Full Length Research Paper

Growth and senescence of *Urochloa brizantha* under Brazilian Cerrado conditions

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The growth and senescence of *Urochloa brizantha* cv. Marandu were analyzed under the Brazilian Cerrado conditions. The seeds were sowed in November at the beginning of the rainy season. Samples of tillers were collected. The culms, inflorescences, along with green and dead leaves were removed to obtain leaf area and dry matter measurements. The maximum leaf area index (LAI = 5.80 m^2 m^{-2}) was achieved at 97 days after emergence (DAE), the maximum above ground total dry matter (TDM = 22.8 Mg ha^{-1}) at 151 days, and the maximum crop growth rate (CGR = 0.260 Mg ha^{-1}) at 70 days. Leaf senescence began at 55 DAE, with less than 0.001 Mg ha^{-1} of dead leaves dry matter (DLDM), and reached 1.753 Mg ha^{-1} at 151 DAE. Between 117 and 151 DAE, in the final cycle of the plants, there was lodging of the canopy by wind. This lodging had favored the sprouting of new tillers and a sudden increase in net assimilation rate (NAR). The LAI values did not show such expressive increase during the same period, suggesting that NAR may contribute to crop growth more than LAI due to increased light penetration after the occurrence of the lodging. In this paper an equation that estimates the net photosynthetic rate from the net assimilatory rate was presented.

Key words: Leaf area, dry matter, growth rate, net assimilation rate, pasture grass.

INTRODUCTION

The Cerrado is the second largest biome available for food and fiber production in Brazil, after the Amazon rainforest, covering an area of approximately 200 million hectare, about 23% of the Brazilian territory. The climate in this region has two well-defined seasons, a dry season (from April to September), with virtually no precipitation, and a rainy season, (from October to March). The soils are generally acidic, rich in aluminum and poor in nutrients and organic matter (Goedert et al., 1980; Fageria and Barbosa Filho, 2008). The vegetation

includes a heterogeneous mix of grassland, bushes, and twisted trees, characteristic of the region (Ribeiro et al., 1983; Gottsberger and Silberbauer-Gottsberger, 2006). In the Cerrado, predominantly located in the mid-western region of Brazil, the cultivated pastures cover about 50 million hectare. *Urochloa* sp. is a grass species that presents an exceptional adaptation to the edaphoclimatic conditions of this biome (Valle et al., 2000; Costa et al., 2016).

Urochloa grass (*Urochloa* sp.) is a species introduced from Africa that has expanded throughout Brazil, especially in the Cerrado region. *Urochloa* grass has enabled the use of vast areas of pastures, making possible the expansion of cattle and contributing to making Brazil a large producer and exporter of meat (ABIEC, 2014; Guard and Guard, 2014). The grass growth is rapid during the rainy season, but gradually decreasing in the dry season. Ultimately, water limitation paralyzes the plant growth inducing the death of the aerial parts, resulting in great herd weight loss, and consequently, economic loss to the producer.

Although *Urochloa* occupies wide areas of cultivated pastures in Brazil, scientific studies on this species have not been carried out systematically. Besides being used as cattle food, the residues of grass promote soil amelioration due to their higher content of lignin. The input of lignin increases the level of carboxylic and humic acids in the substrate and favors the structure and stability of soil aggregates (Primavesi, 1982; Fassbender and Bornemisza, 1994; Oliveira et al., 2015; DiDonato et al., 2016). Besides, the increase in lignin content turns the soil less susceptible to compaction and erosion (Stone et al., 2004), and improves the microbiological soil conditions, such as higher mycorrhizal fungi (Soares et al., 2010).

Among the issues that deserve attention and further studies lies the follow-up of *Urochloa* growth in the Cerrado environment, as well as its senescence and residue production. The technique of growth analysis is employed to follow up plant growth, and, for higher plants, is based on the conversion of light energy into chemical energy, because an average of ca. 96% of the dry matter accumulated by plants during their growth period results from photosynthesis (Hunt, 1990; Walker, 1992). Nevertheless, in most studies focusing on plant growth analysis researchers do not calculate the crop senescence rate (CSR). However, information on CSR is important because it allows crop physiologists and agronomists to create patterns for each type of culture, thus guiding the producer in order to predict the duration of each growth phase and therefore maximizing yield. Also, this helps estimate the production of *Urochloa* residue at the end of its life cycle, the contribution of this biomass residue production to soil amelioration, and the quantity of carbon accumulated in the residue.

The plant growth analysis, although a classic technique

(Blackman, 1919) is still very useful in determining the partitions of photosynthates among the various plant organs, providing subsidy for those working on grain or forage production by helping in the selection of the best genotypes. Additionally, the plant growth analysis requires few instrumental resources, therefore being a low-cost technique, a very appropriate tool for researchers based on developing countries.

Depending on the planting system, it might be desirable to have a faster or a slower development pace of the plants at a specific time. For instance, this is what happens in pasture recuperation/renewal systems intercropped with annual crops (that is, crop-grass mixture, locally known as Barreirão System). In this system, from the beginning of the annual crop's development until harvest it is desirable that they face the least grass competition as possible. From this point on, the grass should have a good development so that the cattle can start grazing in a short time (Oliveira et al., 1996; Portes et al., 2000). Besides, Avci and Bilir (2013) reported that there could be many genetical and environmental factors on plant growth. They reported large morphological variation among and within clones of *Lavandula hybrida* and *L. officinalis*.

The aim of this study was to quantify, using the technique of growth analysis, *Urochloa brizantha* cv. Marandu growth, a C4 species, under Brazilian Cerrado conditions, as well as its senescence during the growth cycle.
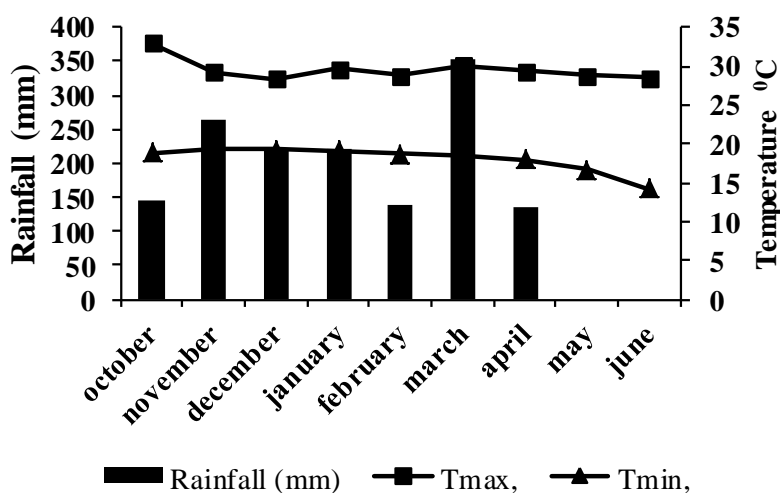
MATERIALS AND METHODS

A field experiment was conducted in a degraded pasture area planted with *Urochloa decumbens* at the Federal University of Goias in Goiania (16°41'S and 49°17' W, 730 m altitude). The chemical characteristics of the soil before the experiment were: Organic matter - 23 g dm^{-3}; pH 5.2 Mehlich I extractable P - 2.3 mg kg^{-1}; K - 50 mg kg^{-1}; Ca - 5.7 cmolc mg kg^{-1}; Mg - 0.5 cmolc kg^{-1}; cation exchange capacity - 9.4 cmolc kg^{-1}. *U. brizantha* cv. Marandu seeds were sowed in a clayey Oxisol fertilized with 2500 kg ha^{-1} lime, 300 kg ha^{-1} NPK (4-30-16), 30 kg ha^{-1} micronutrients (FTE BR 12), and 20 kg ha^{-1} zinc sulfate.

Initially, the soil was tilled with a disc harrow to grind the *Urochloa* residues and to destroy termite mounds. After that, the soil was tilled with a moldboard plow to incorporate the *Urochloa* residues at 0.40 m depth to make crop regrowth and the remaining seed germination more difficult.

Urochloa seeds were mixed with fertilizers and distributed mechanically in the planting furrow at a 10 cm depth along a soil band of approximately 120 m length and 10 m width, divided into four plots of 4 m × 10 m, where the samples were collected. In each plot, two linear meter was marked in the planting row, excluding the border and the useful areas to count the number of tillers (NT). The rainfall and monthly average temperature data were monitored daily during the experiment Figure 1.

Plant samples were collected at 39, 47, 55, 70, 82, 97, 117 and 151 days after emergence (DAE) for growth analysis. Each sample consisted of two plants collected in each plot and placed in PVC tubes (1 m length × 0.10 m diameter) with their roots immersed in

Figure 1. Rainfall (mm) and average temperature (°C), during the period of experiment, recorded at the Weather Station of Embrapa Rice and Beans, in Goiania-GO, Brazil.

water to avoid wilting. Then they were transported to the laboratory, where the roots were removed and the leaves were separated from the stems and inflorescences. The tillers were counted (tiller sample[-1]) and the leaf area (LA), green leaf dry matter (GLDM), stem dry matter (SDM), inflorescence dry matter (IDM), dead leaf dry matter (DLDM), and total dry matter (TDM) were measured.

The number of tillers per square meter (NT m^{-2}) was calculated based on the number of tillers per linear meter (NT m^{-1}), counted within a 2 m line previously marked in the planting row, excluding the border and the useful areas, and dividing the value by the space between the rows (m):

NT m^{-2} = [(NT m^{-1}) × (space between rows^{-1})]

The LA, in cm^2, of each sample was measured using an LI-COR electronic leaf area meter (Ll 3100, Lambda Instruments-Corportion, Lincoln, Nebraska). After that, the leaf area index (LAI) was estimated using the following equation:

LAI = [(NT m^{-1} × LA sample^{-1}) × (space between rows × NT sample^{-1} × 10.000)$^{-1}$] or   LAI = [(NT m^{-2} × LA sample^{-1}) × (NT sample^{-1} × 10.000)$^{-1}$]

Where LAI is the leaf area index in m^2 of leaves per m^2 of ground surface and 10.000 transform cm^2 to m^2.

The green leaves, stems, inflorescences, and dead leaves were placed in paper bags and air-dried at 65ºC for 24 h, until constant weight. Based on the collected data estimates were made for GLDM, SDM, IDM, and DLDM using the following equation:

DM = [(NT m^{-1} × DM sample^{-1}) × (space between rows × NT sample^{-1})$^{-1}$]

Where DM is the dry matter per m^2; NT m^{-1} is the number of tillers per linear meter; DM sample^{-1} is the dry matter per sample collected and NT sample^{-1} is the number of tillers per sample collected. To calculate TDM, the results of GLDM, SDM, and IDM were added up.

Mathematical equations were fitted to the values obtained for LAI, GLDM, SDM, IDM, DLDM and TDM, as a function of time (DAE), and the significance tests for the regression were carried out using the computer program "Ajuste" (Zullo and Arruda, 1987).

Using TDM and LAI fitted equations, the physiological indicators of the growth, crop growth rate (CGR), net assimilation rate (NAR), and leaf area ratio (LAR), in instant values, were calculated using the growth analysis program "Anacres" (Portes and Castro Jr, 1991). The equations used to calculate these variables were the following: CGR = dTDM/dT; LAR = LAI/dTDM; NAR = dTDM/dT/LAI, where d is the derivative of the equation TDM and T = DAE (Hunt, 1982; Portes and Castro Jr, 1991).

In order to estimate photosynthesis rate in µmol CO_2 m^{-2} s^{-1} from net assimilate rate (g of dry matter m^{-2}day^{-1}) the following equation was used:

$$\mu mol CO_2\, m^{-2} s^{-1} = g\ of\ dry\ matter \times \left(\frac{c}{100}\right) \times \left(\frac{44}{12}\right) \times (1/44) \times \left(\frac{1}{86400}\right) \times 10^6$$

Where: C/100 = % of carbon (C) in the dry matter; 44/12 = transform C in CO_2; 1/44 = transform g of CO_2 in mol of CO_2 (that is, one mol of CO_2 equals 44 g); 1/86400 = transform hours in seconds and 10^6 transform mol of CO_2 in µmol. The percentage of carbon in the dry matter is approximately 45% (Walker, 1992).

Instantaneous CSR (Crop Senescence Rate) was calculated using DLDM data and the following equation: CSR = dDLDM/dT, where dDLDM/dT is the derived DLDM fitted equation in relation to time (DAE).
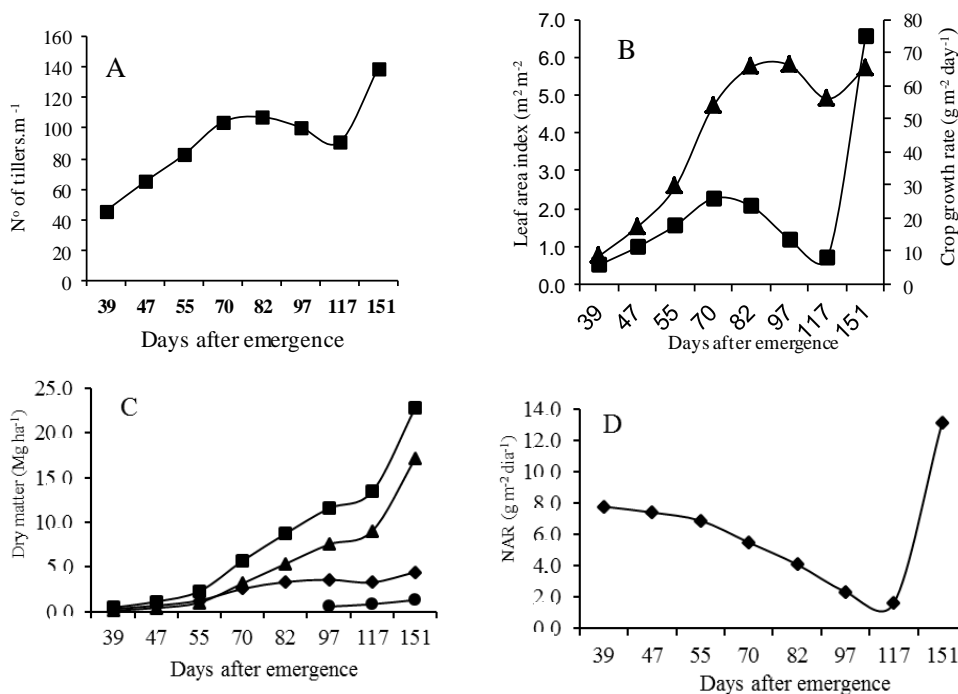
RESULTS AND DISCUSSION

Table 1 presents the cubic exponential polynomial equation [$y = k\ Exp\ (ax + bx^2 + cx^3)$] with better fit to the data of LAI, GLDM, SDM, and TDM (y axis) with time (x = day after emergence, DAE). For DLDM the best equation was the quadratic polynomial ($y = a + bx + cx^2$), whereas IDM the best model was a linear equation

Table 1. Mathematical models fitted to NT, LAI, GLDM, SDM, IDM, DLDM, and TDM data as a function of time (x = DAE), and the respective correlation coefficients (r) and F test.

Variable	Mathematical models	r	*p*
NT	$y = 1.186\,Exp\,(0.145\,x - 1.516*10^{-3}*x^2 + 5.050*10^{-6}x^3)$ NT m^{-1}	0.95	<0.01
LAI	$y = 9.830*10^{-4}\,Exp\,(0.25\,x - 2.356*10^{-3}x^2 + 7.104*10^{-6}x^3)$ (m^2 m^{-2})	0.98	<0.01
GLDM	$y = 2.52*10^{-4}\,Exp\,(0.269\,x - 2.480*10^{-3}x^2 + 7.471*10^{-6}x^3)$ (g m^{-2})	0.99	<0.01
SDM	$y = 1.576*10^{-5}\,Exp\,(0.334\,x - 2.865*10^{-3}x^2 + 8.356*10^{-6}x^3)$ (g m^{-2})	0.99	<0.01
IDM	$y = -7.42*10^{-1} + 1.374*10^{-2}x$ (g m^{-2})	0.96	<0.01
DLDM	$y = 821.630 - 25.694\,x + 0.210\,x^2$ (g m^{-2})	0.99	<0.01
TDM	$y = 2.91*10^{-2}\,Exp\,(0.27\,x - 2.311*10^{-3}x^2 + 6.739*10^{-6}x^3)$ (g m^{-2})	0.99	<0.01

NT = number of tillers per linear meter, LAI = Leaf area index, GLDM = Green leaf dry matter, SDM = Stem dry matter, IDM = Inflorescence dry matter, DLDM = Dead leaf dry matter, TDM = Total dry matter, DAE = Days after emergence.

Figure 2. A: Number of tillers per square meter (NT m^{-2}); B: Leaf area index (LAI =▲), Crop growth rate (CGR = ■); C: Total dry matter (TDM = ■), Stem dry matter (SDM = ▲), Green leaf dry matter (GLDM = ◆), Inflorescence dry matter (IDM = ●); D: Net assimilation rate (NAR); of *U. brizantha* cv. Marandu cultivated under Brazilian Cerrado conditions.

$(y = a + bx)$. The physiological indicators of the growth NAR, LAR, and CGR were derived from the equation fitted to LAI and TDM data, whereas CSR was derived from the equation fitted to DLDM data, as previously described.

In this research, the experiment was divided in two parts, the first from emergence up to 117 DAE, when the plants were in full bloom. The second part from 117 up to 151 DAE, when there was lodging of the plant canopies by wind, allowing the solar radiation to reach the inferior strata with the sprouting of new tillers.

At the beginning of sampling (39 DAE) *Urochloa* already presented higher NT m^{-1} (approximately 42.25), with constant increment until 82 DAE, when the crop reached the value of 107.35 tillers m^{-1} (Figure 2A); after

lodging there was an increase to 138.33 tillers m^{-1}. The LAI increased exponentially until 5.8 m^{-2} m^{-2} at 97 DAE (Table 1 and Figure 2B). Decreased after this date (4.1 m^{-2}) but increased again due sprouting of new tillers after lodging, reaching in this situation 5.7 at 151 DAE. Optimum LAI (4.7) occurred when maximum CGR (0.260 Mg ha^{-2} day^{-1}) was reached by plants at 70 DAE. For other side, maximum CGR was observed at 70 DAE (0.26 Mg ha^{-1} day^{-1}) in the inflexion point of the equation of TDM in function of DAE (Table 1, Figure 2B and C), but after the lodging it reached 0.751 Mg ha^{-2} day^{-1}.

It was observed at 39 up to 55 DAE (Figure 2C) an initial allocation of photoassimilates for leaf production (GLDM = 0.324 Mg ha^{-1}) over stem production (SDM = 0.151 Mg ha^{-1}). However, after 70 DAE this pattern inverted when the grass started to invest more in stem production, reaching a maximum value of 17.11 Mg ha^{-1} at 151 DAE. For animal production, this investment on stems is a disadvantage since the animals prefer to feed on leaves rather than others parts of the plant. In this same date GLDM reaching 4.45 Mg ha^{-1} and TDM 22.8 Mg ha^{-1} (Figure 2C).

The inflorescence dry matter started to be registered at 97 DAE coinciding with the period when *Urochloa* reached maximum LAI of 5.80 (Figure 2B and C), suggesting preferential investment in the formation of reproductive organs after 82 DAE. The IDM continued showing a linear increase until 151 DAE. The decrease of LAI after 97 DAE might be explained by leaf self-shading, which reduces light penetration cross the crop canopy profile. Light reduction might lead to an unbalance between photosynthesis and respiration with a lower gain of carbon compared to the loss of carbon in the respiratory process triggering the senescence of leaves. Corroborating this idea, it was shown recently that there is a convergence of the two most important factors expected to trigger the leaf senescence, which is the absence of light and the presence of ethylene. Leaf senescence might also involve the transcription of a gene related to phytochrome (PIFs), and ethylene production (EIN3) (Jeong et al., 2016).

Under favorable environmental conditions, LAI increases with plant age, consequently increasing CGR (Silva and Pedreira, 1997). Nevertheless, it is important to emphasize that besides LAI, NAR also plays an important role in CGR performance. The comparative analysis of Figure 2B and D suggest that the increase observed in LAI between 39 and 70 DAE, simultaneously with an almost constant NAR, favored the increase in CGR (Figure 2B), which reached a maximum of 0.260 Mg ha^{-1} day^{-1} at 70 DAE. However, after 70 DAE, when CGR was maximum and LAI was considered optimum, CGR started to decrease and reached a very low value (0.079 Mg ha^{-1} day^{-1}) at 117 DAE, the same occurring to NAR.

When the crop reached optimum LAI, the stratum in the bottom of the canopy were progressively shadowed leading to a less effective CO_2 exchange and causing an inflection in the growth curve (Table 1 and Figure 2C).
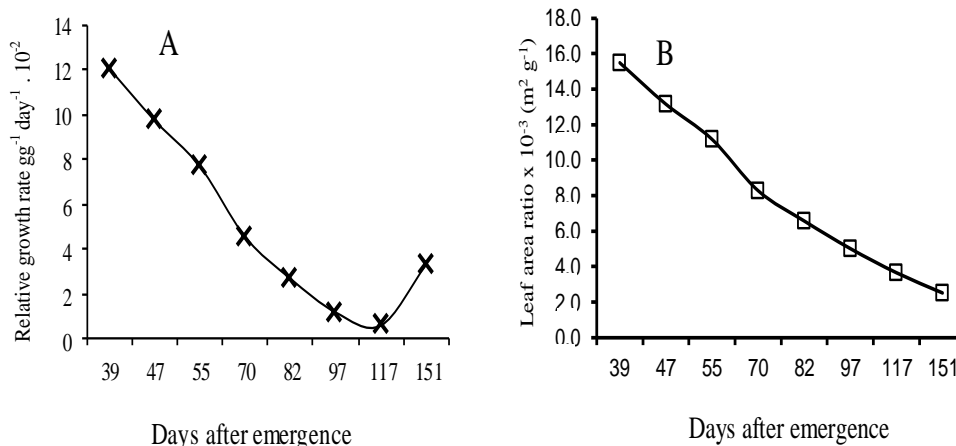
Thus, high LAI causes low NAR (Figure 2D) due to self-shadowing (Portes and Castro Jr, 1991; Silva and Pedreira, 1997; Portes and Melo, 2014). But after the lodging of grass plants, in the second part of the experiment, TAL started to grow again resulting in an increase in the TDM, since this variable increased continually up to a maximum of 22.60 Mg ha^{-1} at 151 DAE (Figure 2C).

The NAR values shown in Figure 2D are 7.8, 7.40, 6.90, 5.50, 4.10, 2.40, 1.60 and 13.10 g m^{-2} day^{-1} observed at 39, 47, 55, 70, 82, 97, 117 and 151 DAE respectively. Used in the equation presented in material and methods, which transforms NAR (g m^{-2} day^{-1}) in photosynthetic rates (µmol CO_2 m^{-2} s^{-1}), the values of photosynthesis obtained would be: 3.80, 3.57, 3.32, 2.65, 1.97, 1.14, 0.78 and 6.33 µmol CO_2 m^{-2} s^{-1}. These values are very low when compared to net photosynthesis rates measured by IRGA equipment (infrared gas analysis). For example, in full sunlight conditions, a rate up to 42 µmol of CO_2 m^{-2} s^{-1} was found for *U. brizantha* (Dias-Filho, 2002). However, the values calculated for the net assimilate rates are averages of a 24 h-period (e.g. considering the periods of day and night). Thus, during the night there is a considerable loss of CO_2 by respiration, when the gain of CO_2 by photosynthesis is zero. Then, considering the self-shading during the day and the loss of CO_2 during the night, the values found here are acceptable. The amount of essential nutrients from the soil (that is, ash) that make up the organic matter ranges from 1 to 5% (Walker, 1992) and because it is a relatively small amount it was disregarded in the study.

The lodging of plant canopies by wind allowed the solar radiation to reach the inferior strata favoring a sudden increase in NAR (Figure 2D), resulting in an increase in TDM as well as in its components; the culms and the leaf dry matter (Figure 2C). Consequently, there was also an increase in CGR, which reached a maximum of 0.751 Mg ha^{-1} day^{-1} in the same period (Figure 2B). The LAI values did not show such an expressive increase in the same period, suggesting that NAR may contribute to crop growth more than LAI due to increasing light penetration after the lodging (Figure 2C).

As CGR estimate does not take into account the dry matter already present in the plant, the relative growth rate (RGR) better expresses the evolution of crop growth. The RGR of *Urochloa* decreased continually from 39 DAE until it reached values close to zero at 117 DAE, following the decrease of LAR (Figure 3A and B).

As found for other crops (Gomide and Gomide, 1999), the RGR decreased with the grass age (Figure 3A) and increased after 117 DAE due to the sprouting of news culms after the lodging of plants. The same occurred for NAR (Figure 2D), which presented high values in the

Figure 3. A: Relative growth rate (RGR); B: Leaf area ratio (LAR) of *U. brizantha* cv. Marandu cultivated under Brazilian Cerrado conditions.

initial period due to higher leaf formation and low self-shadowing. This is an evidence that there is an initial investment in broader LAR (Figure 3B) and, consequently, higher NAR (Figure 2C).

As the plant grows, LAR declines due to self-shadowing, enhancing the interference of the upper leaves in the inferior ones (Benincasa, 1988). In the specific case of *Urochloa*, LAR decreased significantly until 151 DAE (Figure 3B). The reduction of LAR, associated to leaf senescence promoted by self-shadowing as well as by internal factors, contributed to the low values of RGR at 117 DAE.

It was expected that any effects on RGR might be interpreted as effects either on NAR or LAR, or on both (Portes and Castro Jr, 1991). Even when NAR values were almost constant between 39 and 70 DAE (Figure 2D), RGR continued to decrease. The continuous decreasing on RGR demonstrates a strong influence of LAR on RGR. So even when there is an increase in dry matter per leaf (efficient NAR) during this period, the useful leaf area for photosynthesis (LAR) is small due to self-shadowing, which explains the continuous decrease in LAR. Thus, the non-shadowed leaves are efficient in their role as "sources", maintaining CGR. The influence of NAR over RGR was only perceptible after 70 DAE, when the decrease of NAR favored the decrease in RGR even more. It is important to observe that RGR increased again along with NAR as a consequence of the lodging between 117 and 151 DAE (Figure 3A).
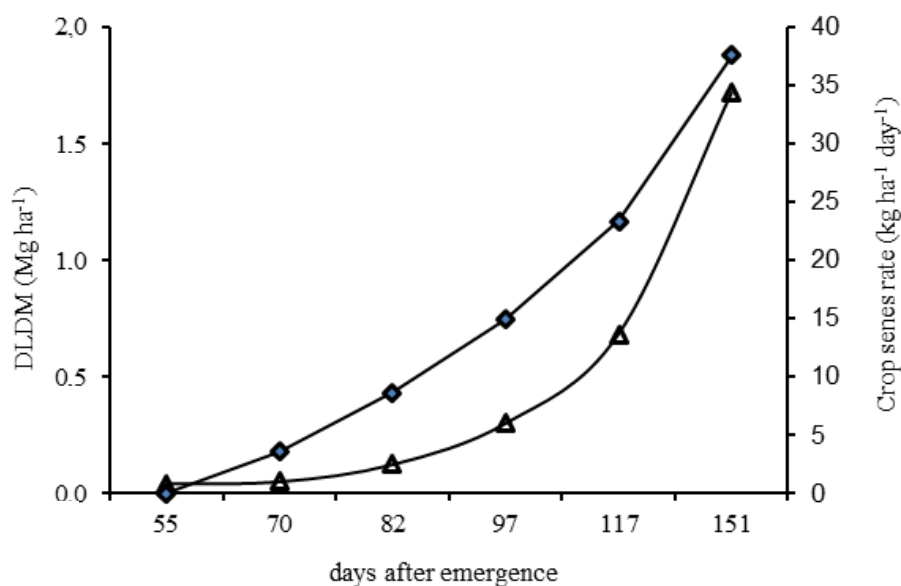
The carbohydrate allocation process occurring on the leaves as a result of the photosynthesis is vital for the plant correct functioning as well as for its growth. The carbohydrate allocation also performs a critical role in grasses since there is a continuous removal of the "unit" of production, the leaves (Silva and Pedreira, 1997). The preference to allocate photoassimilates varies according

to the crop phase. In general, during the initial growth phase, the leaves have a higher strength to drain photoassimilates compared to the stems or roots, but the inflorescences predominate as a drain during the reproductive phase (Snyder and Carlson, 1984). During the exponential phase of growth, the stems have priority to receive photoassimilates, whereas the roots are the strongest drain when this stage ceases (Snyder and Carlson, 1984).

Besides the exponential phase, another factor that interferes in the allocation process is grazing. The meristematic tissues need the energy derived from photosynthesis to support continuous growth and to regenerate the parts of the plant that are removed. This can be explained since the photoassimilate flux towards the roots after leaf removal is minimum or non-existent and a flux in the opposite direction prevails (Silva and Pedreira, 1997).

The allocation and partitioning of photosynthate and tillers formation are highly regulated by the hormonal balance in plants. In rice and wheat auxin inhibits axillary buds growth and consequently the tillers differently of the cytokinin which stimulate the lateral bud outgrowth as a result of apical dominance inhibition induced by auxin (Chatfield et al., 2000, Liu et al., 2011). In field conditions, it is expected that cattle grazing eliminates the aerial part of young plants favoring the action of cytokinins, which is highly produced in roots overcoming the apical dominance, and increasing the tillers growth (Koa et al., 2014).

Urochloa DLDM production (Figure 4) started prematurely at 55 DAE, even before the crop reached optimum LAI (Figure 2B), which occurred at 70 DAE. A premature DLDM production reinforces the idea that, in this period, leaf senescence was promoted by internal factors, since theoretically self-shadowing just starts

Figure 4. Dead leaf dry matter (DLDM = ◊), Crop senescence rate (CSR = Δ) of *U. brizantha* cv. Marandu cultivated under Brazilian Cerrado conditions.

when the crop reaches optimum LAI. According to Corsi and Nascimento Jr (1994), leaf senescence might occur due to factors such as shadowing, water stress, insects attacks, diseases, grazing intensity, nutritional insufficiency such as nitrogen and phosphorus, and, evidently, genetic control, a characteristic of each species.

The DLDM values also started to increase sharply at 82 DAE (Figure 4). These results emphasize the importance of adequate grazing management, because while the animals feed on the leaves, the grass produces new sprouts.

An initial production of 0.042 Mg ha^{-1} of dead leaves was registered, but it increased significantly between 117 and 151 DAE due to the lodging, reaching a maximum value of 1.719 Mg ha^{-1} at 151 DAE (Figure 4). Consequently, CSR (Figure 4) followed the values of DLDM, progressively increasing from zero value at 55 DAE up to a maximum of 0.038 Mg ha^{-1}day^{-1} at 151 DAE, when DLDM was also maximum (Figure 4). Nevertheless, when GLDM production is compared to DLDM (Figure 2C and 4), it is possible to conclude that even with the death of older leaves the production of green leaves was predominant. This suggests a continuous photosynthetic activity and, therefore, almost constant NAR until 70 DAE (Figure 2D), which would be capable of maintaining CGR in the same period (Figure 2B).

Conclusion

The maximum leaf area index (5.80 m^2 m^{-2}) was achieved at 82 days after emergence (DAE), maximum above ground total dry matter (22.6 Mg ha^{-1}) at 151 days, and maximum crop growth rate (0.260 Mg ha^{-1}) at 70 days. Leaf senescence began at 55 DAE, with less than 0.001 Mg ha^{-1} of dead leaves dry mass and reached 1.719 Mg ha^{-1} at 151 DAE. Between 117 and 151 DAE, at the end of plant cycle, the wind caused lodging of plants and this favored a sudden increase in net assimilate rate (NAR), resulting in an increase in the crop growth rate (CGR) and total dry matter (TDM). After 82 DAE, with a maximum LAI, *Urochloa* starts investing at forming the reproductive structures (inflorescences), thus characterizing the beginning of the crop reproductive phase. The premature registering of dead leaf dry matter (DLDM) and, consequently, the Crop Senescence Rate (CSR) at 55 DAE, even before the crop reaches optimum LAI, reinforces the idea that during this phase senescence is promoted mainly by internal factors. In this paper it was adapted and presented, by the first time in the literature, an equation that estimates the net photosynthetic rate in µmol CO_2 m^{-2} s^{-1} from net assimilation rate data in g m^{-2} day^{-1}.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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