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Cutting management modifies the phyllochron, the growth and the production of forage sorghum under the cool environment

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SUMMARY

Our hypothesis is that forage sorghum modifies its growth and phyllochron when submitted to different cutting managements. Our objective is to evaluate if different cutting managements modify the growth and phyllochron of forage sorghum. A field experiment subjected the forage sorghum to different cutting managements: uncut, 1 cut, 2 cuts, 3 cuts and 4 cuts. Were evaluated the meteorological conditions during the cycle of the crop, the rates of crop growth, the distribution of the photoassimilates and the phyllochron. The temperature influenced the growth and development of the culture. The photoassimilates were allocated according to the need of the culture, determined by their stage of development. Plants that have not been cut tended, in general, to reduce rates over time, due to the physiological development. While the plants that were cut, had their cycle prolonged, by the regrowth, and some rates were diminished after each cut, by the removal of the vegetal material, as for example, the absolute growth rate, the net assimilation rate, the leaf area ratio and leaf weight ratio. An increase of the phyllochron was observed, with the increase of the number of cuts.

ADDITIONAL KEYWORDS

Dry matter.
Sorghum bicolor.
Thermal sum.
Phenology.
C4 plant.

O manejo de cortes modifica o filocrono, o crescimento e a produção do sorgo forrageiro sob ambiente de temperatura amena

RESUMO

Nossa hipótese é que o sorgo forrageiro modifica seu crescimento e filocrono quando é submetido a diferentes manejos de corte. Nosso objetivo é avaliar se diferentes manejos de corte modificam o crescimento e filocrono do sorgo forrageiro. Um experimento de campo foi conduzido e submeteu o sorgo forrageiro a diferentes manejos de corte: sem corte, 1 corte, 2 cortes, 3 cortes e 4 cortes. Foram avaliadas as condições ambientais durante o ciclo da cultura, as taxas de crescimento da cultura, a distribuição dos fotoassimilados e o filocrono. A temperatura influenciou o crescimento e o desenvolvimento da cultura. Os fotoassimilados foram alocados de acordo com a necessidade da cultura, determinada pelo seu estádio de desenvolvimento. Plantas que não sofreram cortes tenderam, em geral, reduzir as taxas ao longo do tempo, devido ao desenvolvimento fisiológico. Enquanto que as plantas que foram cortadas, tiveram seu ciclo prolongado, pelo rebrote, e algumas taxas diminuíram após cada corte, pela remoção do material vegetal, como por exemplo, a taxa de crescimento absoluto, a taxa de assimilação líquida, a razão de área foliar e a razão de peso foliar. Aumentos no filocrono foram observados com o aumento no número de cortes.

PALAVRAS CHAVE ADICIONAIS

Matéria seca.
Sorghum bicolor.
Soma térmica.
Fenologia.
Planta C4.

INFORMATION

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INTRODUCTION

It is important to quantify crop production, and to know the contribution of different organs to plant growth. For this, growth analysis is used, which details the morphophysiological changes of the plant over time and its accumulation of dry matter by photosynthetic production (Concenço et al. 2011).

Forage sorghum (*Sorghum bicolor* (L.) Moench) is a fast growing C4 plant (Gomes et al. 2014). It is emerging as an alternative to animal feed, adapting even to semi-arid regions (Akinseye et al. 2017; Silva et al.

2017). Sorghum is a culture sensitive to low-temperature stress (Maulana and Tesso, 2013).

Temperature is one factor that influence growth and forage yield of sorghum (Abbas 2012), even as other agronomic factor like soil type and availability of wáter (Getachew et al. 2016). The responses of sorghum to low temperature, relation to growth and yield depend on factors, like duration of exposure, stage of development and termal adaptation of the cultivar (Getachew et al. 2016).

The study of Ortiz et al. (2017) shows that different lines of sorghum have variation in photosynthetic response to cold stress. Events of cold can reduce growth, biomass production and yield of sorghum (Maulana and Tesso 2013). This negative influence by low temperature must be in function of sensitivity of C4 plants, where photosynthetic apparatus is affected (Fiedler et al. 2014). Carbon assimilation is also limited by reduced rubisco activity in temperatures below 20°C (Kubien et al. 2003).

The adaptation, recommendation and management of a crop were evaluated by phenology (Chimonyo et al. 2016; Chaves et al. 2017) through the phyllochron. By modifying the management of plants, one may be changing the phyllochron. A management practice used in the sorghum crop is the cut, once the plants have regrowth capacity after the removal of the leaf area, enabling new production without the need for new crop implantation (Foloni et al. 2008).

The management of cuts is considered a stress for the plants, once their leaf area is removed, leading to loss of photosynthetic capacity. Despite the reduction of growth rates, the leaf area is renewed and the physiological processes are intensified for the recovery of the plant. Know the behavior of plants against this type of situation becomes relevant, as well as evaluating morphology, organ recovery and translocation of assimilates. This management can change the development of the plant, modifing the vegetative period to the reprodutive, which depends of the sensitivity of the photoperiod (Alagarswamy et al. 1998). Genotypes photoperiod-sensitive requires a minimum day lenght to flowering (Packer and Rooney 2014). If the environment is caracterized by longer photoperiods and cooler temperatures, then the flowering was delayed (Craufurd et al. 1998), factor that either depends on the daily variation in sunrise and sunset hours (Clerget et al. 2012).

Our hypothesis is that forage sorghum modifies its growth and phyllochron when submitted to different cutting managements. Our objective was to evaluate if different cutting managements modify the growth and phyllochron of forage sorghum.

MATERIAL AND METHODS

The experiment was conducted in the 2014/2015 field crop, in the experimental area of the Agroclimatology Laboratory linked to the Federal University of Santa Maria, Frederico Westphalen Campus at coordinates 27º23'48''S, 53º25'45''O and altitude of 490 m. According to the climatic classification of Köppen, the climate of the region is Cfa, subtropical humid with hot summer (Alvares et al. 2013).

The soil of the experimental area is classified as a typical dystrophic red latosol, a clayey, deep and well drained texture (Streck et al. 2008a). The fertilization was carried out based on the soil analysis and recommendation of the fertilization and liming manual of the Soil Chemistry and Fertility Commission RS / SC (2004).

The experimental design was a randomized block design, characterized by a factorial scheme, from uncut to 4 cuts. Each treatment contained 4 replicates, with dimensions of 7.5 m in length, 6 m in width, and spacing between 0.7 m lines (Neumann et al. 2008), thus composing 8 lines in each experimental unit.

The sowing was done manually on January 5, 2015, at 5 cm depth. The final population of plants was 150,000 plants ha^{-1} of the hybrid AG2501-C, considered to be super-precocious cycle. After the emergence of the crop, plants were sampled in order to obtain the dry matter. Each sample occured every 2 weeks. The first sample was made on January 22, 2015 and the last one on August 21, 2015, where the dry matter (after drying in an oven with air circulation at 60°C, until constant mass) was estimated. The samples were carried out throughout the entire productive cycle of the crop, which varied from 130 to 215 days, considering the cuts made.

The cutting of the plants was carried out 15-20 cm from the soil, with a manual brushcutter, simulating the grazing, where the cut material was removed from the site. The first cut was performed 44 days after sowing (DAS), the second 72 DAS and 23 days after regrowth, the third 102 DAS and 25 days after regrowth and the last after 40 days of regrowth, and 156 DAS. These cuts occurred according to the recommendation for the crop, after reaching 50 cm in height (Neumann et al. 2010). This is because young plants contain durrina, which turns into hydrocyanic acid in the rumen, making them toxic (Tamele et al. 2009; Simili et al. 2013).

During the period of development of the crop, meteorological data were collected at the INMET (National Meteorological Institute) Climatological Station to characterize the growing site. The station is located about 150 m from the study site, under coordinates 27°39'56"S and 53°42'94"W and is linked to the Laboratory of Agroclimatology.

From the data collection, it was possible to calculate the daily thermal sum (STd):

$$STd = (Tmean - Tb).1\ day$$

where: Tmean = mean air temperature, calculated by the average of the 24 instantaneous temperature values marked during the day; Tb = culture base temperature, 10°C (Houx and Fritschi 2015).

From the sum of the daily thermal sums, the accumulated thermal sum (Sta) was calculated:

$$STa = \sum STd$$

Thus, phyllochron was obtained by the angular coefficient of linear regression between STa and the number of leaves (NL) of the main stem and tillers. The number of leaves was obtained by counting the fully expanded leaves, separately from the mother plant and tillers, from random plants and performed twice a week.

To evaluate this we have the phyllochron, which consists of the interval between the appearance of 2 consecutive leaves on the main stem, given by °C day $leaf^{-1}$ (Rosa et al. 2009).

The phyllochron relates the number of leaves accumulated by the plant to the thermal sum (Martins et al. 2012). The thermal sum represents the effect of air temperature on crop development and is given in °C day^{-1} (Rosa et al. 2009).

Growth analysis was performed according to the methodology proposed by Benincasa (2003); Barbero et al. (2013). Were measured:

Biological Productivity – BP = $\frac{DM}{SA}$

where DM is the dry matter, in grams, and SA is the soil area occupied by the plant, in m^2

Absolute Growth Rate – AGR = $\frac{DM2-DM1}{t2-t1}$

where DM1 and DM2 are the dry matter of two successive samples, in grams, and t1 and t2 the time of each simple, in days.

Relative Growth Rate – RGR = $\frac{ln DM2 - ln DM1}{t2-t1}$

where *ln* is the natural logarithm.

Net Assimilation Rate – NAR = $\frac{DM2-DM1}{t2-t1} * \frac{ln LA2 - ln LA1}{LA2-LA1}$

where LA1 e LA2 is the leaf area of two successive samples.

Specific Foliar Area – SFA = $\frac{LA}{DMleaves}$

Leaf Area Ratio – LAR = $\frac{DM}{LA}$

Foliar Weight Ratio – FWR = $\frac{DM\ leaves}{DM\ accumulated}$

The leaf area was calculated from the disc method using the equation:

LA = $\frac{(number\ of\ discs*leaker\ area)*(DM\ leaves+discs)}{DM\ discs}$

RESULTS AND DISCUSSION

There is a higher proportion of leaves at the beginning of the crop compared to the stems (**Figure 1**), but this ratio reverses with the passage of days. There is a marked reduction of leaf components from the appearance of the panicles, which leads us to an inversion in the translocation of photoassimilates, due to the transition from the vegetative to the reproductive stage. This is in agreement with Streck et al. (2008b), according to which, the photoassimilates are allocated between the different organs of the plant according to the stage of development of the same.

The highest proportion of the components from the tillers was verified in the treatments that were cut, since the cutting of the plant induced the appearance of the tillers. Increased tillering due to cuttings had already been observed in sugarcane (Silva et al. 2008).

In cut treatments, the presence of panicles decreases because the plant invests in the vegetative portion as a way of recovering, presenting difficulties to complete its cycle. In general, from 85 DAS, contributions from the senescent material were more perceptible.

The dry matter increase observed for this crop is related to its growth habit and the characteristic metabolism of this plant, C4. The crop was favored by high temperature weather conditions. This result corroborates with Houx and Fritschi (2015) and Martins et al. (2016).

The appearance of tillers demonstrated in **Figure 1**, probably contributed to increases in dry matter, represented by BP (**Figure 2A**). After 44, 72, 102 e 156 DAS (dates of cuts) is possible to observe these increments. From 85 to 130 DAS the treatment of 1 cut is highlighted, but after 144 DAS the plants with 3 cuts were superior to the others.

This is due to the fact that plants that suffered more cuts have extended their cycle longer. Thus, plants from 1 cut treatment have a 144 days cycle, while plants with 3 cuts have 215 days of development, which allowed them to accumulate more dry matter.

The AGR of sorghum plants (**Figure 2B**) maintained a pattern, decreasing as cuts occurred. Thus, the plants that were uncut had higher rates between 44 and 85 DAS and then decreased due to stabilization of growth and tissue senescence. The plants with 1cut had higher AGR between 102 and 114 DAS, those with 2 cuts between 144 and 156 DAS and those with 3 cuts between 172 and 199 DAS.

This shows a higher speed growth in the earliest stages of plant development, and as the cycle ends, the speed of growth reduce and the rate of growth is reduced either.

The rate growth of a crop is dependent on meteorological elements, radiation and temperature, as well as other factors such as atmospheric CO_2 and plant genetics, that is, its capacity to capture light, convert it into biomass and the assimilated partition in the organs (Zanon et al. 2016). In the present work, besides the mentioned factors, the cut management influenced the growth rate of forage sorghum.

For physiologists, the RGR is usually more accurate since it considers the dry matter that has already been allocated by the plant, the rate being proportional to the size of the plant and its photosynthetic capacity (Lima et al. 2007). Thus, RGR generally tends to reduce at the end of the cycle, because according to Benincasa (2003), as the dry matter increases, photosynthesis increases and thus the greater need to maintain the structures formed.

However, because in this work cuts were made during the plant cycle, this continued to produce dry matter, with great part of the leaf area of the plant constituted by young leaves, with high growth rate and high photosynthetic capacity (Aumonde et al.

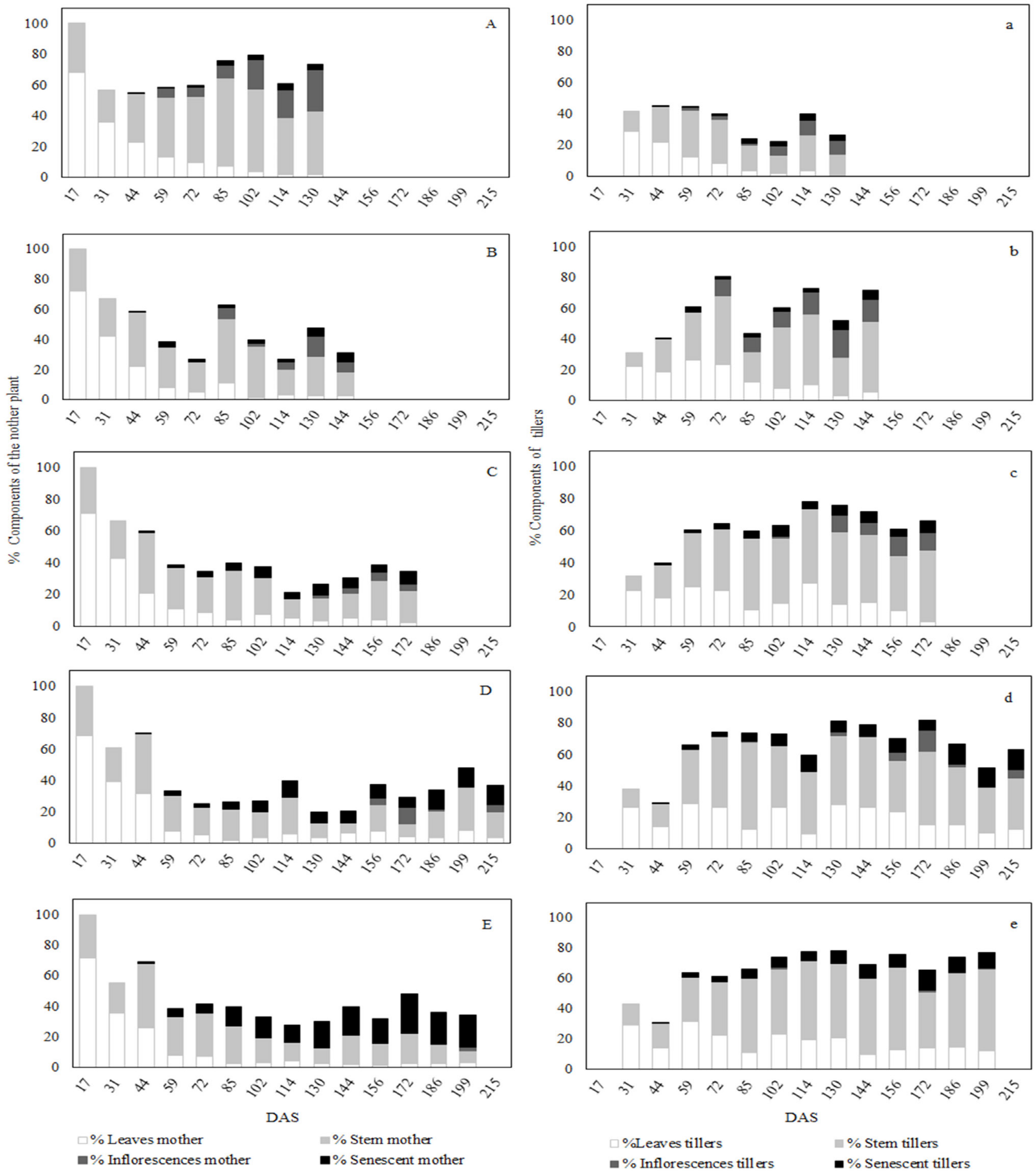

Figure 1. Partition of photoassimilates of forage sorghum submitted to cutting managements. Capital letters represent the mother plant and lowercase letters the tillers. (A, a) Uncut; (B, b) 1 cut; (C, c) 2 cuts; (D, d) 3 cuts; (E, e) 4 cuts (Partição de fotoassimilados de sorgo forrageiro submetidos a manejo de corte. As letras maiúsculas representam a planta-mãe e letras minúsculas os lemes. (A, a) Sem cortes; (B, b) 1 corte; (C, c) 2 cortes; (D, d) 3 cortes; (E, e) 4 cortes).

2013). The behavior of this parameter was similar to that observed by AGR, and the uncut plants reached the highest RGR (**Figure 2C**) between 44 and 114 DAS, plants with 1 cut between 130 and 144 DAS, plants with 2 cuts between 156 and 172 DAS and plants with 3 cuts between 186 and 199 DAS.

The NAR (**Figure 2D**) was higher in the initial stages of growth, between the first 2 samples of the plants, corroborating to Fageria (2007). It shows the increment in the size and efficiency of the assimilator system, demonstrating the photosynthetic efficiency of the leaves in intercepting radiation and thus, produce dry matter. So, NAR demonstrates the assimilatory capacity of the plant, due to the presence of the variable leaf area.

According to Aumonde et al. (2011), NAR does not only depend on the photosynthetic rate, but is determi-

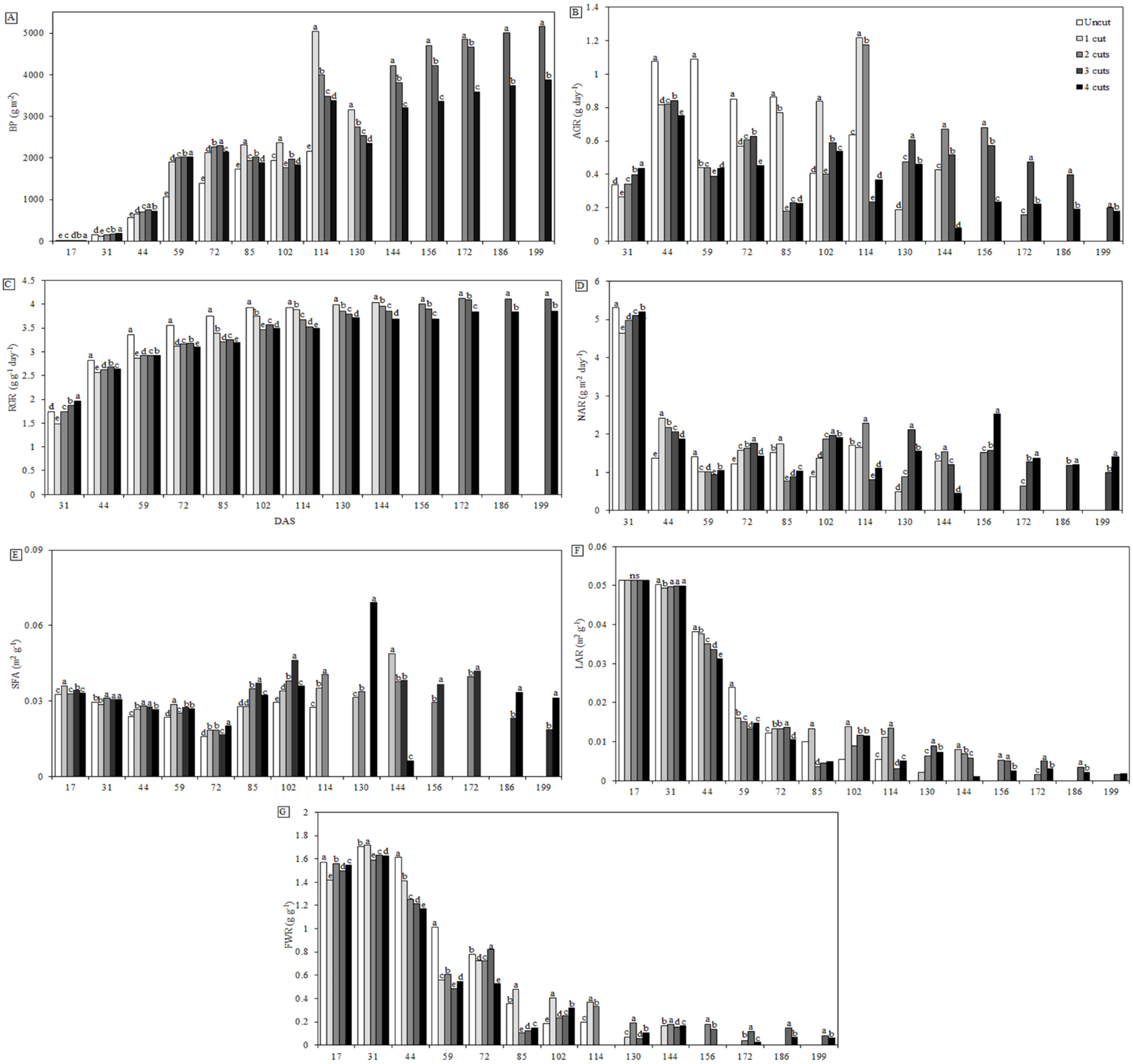

Figure 2. A. Biological Productivity (BP); B. Absolute Growth Rate (AGR); C. Relative Growth Rate (RGR); D. Net Assimilation Rate (NAR); E. Specific Foliar Area (SFA); F. Leaf Area Ratio (LAR); G. Foliar Weight Ratio (FWR) of forage sorghum submitted to uncut, 1 cut, 2 cuts, 3 cuts and 4 cuts (A. Produtividade Biológica (BP); B. Taxa de Crescimento Absoluto (AGR); C. Taxa de Crescimento Relativo (RGR); D. Taxa de assimilação (NAR); E. Área Foliar Específica (SFA); F. Razão de área foliar (LAR); Razão de peso foliar (FWR) de sorgo sem corte, 1 corte, 2 cortes, 3 cortes e 4 cortes).

ned by other factors such as leaf area dimension, vegetative period duration, leaf distribution in the canopy, leaf angle and translocation and assimilate partition.

As the cutting management alters a large part of these factors cited above, it is possible to infer that the NAR was influenced by the cuts. It was observed that in the first samples, in general, NAR was superior for plants with no or few cuts, however, from 156 DAS the plants with 4 cuts obtained the highest NAR.

SFA remained close to 0.03 m^2g^{-1} (**Figure 2E**) at the beginning of the cycle for all treatments. For the treatments that have been cut, there are increases after the cuts, indicating a greater translocation of photosynthesized to the leaves, necessary for the growth of the plant, because they are responsible for the photosynthesis.

For Alvarez et al. (2012) increases in SFA may be due to some morphological alteration in the leaves, due to leaf expansion. This variable also indicates the accumulation of photoassimilates in the leaves or the translocation to the other organs, that is, indicates differences in leaf thickening (Taiz et al. 2017).

The highest rates of LAR and FWR were found in the first 4-5 samples, decreasing after this (**Figure 2F** and **Figure 2G**). It is observed at the 44 DAS (1st cut) and 59 DAS, that the treatment that did not suffer cuts was superior to the others, because it did not have its leaves removed.

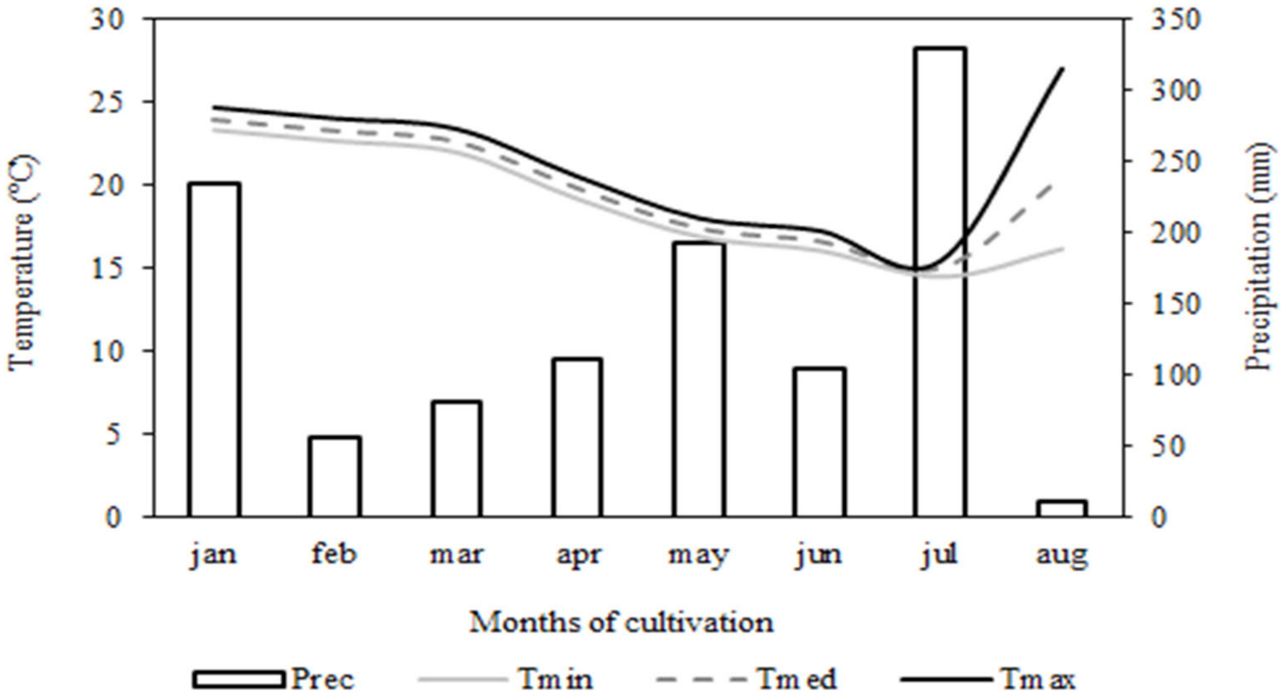

Figure 3. Minimum, medium and maximum temperature (°C) and precipitation (mm) during cycle of forage sorghum (Temperatura mínima, média e máxima (°C) e precipitação (mm) durante o ciclo do sorgo forrageiro).

Already from 72 DAS (2nd cut), who stands out is the treatment of 1 cut, reaching higher LAR, because at this time does not have the influence of cut treatment. From this moment on, plants without cut management have a reduced rate due to the normal physiological development of the crop, the appearance of non-assimilatory tissues and self-shading, with interference of the upper and lower plants (Zuffo et al. 2016).

After the cuts were verified increases, which are justified because the cut represents the loss of leaf area and dry matter, and when regrowth, they return their growth. As was observed at 85 DAS, after the 2nd cut (72 DAS) the rate decreased in plants that were cut due to loss of leaf area and increased again by regrowth until 102 DAS, time of the 3rd cut. After this, higher rates were observed for the treatment plants of uncut, 1 and 2 cuts, and lower for 3 and 4 cuts, which had their leaf area removed.

FWR had similar behavior with LAR (**Figure 2G**), and represents that as the plant grows, it stops investing so much in the leaves and reduces the photosynthetic area useful for export to the other drains. These results corroborate with Zuffo et al. (2016); Martins et al. (2016). As mentioned above, the plants of the uncut treatment also had its FWR diminished and the other treatments increased this rate after each cut, with the development of the new leaves.

During the cycle of forage sorghum an irregular distribution of rainfall is observed, with months of high and low rainfall (**Figure 3**). It can be observed that the period from February to April had below average rainfall, which may have negatively affected biological productivity.

The temperature had a greater influence on the growth, since the culture is originated in tropical regions and cultivated in hot seasons and characterized by not tolerating low temperatures. The temperature drop was more pronounced in the months of June and July, which coincided with the greater difficulty of regrowth and growth for treatments with 3 and 4 cuts. This negative influence by low temperature according to Fiedler et al. (2014), can be in function of sensitivity of C4 plants.

As a consequence, there is a need for the culture to accumulate a greater amount of degree-day during this period of low temperatures, which resulted in increased cycle and higher phyllochron values (**Figure 4**). In contrast, it can be observed that the mean temperature was higher than the base temperature of the crop during the whole growing period, which means that the crop accumulated thermal time during this period, corroborating with Chaves et al. (2017) when working with oats.

The high linear relationship between the number of accumulated leaves and the accumulated thermal sum indicates that the leaf emission of the crop is influenced by temperature. The average phyllochron accumulated by the plants during their cycle were: 33.03°C day $leaf^{-1}$ for the uncut; 67.98°C day $leaf^{-1}$ for 1 cut treatment; 86.26°C day $leaf^{-1}$ for 2 cuts; 118.68 and 104.67°C day $leaf^{-1}$, respectively for 3 and 4 cuts.

This demonstrates the different thermal energy accumulation needs (°C day) for the emission of forage sorghum leaves in front of the different cutting managements. As the temperature decreases at the end of the cycle of treatments with 3 and 4 cuts, these plants needed more calendar days for the emission of a leaf,

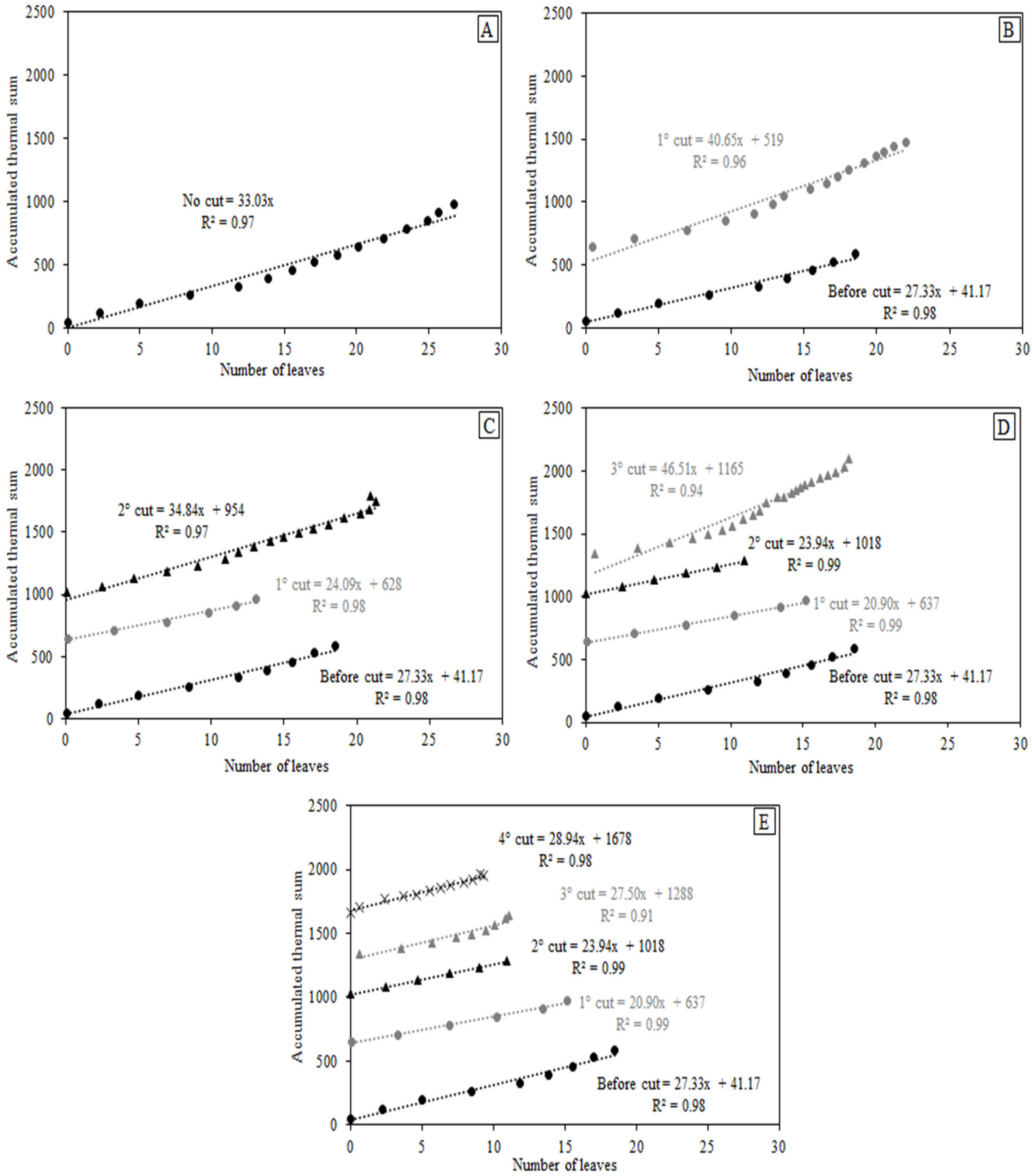

Figure 4. Phyllochron of forage sorghum with cutting managements: (A) Without cutting; (B) 1 cut; (C) 2 cuts; (D) 3 cuts; (E) 4 cuts (Filocrono de sorgo forrageiro com manejo de corte: (A) Sem corte; (B) 1 corte; (C) 2 cortes; (D) 3 cortes; (E) 4 cortes).

prolonging its cycle. In addition to the lower temperature values, the stress caused by the cuts may have impaired the growth of these plants.

The R^2 values observed in these estimates are considered high and this confirms that the linearity between the number of leaves and the accumulated thermal sum is used with precision, demonstrating that the method used was adequate to estimate the phyllochron.

CONCLUSIONS

High R^2 values observed confirms the precision used in linearity between the number of leaves and the accumulated thermal sum, demonstrating that the method used was adequate to estimate the phyllochron of forage sorghum plants, which enhanced with number of cuts increase, ranging from 33.44 to 118.68°C day leaf^{-1} for the uncut and 3 cuts plants, respectively. The growth, phyllocron and forage biomass of forage sorghum were affected under the cool environment. Cutting managements also modified the growth rates of forage sorghum plants, being possible recommend their use for grazing or green forage for up to 3 cuts.

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