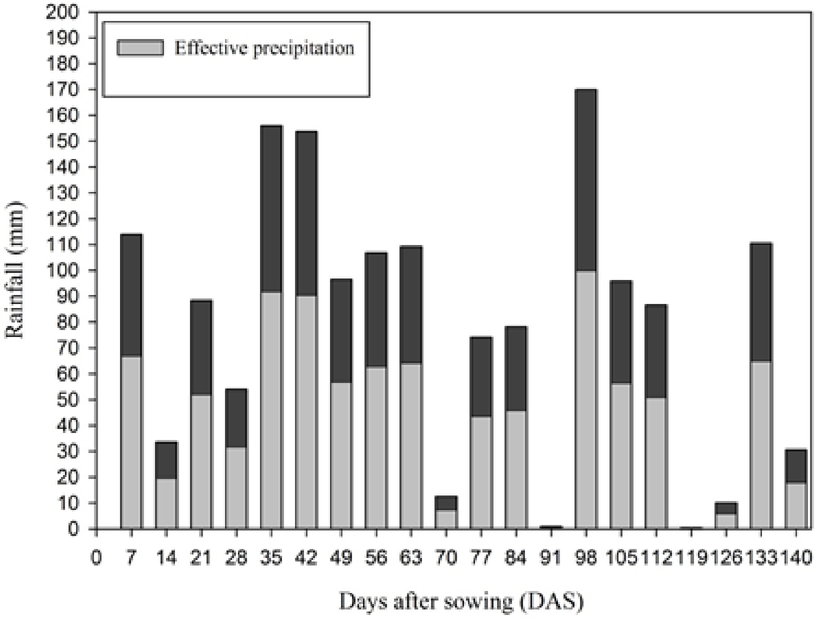

Figure 2. The rainfall and effective precipitation occurred during the experiment.

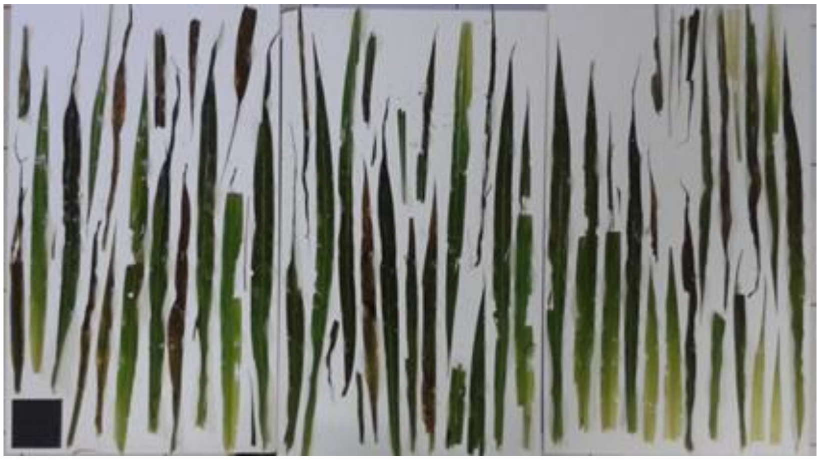

Figure 3. Photography for determining the leaf area index of the forage sorghum culture.

data obtained referring to the leaf area index found for each of the assessments carried out over the days after sowing (DAS) were evaluated statistically by variance-ANOVA and subsequently the individual effects of the treatments were evaluated by regression analysis using software SISVAR 5.3 (Ferreira, 1998), considering the statistical tests at 5% probability of error and for the preparation of graphic images was used SIGMAPLOT 11.0 software.

RESULTS AND DISCUSSION

During the experiment period of implementation, within the scope ranging between November 18, 2014 and April 6, 2015, that is, during the four cuts made in the sorghum crop, the amount of rainfall was 883 mm. However, since the experiment is divided into cuttings period, precipitations within each cutting interval were quite varied, and, in certain occasions it was required to replenish the evapotranspiration demand of the crop through irrigation. In addition, according to Millar (1978), part of the total rainfall occurred is lost, called lost by rainfall surface run-off. This fraction of the lost precipitation can be estimated according to the type of soil, soil slope and the cultivation condition. For the location of the study, the fraction of precipitation lost by runoff used is 30% of the total precipitate. Thus, the actual rainfall during the study conduct was 618 mm.

Table 1. Effective precipitation, reference evapotranspiration (ETo) and irrigation depth applied in the seven-day irrigation schedule established.

	DAS	EP (mm)	ETo (mm)	Irrigation levels (mm) – % ETo				
				60	**80**	**100**	**120**	**140**
1º 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**
2º 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
	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**
3º 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**
4º 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**

In Table 1 is shown the effective precipitation (EP) the reference evapotranspiration (ETo) and the total water applied in each irrigation levels on each cut made at intervals of seven days due to the irrigation schedule. As shown in Table 1, the variation in precipitation incurred within the seven-day interval irrigation schedule was high, where, at certain periods, there was no need for water replenishment through irrigation, and other times the supplement of water was necessary.

According to Von Pinho et al. (2007), the water demand required for normal yields compared to the culture average, provided by an elevated LAI of the sorghum is 380 to 600 mm. Thus, the effective precipitation of 618 mm incurred would be enough to meet the water requirement of the crop.

However, in the case of forage sorghum, conducted in dynamic cuts, this data becomes quite relative, as the variation of water regime is characterized as essential, where the variability over the days and cuts may compromise development of crop LAI, once that, if the occurrence of rainfall regime is poorly distributed, it will result in low growth and senescence of leaves, then being required an evaluation of rainfall through specific irrigation schedules, so that there is no impairment of LAI and consequently in the crop yield. Previous studies carried out in the same experimental site, already point to the occurrence of dry spells in previous years, that is, water deficit periods for the culture, causing a decrease of leaf area index and consequently the final crop yield of corn, soy and beans, as well, results show increment of leaf area index in these different species depending on the variation of the replacement of the water requirement through different irrigation levels (Parizi et al., 2009; Gomes, 2011).

During the trial implementation period, the distribution of rainfall was irregular, requiring replenishment of evapotranspiration demand through irrigation. Seven supplemental irrigations were required, three in consecutive weeks in the interval between the sowing and the first cut, one between the first and the second cut, one between the second and third cut and two, in consecutive weeks, between the third and fourth cut.

Although the experiment was conducted in a year with above average rainfall for the period, and some irrigations were performed interleaved way with the rainfall, there was influence of irrigation on the variation

Table 2. Values of leaf area index found for the different irrigation depths applied throughout the forage cycle of the culture.

irrigation depths (%ETo)	Days after sowing (DAS)						
	50*	65*	80*	95*	110*	125*	140*
Without irrigation	2.808	1.482	3.280	1.192	2.768	0.461	1.320
60	3.868	2.369	4.449	1.606	4.292	0.562	1.570
80	4.183	2.526	4.526	1.930	4.465	0.622	1.860
100	4.432	2.647	4.715	2.091	4.684	0.706	2.222
120	4.260	2.544	4.806	2.144	4.783	0.738	2.124
140	4.188	2.334	4.503	2.076	4.562	0.715	2.090

*Significative at 5% of probability by test F.

Table 3. ANOVA for the influence of irrigation depths on LAI of forage sorghum in the DAS.

Days after sowing (DAS)	Sum of square (SQ)	Middle square (MS)	Fc	Pr>Fc
50	6.984900	1.396980	39.712	0.0000*
65	3.611871	0.722374	33.629	0.0000*
80	6.189033	1.237807	33.832	0.0000*
95	2.778033	0.555607	36.367	0.0000*
110	11.227921	2.245584	125.563	0.0000*
125	0.232783	0.046557	16.048	0.0000*
140	14.526950	2.905390	76.330	0.0000*

*Significative at 5% of probability by test F.

of the leaf area index in different depths applied. To determine the treatments were used and adjusted calibrated irrigation water according to Christiansen uniformity coefficient being also 0, 60, 80, 100, 120 and 140% of the reference evapotranspiration (ETo).

In Table 2 is shown the leaf area index found in different water depths applied in different days after sowing (DAS) evaluated in 15 days interval from the first cut. As shown in Table 2, there was great variation in leaf area index for all valuation dates, and between the irrigation depths applied, where, in general, there was an increase in the LAI as the increase of the depth up to a point where excess water caused the decrease of the LAI.

In Table 3 is shown the ANOVA for the influence of irrigation depths on LAI of forage sorghum in the DAS. For the first valuation date, that is, the first cut of culture, held 50 days after sowing, the LAI ranged from 2.808 in non-irrigated plot to 4.432 in water depth of 100% of ETo, as shown in the Figure 4.

The results obtained for the variation of the LAI in the first cut (50 DAS), it is possible to observe as shown in Figure 4, the importance of water for growth and leaf development in the forage sorghum crop, where the lowest value was obtained in non-irrigated plot with 2.808, featuring that there was water stress, and that development was not according to the potential of culture, once that the LAI for the plot with 100% replacement of ETo was 4,432. According to Jaleel et al. (2009), the water stress is responsible for cell growth inhibition, resulting therefore in less LAI, because the plants under water stress undergo changes in various physiological processes such as photosynthesis and respiration, resulting in the lower leaf expansion.

The results found are opposite to those obtained by Marcelino et al. (2003), which analyzed the leaf area index in Tifton 85 culture, cultivated under different water stress in the soil, found no significant statistically difference for the LAI in assessment carried out in the first cut. However, although there was no significant statistical difference, the values found are of increased LAI as increased irrigation to values close to 100% of replenishment, declining soon after, being consistent with those found for the first cut of forage sorghum. On the other hand, the results obtained of increase of the LAI in different depths of water in relation to the non-irrigated treatment are similar to those obtained by Andrade et al. (2005). The authors, in study realized analyzing the growth of grass-elephant "NAPIER" fertilized and irrigated, observed increased leaf area index in the irrigated plot, with an average of 8.27 compared to the average of the non-irrigated treatment 7, 76. According to Müller et al. (2005), those of the LAI increased results with the use of irrigation can be explained by the significant increase in CO_2 assimilation surface and photosynthetic active radiation interception, increasing respiration and increasing the plant’s consumption of the water available.

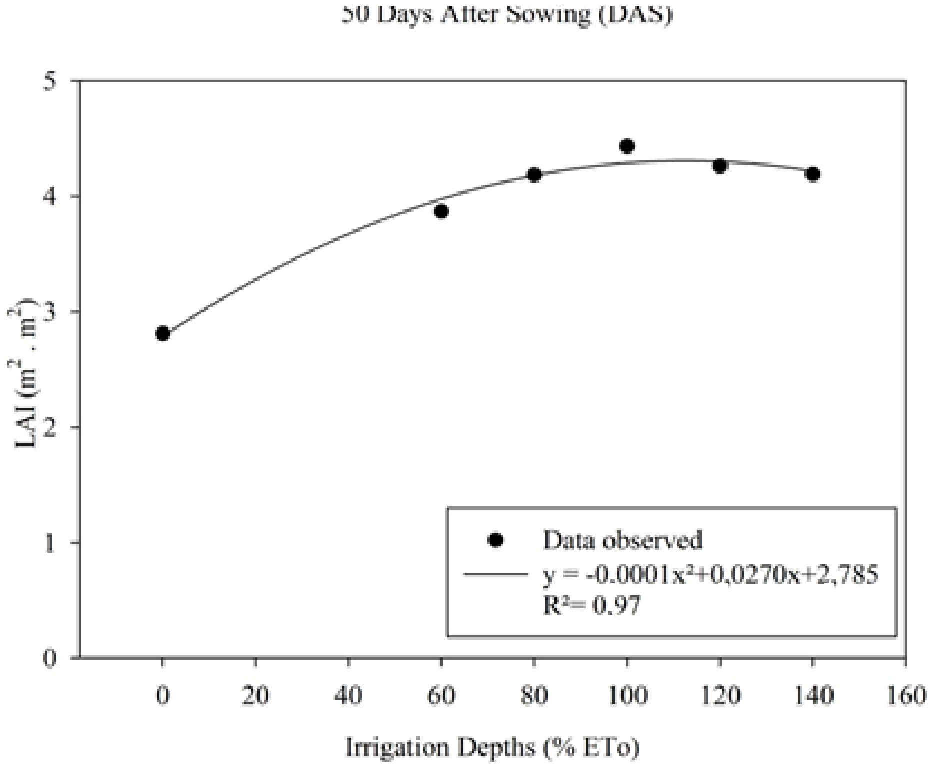

Figure 4. Leaf area index of the forage sorghum culture, at 50 DAS, in the different irrigation depths applied.

Ferraz et al. (2012) highlights that through the greater availability of water, plants increase gas exchange between plant and atmosphere, causing expansion of plant tissues and shoot development. For the evaluation of the LAI in the second cut, two collections were made, the first 15 days after the first cut, or 65 DAS, in order to verify the culture resprouting behavior and the importance of water on the new leaf area index. The second, 30 days after the first cut due to the fact that the recommended period for cutting or grazing entry for the second time for the forage sorghum crop.

The results for the variation of the LAI in different irrigation levels at 65 and 80 DAS are shown in Figure 5. As shown in Figure 5, the influence of the different depths of irrigation applied followed the same trend found in the first cut to 65 DAS and the second cut (80 DAS) with a quadratic response and increased leaf area index with increasing irrigation depth up to a point where the excess water caused a drop in rated parameter. In the evaluation at 65 DAS, or 15 days after the first cut, the leaf area index ranged from 1.482 in non-irrigated plot to 2.647 in the depth of 100% of ETo, thus demonstrating the importance of water to the establishment of new leaf area after the cut, as the case of forage species, the leaves are the main component for animal feed.

For the second cut, performed at 80 DAS, or 30 days after the first cut, the behavior followed the same trend, with adjusted quadratic equation, where the values found ranged from 3.280 in the treatment without irrigation to 4.806 in treatment with replenishment 120% of ETo. It is noted that the second cut was the one that had the largest LAI, the main cutting for the forage sorghum culture. These results are attributed to the period of the year favorable to the growth and development for the forage sorghum culture in State of Rio Grande do Sul optimum after the first cut, as for sowing done in November, the growth period after cutting is in the months of December and January, a period where there are high temperatures and with adequate water supply and photoperiod, supplies the main growth and development needs of the forage sorghum culture.

Corroborate with the results found in the work Zwirtes et al. (2015), that evaluating the morphological characteristics and productivity of sorghum plants submitted to deficit irrigation, achieved increment of 15% in the LAI in treatment 100% of ETc with LAI of 7.96 cm from the treatment of 25% ETc with 6.04 cm, at 60 days after emergence. With these results, it is clear that the change in water depth, variation provided the LAI with increased rate as the increase in irrigation depth. As the results found by Zwirtes et al. (2015), the obtained in this study had an increase in the LAI with the increased level of irrigation, however, due to the standardization of cuts made, the IAF's maximum obtained were below those

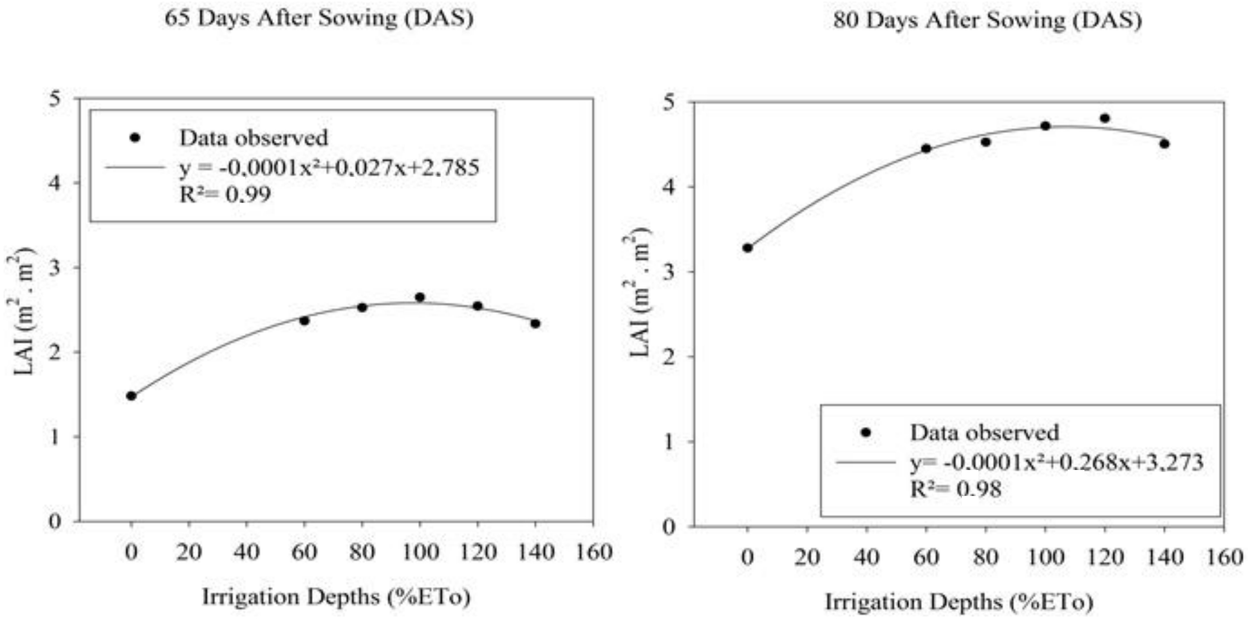

Figure 5. Leaf area index of the forage sorghum culture, at 65 DAS and the second cut (80 DAS) in different irrigation depths applied.

found by the author cited, where the highest levels were found at 80 DAS, with 4.80, at depth 120% of ETo.

Also corroborate Viana et al. (2005), that working with the production of biomass and LAI in forage grasses in irrigated and dry during the dry season, obtained increase in LAI of 25% in the system irrigated compared to non-irrigated for forage species studied, they are the grass Tanzania, Marandú and Pioneer. The authors cited, found rates ranging from 1.52 to 4.16, being close to the minimum obtained at 65 DAS in treatment without irrigation with 1.48, and also to the maximum obtained at 80 DAS in the treatment with 120% of ETo with 4.80.

According to Peiter and Carlesso (1996), the results of reducing the LAI, caused by water stress, is an irreversible fact for the plant. The authors point out that this behavior is the morpho-physiological adaptation of the plant, especially when it occurs during the growth and development of the sorghum crop, causing decreased absorption in interception and photosynthetically active solar radiation.

For the evaluation of the LAI in the third cut, two samples were collected, the first 15 days after the second cut, that is, 95 DAS, in order to verify the crop resprouting behavior and the importance of water on the new index leaf area and the second, 30 days after the second cut due to the fact that the recommended period for cutting or grazing entry for the third time for the forage sorghum crop. The results for the variation of the LAI in different irrigation levels at 95 and 110 DAS are shown in Figure 6.

As seen in Figure 6, the influence of the different depths of applied irrigation followed the same trend found in previous evaluations, adjusted quadratic equation, that is, quadratic, both for 95 and for 110 DAS. For the two evaluations, there was an increase in LAI with increasing water depth up to a point where the excess water caused a drop in rated LAI. For the evaluation carried out at 95 DAS, or 15 days after the second cut, LAI ranged from 1.192 to 2.144 non-irrigated treatment in the treatment with replacement blade 120% ETo.

These results show that with adequate water supply, completion of the third cut period recommended for the forage sorghum crop in the Midwest region of Rio Grande do Sul is possible because the LAI in larger blades kept values close to those obtained in the first resprouting after the first cut (65 DAS).

For the third cut, held at 110 DAS, or thirty days after the second cut, the behavior followed the same trend, with adjusted quadratic equation, where the values found ranged from 2.768 in the treatment without irrigation to 4.783 in treatment with replenishment 120% of ETo. It is noted that the second cut was the one that got the largest LAI, the main cutting for the sorghum crop.

Favarin et al. (2002), points out that the study of variation of leaf area index allows to estimate the variation of the water requirement of culture, being an extremely important tool to define the best management strategy for irrigation. Similarly, the authors state that the variation of water availability is responsible for changes in the LAI and consequently productivity, a fact, checked on the results found.

According to Andrade et al. (2005), the evaluation of growth of forage species makes it possible to identify the characteristics of plants, associated with the adaptations

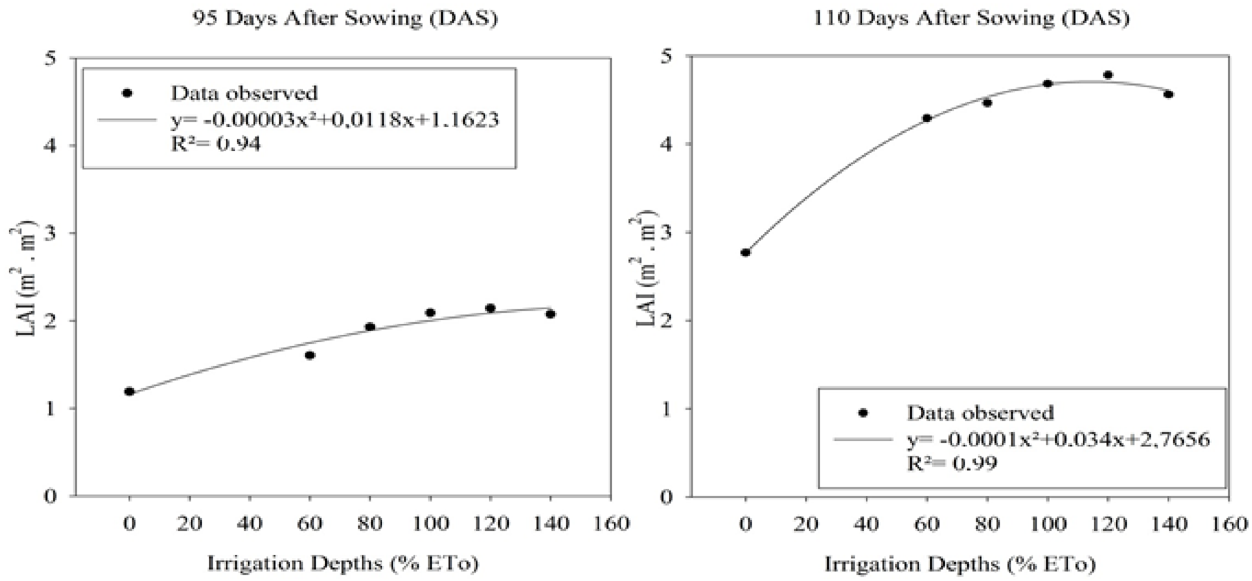

Figure 6. Leaf area index of the forage sorghum culture, at 95 and 110 DAS, in different irrigation depths applied.

to adversities caused by stress, as well as their potential for optimal growth conditions. The results are consistent with those obtained by Fagundes et al. (2006), who observed reduction in grass-braquiária IAF in the period with lower availability of water.

Also corroborate the results, obtained by Coutinho et al. (2015), who observed that the LAI decreased with increasing irrigation interval ranging from 0.1 to 10-day watering part, 1.1 at 2 days irrigation schedule work with the culture Capim -buffel. In contrast, the results obtained by Cunha et al. (2008), working with the relation between the spectral behavior, leaf area index and dry matter production in Tanzania grass under different levels of irrigation and nitrogen doses did not achieve significant results for leaf area index for irrigation depths of 0, 30, 70, 100 and 150% of field capacity, attributing these results the occurrence of heavy rainfall during the experiment.

For the evaluation of the LAI in the fourth cut were two collections, the first 15 days after the third cut, that is, 125 DAS, in order to verify the crop regrowth behavior and the importance of water on the new LAI and the second, 30 days after the third cut due to the fact that the recommended period for cutting or grazing entry for the fourth time for the forage sorghum culture. The results for the variation of the LAI in different irrigation levels at 125 and 140 DAS are shown in Figure 7. As seen in Figure 7, the influence of the different depths of irrigation applied followed the same trend found in previous evaluations, adjusted quadratic equation, or quadratic, for both the 125 and 140 DAS. For the two evaluations, there was an increase in LAI with increasing water depth up to a point where the excess water caused a drop in the LAI.

It should be noted that in all evaluation dates made the fourth cut was where we found the lowest LAI amounts. This behavior is due to the fact that the period of growth and development of regrowth after the previous cut, match the decline in temperatures in the state of Rio Grande do Sul, and because sorghum is extremely sensitive to low temperatures, the LAI was smaller than the other evaluation periods.

According to Diniz (2010), sorghum has high capacity in average temperatures over 21°C, and the productive aspects severely hurt by lower average temperatures, a fact which was verified in this study. Some authors point out that although the entire climate complex exercise influence on the growth and development of plants, the temperature is the dominant factor (Berlato and Sutili, 1976; Berlato et al., 1984).

For the evaluation conducted at 125 DAS, or 15 days after the third cutting, ranged from 0.461 LAI without irrigation treatment at 0.738 in treatment with replenishing depth of 120% ETo. These results demonstrate that with proper water supply, there is variation in the LAI, however, yields found are low compared to other sprouts after the previous cuts. For the fourth court, held to 140 DAS, or thirty days after the third cut, the behavior followed the same trend of previous cuts.

The equation was adjusted quadratic where LAI values found ranged from 1.320 in the treatment without irrigation to 2.124 in treatment with replenishment of 120% of ETo. It is noted that the LAI values found for the fourth court were much lower compared to previous cuts. The highest LAI found in the blade replacement of 120% of ETo, or 2.124 in the fourth cut is less than half of the observed value for the second cut, the most productive, the depth of 100% ETo or 806.

The factor responsible for this decrease is the drop in

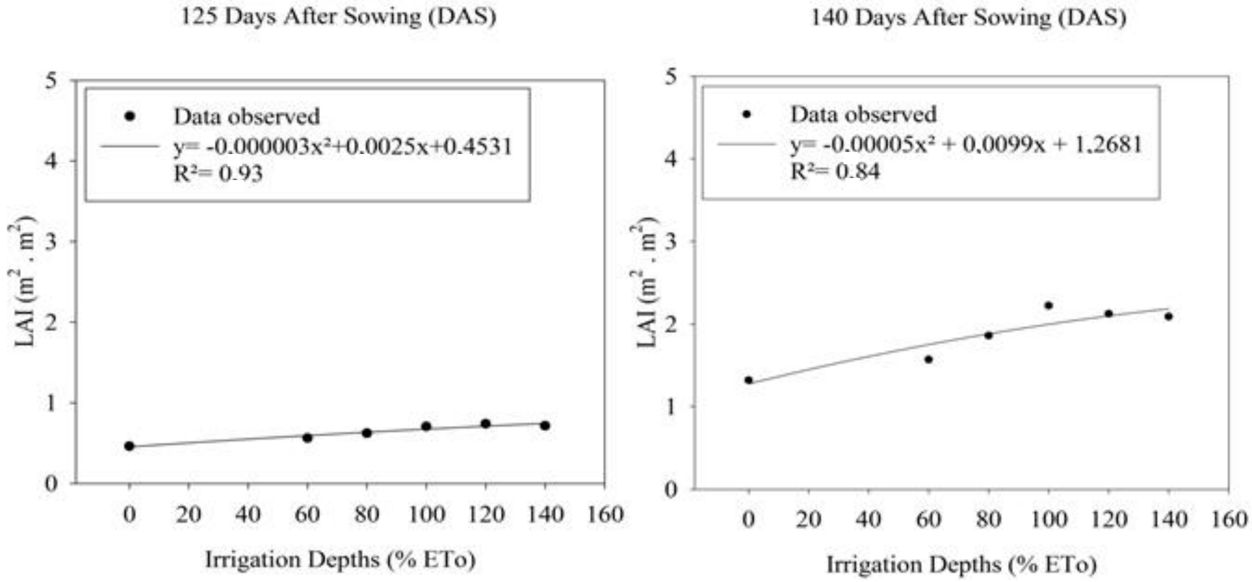

Figure 7. Leaf area index of the forage sorghum culture, at 125 and 140 DAS, in different irrigation depths applied.

temperatures in April in the state, that limit the growth and development of culture, making it impossible for producers in the region due to costs and the small return, forage sorghum cultivation is recommended only until the third cutting for the region.

The results are opposite to those obtained by Marcelino et al. (2003), which analyzed the leaf area index in Tifton 85 culture, grown under different water stress in the soil, found no statistically significant difference for the LAI evaluation performed on the fourth cutting. However, although there was no statistical difference, the values found are of increase of the LAI as increased irrigation to values close to 100% of replacement, declining soon after, being consistent with those reported for the fourth cutting of forage sorghum.

Regarding the total dry mass production found due to different levels of irrigation in the sum of the four cuts the same is represented in Figure 8. From the results seen in Figure 8, it was possible to see the effect of different irrigation levels on increasing the amount of total dry matter produced in the sum of the accumulations of the four cuts made.

Thus, it was observed that the total productivity of the sum of the four cuts maintained the same trend obtained in the individual analysis of the cuts, where the highest yields were found in depths with higher levels of irrigation, which were in the one of 140 % of the ETo with 13,690 kg.ha^{-1} and then the one of 120% with 13,058 kg.ha^{-1}. The variation between the irrigation level yields with higher means, that is, replacement of 140% of ETo and the non-irrigated level was 80.36%.

And according to the recommendations by Atlântica seeds, producer of the seeds used, yields can be up to 100% higher when using irrigation in connection with flooded farming agriculture systems. However, the results of increase found in the production of irrigation levels with higher productivity compared to the non-irrigated one are attributed to the year of the work, which presented high total precipitation and only seven irrigations were necessary throughout the period. And in years with lower precipitation it is possible to find better results for the use of sorghum irrigation.

Vale and Azevedo (2013), evaluating the productivity and quality of elephant grass (*Pennisetum purpureum*) and sorghum irrigated with desalinated ground water and waste, have obtained a productivity of 14,500 kg.ha^{-1} of dry matter in treatments irrigated with groundwater, while in this study the highest total production of dry matter in the sum of the production of the four cuts made was in the level of 140% of the ETo with 13,680 kg.ha^{-1}, that is, close to what the authors found.

Another work which corroborates the results obtained is the one by Zwirtes et al. (2015), who, in evaluating morphological and physiological characteristics and productivity of sorghum plants submitted to deficit irrigation, have found higher dry matter yield in the level of 100% of the ETo with 13,785 kg.ha^{-1}, being close to the 13,680 kg.ha^{-1} found in the level of 140% of the ETo.

Skonieski et al. (2010) also contribute, when working with double purpose sorghum, in finding dry matter production of 13,006 kg.ha^{-1}, while for sorghum they obtained a productivity of 17,527 kg.ha^{-1}. Cunha et al. (2010), evaluating the dry matter production in 23 genotypes of sorghum, have obtained an average of 15,703 kg.ha^{-1} of dry matter production, with productivity of the genotypes ranging from 13,467 to 26,100 kg.ha^{-1}, and the average productivity close to the maximum found in this study which was 13,680 kg.ha^{-1} in the level of

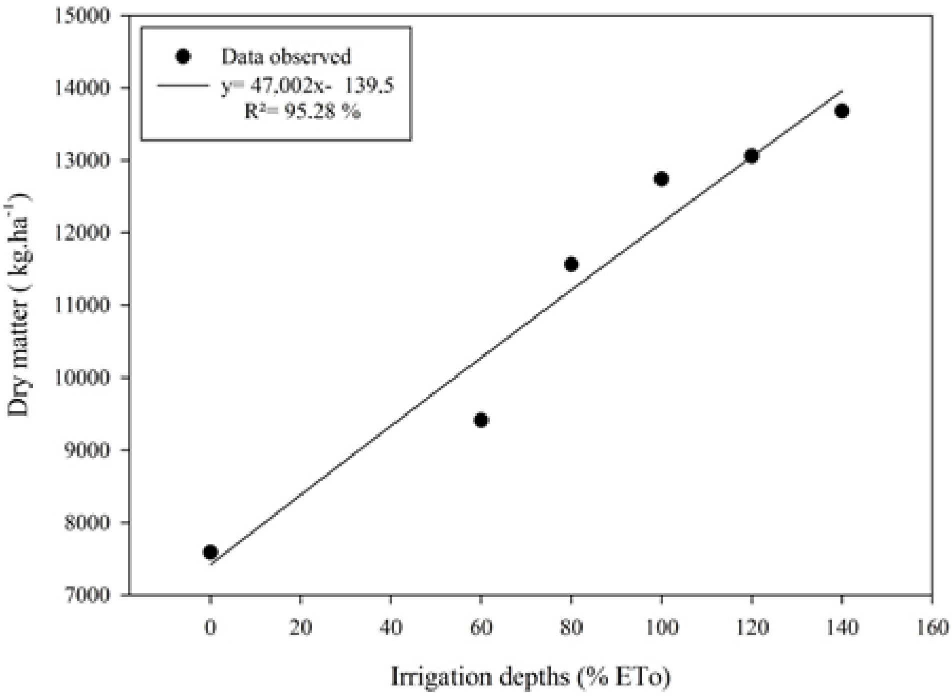

Figure 8. Total dry matter in different irrigation depths in the sum of the four cuts made.

140%.

Tabosa et al. (2002) also contribute for the results found in the study in an experiment with sorghum cultivars in different agroecological environments. They have obtained varied yields of dry matter in water stress conditions, with an average production of dry matter ranging from 3,320 to 15,860 kg.ha^{-1} for cultivar 02-03-01 and 2,820 to 20,130 kg.ha^{-1} for SF-25, grown in five different locations in the Brazilian state of Pernambuco.

As for Silva et al. (2005), in a study on the adaptability and stability of forage sorghum cultivars at different times of the year, have found a yield ranging from 9,423 to 13,426 kg.ha^{-1}. As for Oliveira et al. (2005), working on the agronomic characteristics of sorghum cultivars, have found yields ranging between 14,220 and 16,380 kg.ha^{-1}, with an average of 15,170 kg.ha^{-1}.

Regarding the increase in production caused by the different irrigation levels tested in relation to the non-irrigated portion, several studies show increased production results with increasing irrigation level use. Melo (2006), also working with sorghum, has obtained 57.9% production increase by irrigation with an irrigation level of 100% of field capacity in relation to the level of 25%, whereas in the present study the increase of the level of 100% of the ETo in relation to the non-irrigated one was 67.87%, with an increase of 5,184.3 kg.ha^{-1}, and, for these authors, these results are due to an adequate water supply in time of need.

Therefore, the results found by the different authors and mentioned show that the results obtained in this study are close to the studies carried out with the crop. They vary within the different irrigation levels and the productivities found within the time ranges reported in the literature. Statistically significant differences are found for the effect of irrigation levels on the yields found.

The results found for the variation of dry matter production per hectare in the different irrigation levels over the four cuts in forage sorghum crop show the importance of water for the plant metabolism. The dry matter production increase per hectare in all evaluations carried out in the study may be explained due to the occurrence of certain factors.

For Pimentel et al. (2016), for proper growth and development of forage species, the correct water supply is one of the essential factors for the growth and development of leaves and stalks. With the correct water availability there is an increase in the exchanges between the environment and the plant, increasing photosynthesis and thus the growth of plants, a fact that can be observed in this study with the results obtained from the production increase in higher irrigation levels.

Bergamaschi et al. (2004), working with corn crops, have attributed the occurrence of water deficit to a reduction in the dry matter production. According to the authors, the damage caused by water deficit within the plants is higher than perspiration, suggesting that in addition to the direct effect of stomatal resistance to gas diffusion, photosynthesis is also affected by the increase in leaf temperature due to the stomatal closure. Also, leaf expansion is also reduced (Lopes et al., 1986) and this process is more sensitive than the stomatal movements and photosynthesis, affecting cell growth and being considered one of the most sensitive processes to water deficit, with the cell division and expansion directly inhibited by water stress, a fact which may have led to growth restriction (Sausen, 2007).

Bengough et al. (2006) and Nascimento (2008) highlight that water stress can be characterized as an adverse condition which inhibits normal functioning and the well-being of biological systems. According to these authors, when undergoing stress, plants receive a series of signals in their receptor cells that trigger responses in an attempt to maintain production. The effect of changes caused or imposed to plants depends on the ability to adapt to this new condition. However, damage usually occurs on productivity (Silva et al., 2012), a fact seen in the levels with lower water replenishment for the four stages of evaluation of this work.

The results of the work can still be explained by the stoppage of the growth and expansion of plants submitted to lower irrigation levels than necessary, together with high temperatures by the plant development period. Ferraz et al. (2012) point out that through the greater availability of water, plants increase gas exchange between plant and atmosphere, causing expansion of plant tissues and shoot development, especially leaves, which are essential when it comes to pasture dry matter.

According to Pimentel et al. (2016), another factor that could explain the results is the change in soil moisture which, when insufficient, entails a conflict between water conservation by the plant and CO^2 assimilation rate for carbohydrate production. In prolonged periods of water stress, even the most adapted plants undergo the consequences of this stress, resulting in lower growth, and consequently lower dry matter yield per hectare for forage species.

Chaves et al. (2003) also contribute to the results found in the work, relating the growth, development and forage productivity of plants, maintaining the hydration of the cells, as this would be maintaining the metabolic activities of the tissue and the integrity of cellular structures, a fact that is severely compromised in times of insufficient water availability. Another fact that may explain the lower production of dry matter in the portions with less replacement than necessary is abortion and death of leaves in forage species (Araya et al., 2011; Valle et al., 2009).

Santos et al. (2013) have found that in water stress conditions there was an increase in dead material in leaves of *B. brizantha cv. Marandu* and consequently decrease in total leaf area and dry matter productivity as mechanisms used to reduce water consumption and balance their water relations in conditions of water stress.

Mahajan and Tuteja (2005) characterize the dry matter decreased productivity per hectare of species when submitted to water stress not only to photosynthesis limiting intracellular CO^2, but also the cellular damage to the photosynthetic apparatus due to accumulation of reactive oxygen species. This takes place due to the decline of CO^2 in the cells, resulting in a marked reduction of components within the electron transport chain that transfer electrons of Photosystem I to oxygen, generating their reactive species, harmful to cells, thus causing stoppage of plant growth.

According to Lawlor (1995), the results found in this study can be explained by the decrease in photosynthetic rate caused by the drought in the levels with lower water replenishment through irrigation. The possible reasons for this decrease in photosynthetic rates when plants are submitted to drought stem from the limited diffusion of CO^2 into the intercellular spaces of the leaf as a result of stomatal reduction and impaired metabolism due to direct inhibition of biochemical processes by loss of water in cells.

Farooq et al. (2009) also relate the decreased productivity of forage species when submitted to water stress to the fact that the plant extracts water from the soil only when the water potential of its roots is more negative than that of the soil solution and the absorption rate is higher as the absorption surface of the root system is greater. The water potential gradient across the soil-plant-atmosphere system constitutes the driving force to transport water through the plant and this relationship is compromised and the root system supply to the shoots is hindered under water stress conditions.

Conclusions

The use of irrigation exerted great influence on the variation of the leaf area index in all evaluation dates performed. All evaluations showed quadratic behavior, which, with increasing applied irrigation depth, an increase of LAI to some extent, where the excess water caused drop in LAI.

The 100 and 120% of ETo water depths were those that provided the best results, characterizing the crop response to water increase provided through irrigation.

The Sorghum crop presented high LAI when irrigated, characterizing the irrigation of forage Sorghum as an alternative to the farmers and ranchers of the Central-West region of Rio Grande do Sul-Brazil.

The irrigation sprinkler is presented as an alternative for producers in the Midwest region of Rio Grande do Sul, since its use has provided high LAI In cultivated pastures increase compared to non-irrigated plot.

The LAI values found indicate that for sowings in November in the state of Rio Grande do Sul, indicate that it is possible to perform three times cutting or grazing of forage sorghum, because after, the occurrence of lower average temperatures there are prejudices of LAI and hence of crop productivity.

There was a great increase of dry mass production in the plots with larger irrigation slides, characterizing that the larger leaf area indices found resulted in higher yields.

Conflict of interest

The authors have not declared any conflict of interest.

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