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Response of carbon exchange and growth analysis in tropical pastures to distinct irrigation levels

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Abstract: This study explores the effect of seasonality on soil carbon efflux and pasture growth based on field and lysimeter experiments during summer-fall and winter-spring in two years. Focus is also pointed on irrigation strategies to alleviate the crop response to seasonal fluctuations in precipitation and surface temperatures. Soil respiration, soil and air temperature, leaf photosynthesis, plant dry weight and leaf area index were quantified and analyzed. It has been found significant differences in the CO_2 efflux between the two growing season. Emission of soil CO_2 allowed to characterize and to prioritize the temperature and rain influence in seasonal brachiaria response. During the seasons, the transient variation of CO_2 efflux was highly correlated with rainfall ($r=0.87$, $P<0.05$), and poorly correlated with soil temperatures ($r=0.5$, $P<0.05$). The CO_2 efflux and plant response to different level of reposition of evapotranspiration demonstrated that irrigation during fall mitigates the reduction of growth conditioned by drying soil and the lower temperatures. The lower temperatures are limiting only when the soil moisture is below 32% of the field capacity. Thus, we propose to keep the soil moisture around 50% during the fall as a key practices for mitigating the effect of seasonality and its intensification with the climate change, even more if added to management routine practices the soil and water conservation.

Keywords: tropical pasture seasonality, soil carbon dioxide emission, irrigation management strategy.

1. Introduction

Global climate change is challenging the sustainability of agricultural systems at all levels. Grasslands plays a major role in the global ecosystem and are commonly used to supply biomass to milk and meat production, and wool. The effects of seasonality on pasture ecosystems are mainly reflected during the driest and coldest periods of the year with a strong drop in pasture production, which can negatively affect the profitability and sustainability of the production systems that depend of grass (O'Mara, 2012, Keller et al., 2014). The reduced capacity of regeneration of the biomass before the arrival of the new rainy season in tropical areas is affected by the pre-eminence of temperature and rainfall factors, which makes it difficult to define resilience strategies. However, throughout the annual growth, winters are a period in which grasslands exhibit low growth rates and low resolution of biometric and growth changes, which in turn, hinders a deeper understanding of the environmental conditions for the delay of the spring regrowth of the pastures (Barbosa et al., 2007). In this context, studies on carbon soil efflux/exchange can help to detect the plant responses to environmental conditions in order to improve resilience strategies which may involve water management practices.

Among pastures, the *B. brizantha* is well spread in vast areas of tropical grasslands, savannas and forests with infertile acid soils of many countries in South America, India, Africa and Australia. Some of the main areas involved are the spear-grass zone of northeastern Australia, the cerrado and Amazonian regions of Brazil and the llanos of Venezuela and Colombia (FAO, 2005; Jank 2014).

Grassland ecosystems store most of their carbon in soils, where turnover is relatively slow, and in most grassland types, below-ground NPP is at least equal to or higher than aboveground production (IPCC, 2007). Both seasonality and irrigation unfeasibility of extensive pasture areas are a threat to pasture and farm profitability in these ecosystems. Several levels of overgrazing occur during the low grass period. This can lead to increased erosion of the soil and its degradation, as well as intensification of the energy partition for sensible heat, resulting in alterations of the hydrological cycle and the capacity of the soil to store carbon in these regions. These events further contribute either to a prolongation of dry season or to reduction of rainfall (IPCC, 2007). Future anthropogenic climate change and variability in weather events increase the need for mitigation in response to agricultural greenhouse gas emissions.

According the Distribution Mapping of World Grassland Types (Dixon et al., 2014) and the International Vegetation Classification (IVC) with dominant grassland types, South America contains 16 different types of grasslands with a large share of Brazil with three dominant types, being a) Brazilian-Parana Lowland Shrubland, Grassland and Savanna (2,035,627 km^2), b) Brazilian-Parana Freshwater Marsh, Wet Meadow and Shrubland (170,501 km^2), and c) Brazilian-Parana Montane Shrubland and Grassland (26,247 km^2). Increasing our knowledge of biomass dynamics and carbon fluxes would be decisive in directing conservation policies and management practices.

In Brazil, the grassland used to production of beef cattle and milk is predominantly situated within the intertropical zone. In this zone the forage plants present vigorous growth during the warm and rainy season (October-March), contrasting with a drastic reduction or halt on the growth in the dry season (April to September) (Barbosa et al., 2007). This seasonal alternation in the growth rate of forage plants, “seasonality”, has been subject of several studies (Li and Snow, 2011; Beecher et al., 2013; Demanet et al., 2015; Wingler and Hennessy, 2016) and is highly correlated to productive performance of animals kept in pastures, affecting significantly dairy and meat production.

Reduced production of tropical forage plants during the driest periods of the year is one of the main issues in worldwide cattle breeding strategies. Pastures commonly reduce their production by near 75% in winter when compared to spring and summer seasons (Pedreira, 1998; Dupas et al., 2010, Silva et al., 2012). The effect of seasonality on pasture is enhanced by solar radiation, temperature and precipitation rates, which also depends on the interaction among these climatic factors and the genetics of the cultivated species. Among several pastures in Brazil, the brachiaria genotypes occupies more than 70% of 172 million hectares used for grazing (Valle et al., 2001). Marandu cultivar is the most commonly used variety due to its tolerance to depleted soil fertility, insect resistance and elevated productivity (Valentini et al., 2008; Cruz et al., 2011). Consequently, agro-ecosystems where Marandu grows represent the most practical and economical alternative for ruminant feeding, by the lower production costs (Dias-Filho, 2014).

There is a consensus about the importance of grassland management to the carbon cycle and compelling reasons to consider this procedure as part of the holistic approach to carbon sequestration (Frank 2002; IPCC, 2007; Soussana et al., 2010; Ward et al., 2016; IPCC, 2014). In this respect, seasonality plays an important role (Skinner, 2007; Peichl et al., 2011) because Brachiaria species have very developed root system, which influence on both microorganisms' activity (Gopalakrishnan, et al., 2009) and carbon sequestration in soils (Andrade et al., 2008; Ramírez et al., 2009).

According to Davidson et al. (2002), the soil stores two or three times more carbon than the atmosphere, and the soil CO_2 efflux is one of the main components of global carbon cycle, accounting for about 50% of the carbon that composes the ecosystems (Wagai et al., 1998;

Roberts, 2000). The understanding of soil CO_2 efflux is the key to elucidate changes in the soil-plant-atmosphere system. Therefore, this comprehension is crucial for improving the mechanisms of the atmosphere-biosphere interaction in global and regional climate models (Zanchi et al., 2003).

The measurement of soil surface CO_2 efflux is the most widely used method to estimate soil respiration rate in ecosystems. This is associated with its temperature and moisture conditions, and dependent on the temporal and spatial variability of these parameters (Davidson et al., 2000; Rustad et al., 2000; Fang and Moncrieff, 2001). Understanding the CO2 flow of soil and carbon stocks in grazing systems has been extremely important in assessing long-term trends in soil organic carbon content (Hopkins et al., 2009). On the other hand, the greatness of their measurements and sensitivity to small changes in the soil resulting from the plant-soil-atmosphere interaction, specifically CO2 efflux, may allow a better characterization of the evaluation of the impact of seasonal variability on pastures, and assist in the definition of pasture management strategies throughout the coldest and driest period of the year to improve annual pasture production

In Brazil, studies analyzing CO_2 efflux in pastures were more restricted to the Cerrado and Amazon biomes (Von Randow et al., 2004; Ruhoff et al., 2009; Silva-Junior et al., 2013). Thus, the understanding of the relationship between soil moisture and CO_2 efflux especially in tropical ecosystems at either, short and long term is still highly limited. The majority of the studies have been focused on variations in CO_2 efflux in short periods of time (Grahammer et al., 1991; Liu et al., 2002), while others assessed the relations of efflux and humidity based on observations of seasonal variation in forests and temperate grasses with organic soils (Davidson et al., 1998, Luo et al., 1996; Jones, 2005), different from the tropical soils of the present study, characterized by low organic matter and high clay content.

The plant growth analysis enables the characterization of plant responses to climate change and weather variability (Hunt, 1990; Poorter and Garnier 1996) which can be applied to alleviate the effect of seasonal water deficit for plant growth. Thus, these analyses can characterize the physiological response related to growth and yield of brachiaria to distinct levels of irrigation (Waldron et al., 2002) and temperature responses (Medek et al. 2007). Comprehensive functions have been considered, such as Relative Growth Rate (RGR), Net Assimilation Rate (NAR) and the Leaf Area Ratio (LAR), from the dynamics of growth of the foliar area and the biomass of the plant, which are used to understand how the plants respond to climate/weather conditions (Hunt, 1990, Munns et al., 2017). Relative Growth Rate (RGR = LAR x NAR) is a prominent indicator of plant strategy with respect to productivity and its relationship with environmental stress and disturbance regime by the factors of the climate. This variable is closely related to the daily rate of photosynthesis per unit LA and time.

The joint evaluation of plant growth characteristics and the CO2 efflux of the soil, could allow to discriminate the temporal hierarchy and the specific response of the brachiaria to the climatic factors and to propose management practices that increase the resilience before the current climatic variability and your tendency for the future. Therefore, the main objectives are (1) to measurement the soil respiration to understand the reasons they change over time; (2) to identify the contribution of each component of climate factors; (3) to clarify the relationships between soil respiration components and abiotic factors; (4) to establish a temporal hierarchy of low temperatures and soil moisture in the dynamics of biomass production and carbon flux throughout the growing seasons of the year.

2. Materials and Methods

2.1. Experimental conditions and plant management

Two experiments were carried out using *Brachiaria brizantha* cv Marandu, at the Agriculture Experimental Area (CCAEA), of the Agricultural Engineering Department of the Federal

University of Viçosa (UFV-Brazil). The first experiment was conducted under field conditions during the year 2014, to determine the physiological response of Brachiaria to climatic factors and the Net Carbon Exchange Rate (NCER) changes, due to seasonal climate variability. Taking into consideration the 2014 results insofar as water availability is concerned, the second experiment was carried out in drainage lysimeters, during 2016, aiming to elucidate changes in biomass production and soil CO_2 efflux linked to distinct levels of water availability in the winter/spring transition period.

2.1.1 Field Experiments

Field experiment was performed from January to December 2014, in an area of 10 m wide by 20 m long, divided in four similar areas, characterized by a red-yellow Latosoil, Dystrophic soil, with 70% of clay; 9% of silt; 12% of coarse sand; and 9% of fine sand. The pasture was sown on December 10, 2013 with 4-6 seeds per sowing point, with spacing of 0.25 x 0.25 m. Moreover, the spacing was adjusted to plant density among 20-25 plants m^{-2}, which is a typical plant density used in tropical pastures. After emergency, the plants were allowed to grow until February 5, 2014 (57 days after sowing), when a “grazing cut equalization” (GCE) was carried out. This practice consists in cutting-off the aerial biomass at 5 cm above ground to stimulate tillering and the root expansion. After that, both pasture and experiment were considered established (Fig. 1 A).

Two harvest cuts occurred throughout the experiment. The first was performed in 21 May, and the second harvest in 12 November. Thus, the study was organized in two seasonal periods covering two-production cycles, summer-fall (05-Feb until 16-May/05) and winter-spring (06-Jun to 11-Dec), as function of the expected plant growth response to climate variability. In addition, the harvest time in both periods were defined as pre-flowering stages.

Soil acidity and fertility in both experimental areas were corrected from the results of physicochemical analysis as recommended by Ribeiro et al. (1999) and Barcelos et al. (2011), the first adjusted to 70% base saturation index and the latter to attain 100, 80, 50 kg/ha of N-P_2O_5-K_2O, respectively. The phosphate was applied at the beginning of the experiment, while half of K_2O and N requirements were split between the experiment start and the first harvest.

2.1.2 Lysimeter Experiment

In the lysimeter experiment (year 2016), the influence of water availability on the growth of both biomass and soil CO_2 efflux were evaluated. Therefore, four treatments of water availability based on accumulated brachiaria evapotranspiration (ETc) were applied with three replicates: T1=100% replacement (L1), T2=75% (L2), T3=50% (L3) and T4=25% (L4). Culture evapotranspiration was obtained as ETc=ETo x Kc, with reference evapotranspiration (ETo) and different values of Kc based on cv. Marandu values which was 0.80, recommended in irrigation of growth pasture (Alencar et al., 2009), and 1.0 for the end phase of growth (Quintanilha et al., 2006).

The crop coefficient (Kc) is obtained by the relation between ETc under potential conditions and reference evapotranspiration (ETo) and varies with the stage of crop growth (Allen et al., 1998).

This lysimeter experiment was conducted from June 1 to November 18, 2016, covering two cycles of production, allowing for evaluation of temporal changes of soil CO_2 efflux, CO_2 leaf influx and biomass accumulation. During this period, brachiaria goes through two weather characteristics with dry and cold months (winter), and in spring when the temperature arose rapidly and the rain increased favoring conditions for brachiaria growth. Prior to the establishment of the experiment a standardization cut was achieved in all experimental units. Afterwards, fertilization and irrigation management have been carried out.

The soil in the lysimiters was red-yellow Latosoil, Dystrophic with textural class of 70% clay; 9% silt; 12% coarse sand; and 9% fine sand. Two fertilizations were performed in the beginning of each production cycle. Aiming to meet the nutritional criteria, the L1 treatment was adopted as reference for other treatments; therefore, 15, 3.5 and 18 kg ha^{-1} of N, P_2O_5 and K_2O were applied, respectively, for each ton of dry mass produced in the previous harvest, as proposed by Vilela et al. (1998) and Barcellos et al. (2011).

The first evaluated cycle covered the end of autumn and the entire winter (01-Jun to 27-Set), with a total of 118 days. The second evaluated cycle was carried out on late spring, totalizing 51 days between the first and the second harvest (28-Set to 18-Nov). The harvest occurred when the plants height was 35 cm.

2.2. Climatic seasonality and meteorological data

The World Meteorological Organization (WMO) defines climate as the statistical description of weather averaged over a period of time (30 years is usually) and describe a long –time atmosphere "behaves". Whilst 'weather' describes the physical state of the atmosphere at a particular place at a particular time, 'climate' can be defined as the probability of deviations from average values, including the probability of extreme values. The standard classification of the climatic zones is mainly based on the annual cycles of temperature and rainfall.

Daily meteorological data of 2014 was obtained from the National Institute of Meteorology (INMET) station No. 83642, located at 0.6 km from the experimental area. In the 2016-year experiment, data were collected by an automatic weather station, model Vantage Pro2 (DAVIS®) located in the experimental site.

Meteorological data of temperature, precipitation and evapotranspiration collected during both experiments are compared with climatological data series based on 34 observed years (1980 to 2013, https://utexas.app.box.com/v/xavier-etal-ijoc-data). This comparison is important to demonstrate the anomalous deviation of temperature and precipitation in the years 2014 and 2016, both in the rainy season and in the dry season, compared to local climatological conditions. Our climatic characterization focus on the seasonal influence of meteorological factors/parameters on brachiaria growth and the CO_2 efflux. Special emphasis is given to the months where changes of air and soil temperatures, precipitation and the evapotranspiration affected the brachiaria phenology and CO_2 efflux.

2.3. Plant dry matter and growth

Dry matter above ground (DMAG) was determined from sampling areas of 0.25m x 0.25m. The sample collection was carried out during nine times along summer/fall period and 11 times in winter/spring. Six samples were collected from each of four plots, and the results were expressed as accumulated dry matter in both space and time.

In 2016 experiment, the dry mass was determined from the biomass collected in a sample area of 0.25 x 0.25 m in four times at first production cycle and three times at second production cycle. The samples were collected from four repetitions.

To determine the total dry matter (stalks plus leaves), the ground biomass was cut-off at seven centimeters above the ground. In each sample, the leaf area, leaf mass and stems were determined. Leaf area was determined with a leaf area integrator LI-3100 (Li-COR, Lincoln, NE, USA). Samples were then dried until achieve constant weight in oven with forced air circulation at 70°C. Fresh and dry weight was determined in semi-analytical scale.

Dry matter, leaf area and ground area were used to calculate the leaf area index (LAI), relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), according to the Growth Analysis Methodology (Hunt, 1990, Munns et al., 2016).

2.4. Soil CO_2 efflux and water capacity

The efflux of CO_2 was measured along the growing season by 16 times in 2014, and seven times in 2016, between 8:00 and 10:00 AM. This process was conducted at two points for each plot, a total of eight points plus an additional central point at each lysimeter during 2016 experiment.

The CO_2 soil efflux was measured through to net carbon exchange rate (NCER, µmmol $CO_2.m^{-2}s^{-1}$) measurements, with an infra-red gas analyzer (LC-Pro+, ADC BioScientific Ltd., Hoddesdon, United Kingdom) which was used coupled with a soil respiration chamber. The chamber was attached to stainless steel rings of 110 mm diameter by 70 mm height, inserted in the soil at a depth of 63 mm to avoid advective air fluxes. NCER readings were performed after an equilibration time of 10 to 15 minutes. The soil temperature was measured at the same time of NCER measurement, at 10 cm depth, and 5 cm away from soil cylinders.

The NCER short-term variability was analyzed by evaluating the physiological features of the biomass (LAI, RGR, Leaf photosynthesis), and daily and accumulated data of the meteorological factors (air temperatures and precipitation) to characterize the relationship with the plant responses through growing seasons. The relationship among variables was analyzed by Pearson correlation. Soil available water capacity (AWC) was determined from soil samples in 12 times in the lysimeter experiment by the difference between volumetric water content in field capacity and the permanent wilting point (Allen et al., 1998; Borges et al., 2009, Silva et al., 2014).

2.5. Leaf photosynthesis

In 2016 experiment, the net CO_2 assimilation of grass leaves was measured between 10:00 and 12:00 AM, concomitant with soil CO_2 efflux measurements in the median region of the +1 leaf (younger and completely expanded leaf). An infrared gas analyzer (IRGA-LI-6400XT, LI-COR, Lincoln, NE, USA) configured to flux density of 1250 µmol m^{-2} s^{-1} has been used, with atmospheric CO_2 inside the equipment chamber kept around 380 µmol CO_2 mol^{-1}, matching the average air concentration of CO_2 at the site, in Viçosa (Pereira-Flores, et al., 2016). The temperature inside IRGA-LI-6400XT block chamber was fixed in accordance with the environment temperature. The experimental data were analyzed by linear regression, Pearson correlation and descriptive statistics.

3. Results and Discussion

3.1 Climate of 2014 and 2016 and brachiaria cardinal temperatures

During winter (June-July-August) can occur low temperatures very close to the minimum cardinal temperature for growth (Tb = 11.5 °C) in *Brachiaria brizanta* cv Maradu (Silva et al., 2012). The T_{min} of June, July and August reached 11.9 °C, 12.0 °C and 11.2 °C, respectively (Table1 in climatological serial data). In months before and after June-August period, the T_{min} varied from 14 to 19 °C, which represent non-limiting factors to the growth of cv. Marandu. It has been found that temperatures rising between 12.5 and 16.5 °C, increases the growth rate by about 1.9-5.9 of biomass compared to the growth reported when temperature is 11.5 °C (Silva et al., 2012).

Annual rainfall average in the experimental location is 1161.8 mm. The rainy season occurs between October and March (monthly rainfall between 130 and 200 mm), and a period of water restriction is experienced from April to September (monthly rainfall inferior to 100 mm). The lowest monthly rainfall occurred during the dry season of June, July and August, recording 17.5, 11.1 and 16.3 mm, respectively. Moreover, these months had also the highest relative ETo resulting in water deficit, with monthly evapotranspiration values exceeding the precipitation in 3.5, 6.3 5.4 times (Table 1 in climatological serial data).

Thus, the experimental location has a prominent dry period and thermal limitation stage from June to August (mainly winter), for the growth of brachiaria and, at some extent, to other species. Prolonged drought conditions, as the rain deficit measured in successive years, can significantly reduce the water availability in the soil and lead to hydrological imbalances with significant higher evapotranspiration in relation to precipitation. The years 2014 and 2016 were characterized by lower minimum temperature and monthly rainfall compared to the climatology for both dry and rainy months (Table 1). This has resulted in significant deviation in annual precipitation accumulated and ETo/monthly precipitation.

During June and August, T_{min} was extremely close to Tb of *B. brizantha* cv. Marandu. In these two years, the major discrepancy from climatology and the smallest T_{min} occurred in August. In 2014, annual accumulated precipitation reached only 68.5% of the expected normal. The anomaly in precipitation reduced by 64, 82, 76, 87, 58, 67, 77 and 16% of the precipitation in the months of January, February (rainy months) and May, June, August, September (reduced rainfall period), October and December (rainy months), respectively. There was rainfall higher than the climatological mean only in October and December, and only in November and December the precipitation was higher than ETo (Table 1). The behavior of the rains this year, allowed to measure intensified responses of the brachiaria, and to propose the experiment in lysimeters in order to improve our knowledge about the most critical period of the year, the transition between winter and spring.

In 2016, the annual rainfall has reached 99.3% of normal conditions and the reductions in monthly precipitation were 37, 32, 53, 33, 96, 28, 53 and 15% in the months of February, March, April, May, July, August, September and October, correspondingly. The greatest reductions in precipitation occurred in June (2014) and July (2016). Collected data of the relative ETo/precipitation rate in the months from May to October in 2014, and both July and August in 2016, revealed that these year periods were those with the largest ETo/precipitation unbalance. This implied also in greater soil draining in the year 2014 during the field experiment, particularly in the second production cycle.

The climatic evaluation showed that the minimum temperature (T_{min}) in 2014 and 2016 approached the minimum cardinal temperature of the brachiaria, and the ETo / precipitation ratio was anomalously disproportional in winter, in relation to the climatic pattern, which was favorable for our study.

3.2 Field Experiment

3.2.1. Dry matter growth (DM) – 2014 experiment

Dry matter above ground and leaf area index (Fig. 1 A, B) increased according to sigmoidal curves until the harvest in the two evaluated growing season, summer-fall and winter-spring. During the summer-fall period (05-Feb to 16-May/05), dry matter growth was higher than winter-spring (06-Jun to 11-Dec). The first harvest cut was carried out at 73 growing-days after grass cut equalization (GCE). In the winter-spring period, there were growth along the 209 growing-days after the first harvest cut, which was separated by a short period of minimum plant growth (between July 28 and October 18), when a significant reduction in DM and LAI occurred (Fig. 1 B). After 18-Oct, a significant and continuous increase in DM and LAI are noted until the second harvest at 11-Dec (Fig. 1 A, B).

The maximum LAI values in the summer-autumn period were around 4.7, 59 days after GCE, and in the winter-summer period was 9.6 on day 209 after GCE. On the other hand, in the winter-spring period a double sigmoidal curve was observed, with a halt in LAI and biomass increase from July 28 to October 18 period of limiting low temperatures. This may be the greatest evidence that the lack of precipitation and consequent reduction of soil moisture are the determining factors in the dynamics of accumulation of the aerial biomass. In the subsequent period after the reduced LAI, these values increased almost linearly until the second harvest cut, coherently with the dry matter and culture growth rate. This fact was coincident with the year period where the highest precipitation and temperatures occurred (Table 1).

In the 2014 experiment, the amount of rain at the beginning of the rainy season (September-November) was lower than the climatological values (Table 1). The significant decrease in precipitation along with the high evapotranspiration recorded from May to October were crucial factors for the significant reduction of LAI and the growth rates (Fig. 1 B, C, D), which may have conditioned the observed delay in the regrowth of the brachiaria after 14-Aug. The growth of biomass was only restored after 18-Oct, with increased precipitation and temperatures, two months after the end of low temperatures.

In consequence, the relative growth rate (RGR) and growth rate of the culture (GRC) of the summer-fall period were clearly higher than the winter-spring transition period. The RGR represents the efficiency of growth with respect to the initial biomass, while GRC expresses the productivity efficiency of the dry matter. Therefore, low values of these indices reflect the periods in which biomass growth was limited by climate.

Apparently, the low temperatures would have less importance than the water availability during the winter-spring and spring transition in the biomass production of the cultivar Marandu. In view of this hypothesis, the need to determine the temporal hierarchy of water deficit in the soil over low temperatures during the winter-spring transition period was identified.

3.2.2. Air and soil temperatures influences

Mean soil CO_2 efflux in summer-fall period was 2.0 ± 0.5 μmol CO_2 m^{-2} s^{-1} and 2.1 ± 0.4 μmol CO_2 m^{-2} s^{-1} in winter-spring period. Although there were prominent changes of efflux in each evaluated season, the values were consistent with CO_2 measurements described by Chang et al. (2013) and Dendy and Li (2010), who reported values between 2.3 and 6.9 μmol m^{-2} s^{-1}, respectively. In addition, Varella et al. (2004) found high seasonal variation of CO_2 efflux in soils with native brachiaria in the Cerrado, and cultivated pasture, with mean values of 2.0 μmol m^{-2} s^{-1} in the dry season.

At the beginning of summer-fall period, the CO_2 efflux followed the minimum air temperature between 05-Feb and 26-Feb. From 26/02 onwards, there was a decoupling between temperature trend and NCER values, which increased up to 19/03. The rise in soil CO_2 efflux coincided with the exponential growth phase of dry matter recorded between 28-Feb to 19-Mar (Fig. 1 A). From 19-Mar, there was a decrease in NCER from 2.5 to 0.5 μmol.m^{-2} s^{-1} coinciding with the stationary phase of dry matter curve (Fig. 1 A), and the decrease of minimum air temperature (Fig. 2). This was 30 days after the first harvest. After this period, the CO_2 efflux rose smoothly until a maximum efflux in 28-May (Fig. 2 B). From this date, the CO_2 efflux decreased continuously until 24-Jul. In this period, decoupling between low temperatures and CO_2 efflux values was evident. While the temperatures decreased, CO_2 efflux maintained minimum values until 24-Jul.

The lower levels of CO_2 efflux coincided with continuous biomass growth until 28-Set (Fig. 1 A), despite the expressive decrease in temperature at 25-Jun, implying that the temperature drop did not hamper the Marandu growth. In addition, it could be inferred that other factors rather than temperature would hold the CO_2 efflux at its lowest level.

After 24-Jul, spikes of CO_2 efflux were observed in 3-Jul, 4-Set, 21-Oct, 23-Oct and 27-Nov. In the same period of efflux peaks observed in the winter, LAI and growth rates reduced significantly between 8-Augand 18-Set, phenomena that cannot be explained by the variation in temperature.

During winter days, it is known that roots and lower shoots may have reduced respiratory rates due to low temperatures, which according to the temperature coefficient Q_{10} (Van't Hoff, 1898, Taiz and Zeiger, 2010) can limit the metabolic rate of soil organisms and roots, consequently, the soil CO_2 efflux. In addition, low temperatures can also reduce the supply of energy for many physiological processes such as photosynthesis and transport of photosynthates to the roots and thus the respiratory rate of roots and microorganisms (Larcher, 2006, Taiz and Zeiger, 2010). According to Boone et al. (1998), the metabolic activity of roots strongly influences the sensitivity of soil respiration to temperature. Root respiration plus carbon oxidation in the rhizosphere contribute to the majority of CO_2 emitted by the soil. If cardinal low temperature limit is reached, the expected effect would be a drastic reduction of vegetative growth (Larcher, 2006).

In the period with the lowest temperatures, after 25-May, the CO_2 efflux remained almost constant in the lowest level already reached, with only small peaks and large peaks on 31-Jul during winter season. In the same period, significant and abrupt drops of air and soil temperatures occurred in 25-Jun, 16-Jul, 31-Jul and 7-Aug. However, on July 31 (Fig. 4c), a peak of CO_2 efflux occurred with the drops of temperatures. Analyzing the occurrence of precipitation from that date to the past, we find the recording of a 10 mm rainfall occurred on 25-Jul, six days before the occurrence of the CO_2 peak on 31-Jul. After 7-Aug, all the temperatures of the soil and air had increased, and from 28-Aug there was also a manifest growth of biomass, characterized by increases of LAI values (Fig. 1B). Leaf area index is an important indicator of land leaf cover and their productive potential through photosynthesis.

By the other hands, the decline in the biomass growth rate was not observed in the period of low temperatures. In fact, the near surface (data not showed) and soil (Fig. 3a) temperatures in three different periods of summer-fall, winter and spring-summer are poorly correlated with CO2 efflux values. It is noted that low temperatures at the experimental location are not restrictive to increase the productivity of pastures, even with the occurrence of events of minimum temperatures below the Tb of the brachiaria (Fig 2a). This differs from the boreal region where low temperatures and the presence of snow strongly limit the production of grasses throughout the year (Davidson et al., 2000).

3.2.3. Precipitation influence

The results of the efflux peaks after rainfall events more temperature and CO_2 efflux evolution (Fig. 4 A) were separated into two graphs (Fig. 4 B, C). According to Fig. 4 B, there was accumulated rainfall of 77 mm in the summer/fall period during three days (from 6 to 8 March). Three days after this rainfall event, there was a maximum of CO_2 efflux on 11-March. A second peak was recorded on 19-Mar, six days after a rainfall of 11.7 mm that has occurred on 13-March. After March 19, a rainfall of less than 2 mm was recorded, and the values of precipitation, temperature and CO_2 efflux decreased until the harvest cut on May 16 (Figure 4 A). In ten weeks after harvesting, small increases in CO_2 flow were followed days after each occurrence of rainfall, even with minimum temperatures below 11 °C (Figure 4 A). The week of July 31 was an expressive increase in CO_2 efflux, after 11.1mm of rain on July 26, and other of different intensity after rains in August 19, 28 and September 2 (Fig. 4 C).

In hot and humid periods, similar CO_2 efflux behavior in response to rain events were also noticed, previously, in 11-March, and later, 02 and 23 of October with rains of 7.0, 9.3, and 12,3 mm in 30 of September and October 20 and 26 respectively (Fig. 4 A). After October, other peaks with lower intensity and greater efflux response followed one another because soil moisture increased with or increased frequency of rainfall. Thus, small rainfall contributions were significant in the CO2 efflux. The CO2 efflux peaks after the rain events have also been verified by the correlation analysis (Fig. 3 D, F). Similar positive correlations between CO_2 efflux and water availability has been found previously (Pinto-Junior et al., 2009; Valentini et al. 2008; Liu et al., 2002), also at low temperatures as in the grasslands of northern Mato Grosso State (Pinto-Junior et al., 2009). There were CO_2 efflux increases on 23/10 and 27/11 of about four times in relation to the period before 16/10. This expressive increase after 16/10 (October to December) could be attributed to the characteristic intensification of precipitation at this time of the year ($r^2 = 0.51$, $p<0.05$; Fig 4 A), but also it can be associated to the observed increase of temperature and biomass which doubled in the last 55 days.

Changes in soil temperature can influence up to 80% of the temporal variations in CO_2 flow, with soil moisture adequate, however, as the soil dries, the influence of soil moisture predominates over temperature (Grahammer et al, 1991; Janssens et al., 2000; Smith et al.,2003). The results of our study were similar to the aforementioned results for periods with more elevated precipitation, between October and November of 2014. Regarding CO_2 efflux variation according to the studied variables, precipitation influenced significantly in CO_2 soil efflux during the different seasons of the year, including periods of low temperatures of soil and air from May to August (Winter/Spring). Additionally, CO_2 efflux increases were verified from November, in agreement with enhanced precipitation, biomass accumulation (Fig 1 A, B) and higher soil and air temperatures (Fig 2 A).

The 2014 results showed the importance of the low temperatures in the production of biomass and soil respiration. However, the cessation of growth after the cold period and the registration of spikes of CO_2 efflux after rainfall events, led us to hypothesize that the humidity of the soil would be the most important factor limiting to early recovery of the post winter pasture production. Therefore, a second study was carried out in lysimeters to better understand and prioritize the influence of the seasonal variation of soil temperature and humidity in the winter-spring transition period, which was decisive for the evolution of CO_2 efflux and biomass production.

3.2 Lysimeter Experiment

3.2.1. Dry matter growth (DM) – 2016 experiment

Dry matter production and LAI were influenced by water availability levels in the first cycle much more than during the second cycle when the water restriction was reduced with rainfall (Fig 5 A, B). The production of biomass per plant during the first cycle (Fig 5 A), result in a production of 4900 kg ha^{-1} to L1 treatment (control with 100% of ETo). The reduction in water availability affected pasture growth in other treatments, being 3229, 2444 and 1929 kg DM ha^{-1} in L2, L3 and L4 treatments, respectively. These values correspond to a decrease of 18, 32 and 43% in relation to L1 treatment. Growth reduction in treatments L3 and L4 occurred since August, while in L2 treatments the growth rate started to decrease only in September (Fig. 5 A), a few days before the rainy season arrives and intensifies. This point is important to support our proposal to prevent rapid soil desiccation by irrigations during the fall with slips that are fractions of crop evapotranspiration, which can shorten the brachiaria production cycle, enhancing the number of harvests and productivity throughout the year.

3.2.4. CO_2 efflux of lysimeter soil and climate conditions

Soil temperatures were lower in July and August varying between 15.3 and 18°C (Fig. 6 A). Temperatures have gradually risen from September to an average of 23.3 °C. But, no significant differences of soil temperature have been found among treatments. In fact, increased vegetation cover in all treatments reduced the solar radiation amount at the soil surface

Soil moisture remained higher during the entire experiment in L1 treatment (Fig. 6 B) with values above 60% of the available water capacity (AWC). In other treatments, the soil moisture gradually decreased due to evapotranspiration levels exceeding the water reposition. In the treatment L2, soil moisture reduced significantly around September, reaching 25% of AWC on September 17. On the other hand, in L3 and L4 assays, soil humidity was lower during almost the entire experiment, oscillating between 5 and 46% in the AWC of L3 treatment and between 2 and 32% in the AWC of L3. From November 11, all treatments denoted soil moisture higher than 50% of the AWC mainly due to rainfall occurrence in November.

These changes in AWC resulted in significant differences on soil CO_2 efflux (NCER) among treatments (Fig. 7 A). NCER showed higher rates in treatments with higher water availability. The NCER were 2.7, 2.4, 1.9 and 1.8 μmol CO_2 m^{-2} s^{-1} for L1, L2, L3 and L4 treatments, respectively, corresponding to a reduction of 11, 30 and 34% of L2, L3 and L4 treatments in relation to L1. It is noteworthy that rain absence between 10/06 and 20/09 highlights the influence of soil moisture on CO_2 soil efflux, until before the onset of the rainy season.

Carbon dioxide efflux in treatments L3 and L4 was lower that L1 during the most of measurements (Fig. 7 A). However, the major discrepancies have occurred between August 25 and September 17. This period coincided with the interval when L3 and L4 treatments experimented restriction in soil moisture, while soil temperature began to rise. In this phase, minor biomass accumulation was also observed (Fig. 5 A). In turn, L1 and L2 CO_2 efflux were similar until mid-September, when soil moisture was still elevated. Nonetheless, when water levels in L2 treatment has fallen below 45% of AWC, a depletion on soil CO_2 efflux was observed.

In the second production cycle, starting in October, the CO_2 efflux increased in all treatments. Initially, this increment occurred due to the raise in soil temperature. Then, in November, the upsurge was fomented by soil moisture increase in every treatment resultant from augmented rainfall in November. In the last measurement of November, CO_2 efflux was above 4 $\mu mol\ CO_2\ m^{-2}\ s^{-1}$ in all assays.

We have found that soil temperature fluctuations also affect the CO_2 efflux. This could be perceived in treatments with greater water availability. The CO_2 efflux was lower during the Brazilian winter months, when soil temperature values decreased. The soil temperature and CO_2 efflux in treatment L1 were analogous (Fig. 6 A, Fig. 7 A) and the correlation between them was 0.94 (Table 2).

In other treatments, correlations between soil temperature and CO_2 efflux were lower due to noticeable influence of lower water availability. Associations between CO_2 efflux and soil moisture were of 0.39; 0.12; 0.71 and 0.86 in L1, L2, L3 and L4 treatments, respectively. The correlation table (Table 2) showed that soil temperature was the main responsible for CO_2 efflux variation when the soil moisture was elevated.

The soil CO_2 emissions present complex nature; therefore, it is not possible to identify a single soil/environment attribute that explains, in isolation, its variation in time and space. Nevertheless, the great influence caused by moisture and temperature of soil exerted on CO_2 efflux is evident in this work. Furthermore, elevated moisture and temperatures offer proper conditions to CO_2 production, as they favor organic matter decomposition, roots respiration and microbial respiration, thus increasing CO_2 emission from soil to atmosphere (Dias, 2006; Brandão, 2012).

Janssens et al. (2000) pointed out that soil temperature changes could influence on 80% of temporal variations of CO_2 flux, since adequate soil moisture is provided. Similarly, Smith et al. (2003) argued that CO_2 released by aerobic respiration is dependent on temperature, however, becomes reliant on moisture as soil dries.

Soil moisture tends to exhibit strong influence on efflux rates below or above extreme critical values of soil moisture (Silva et al., 2016). An elevated water content could prevent the diffusion of both O_2 and CO_2 in soil. In contrast, a limited water content in soil could inhibit soil microorganism activity and radicular respiration (Gonçalves; Pelegrine, 2015; Dias, 2006; Liu et al. 2002). In this work, critical soil moisture has been found close to 45% of the AWC, which fomented reduction of soil CO_2 efflux rates. Rosenthal et al. (1987) indicated values inferior to 0.50 as factors responsible for significant reduction in plant growth and development.

Coser et al. (2008), has found increases of 24% in winter dry matter yield of elephant grass under nitrogen fertilization coupled with irrigation of 50% from evapotranspiration, in a region near to the site of this experiment. Similar findings were reported by Correa and Santos, 2006 in the state of Sao Paulo-Brazil with Tanzania grass, in which they verified that irrigation did not change the seasonality of production but promoted an increase in forage accumulation rate during spring and autumn. These authors also pointed out that the most pronounced effects of dry matter reduction were observed from September, especially in October, when there was no precipitation.

3.2.5. CO_2 efflux of lysimeter soil and Net leaf assimilation of CO_2

Net assimilation rate of CO_2 in leaves (*A*), also known as leaf photosynthetic rate, was greater in treatments with more elevated water availability (Fig. 7 B), with values by about 28.3; 25.4; 20.8 and 16.6 μmol CO_2 m^{-2} s^{-1} for L1, L2, L3 and L4 treatments, respectively. This corresponds to a reduction of 11, 27 and 42% in L2, L3 and L4 treatments in relation to the L1 plot. It is noteworthy that these decreases were expected in plants subjected to water deficiency, which reflected strong stomatal adjustment to avoid excessive loss of water under stress conditions (Larcher, 2006; Romero and Botía, 2006).

In addition, the leaf net assimilation rate of CO_2 occurring in L3 and L4 treatments was inferior to L1 during the majority of measurements. Nonetheless, the sharpest reductions arose in September. In turn, the effects of lower water availability on L2 photosynthetic rates began in mid-September, when soil moisture was inferior to 45% of AWC, in line with data on soil CO_2 efflux rates (Fig. 6 B). Elevated soil temperature and soil moisture and (Fig. 6 A, B), favoring soil CO_2 efflux has also led to higher photosynthetic rates. The greater reduction in photosynthetic rates occurred on September 17, which coincides with driest soil period in L2, L3 and L4 treatments. There were declines of 30, 88 and 99% of A values for L2, L3 and L4 assays, correspondingly.

The lower soil moisture between August and September in treatments with 50% or less of ETo compromised significantly the photosynthetic rates, biomass production and reduces soil CO2 efflux. The partial irrigation could be an option as a management strategy to increase productivity.

CO_2 leaf net assimilation also showed elevated relation with CO_2 efflux (Fig. 7 A, B). The correlations between efflux data (NCER) and photosynthesis data (A) were 0.78; 0.75; 0.79 and 0.85 in treatments L1, L2, L3 and L4. Several studies confirm the photosynthesis influence on soil efflux rates (Bahn et al., 2009; Kuzyakov and Gavrichkova, 2010). Photosynthesis affect the efflux of soil CO_2 through the substrate provision for respiration of both microorganisms and roots. Increasing evidences suggest that the supply of assimilates from photosynthetic active plant organs significantly modify root respiration (Luo and Zhou, 2006, Subke et al., 2009). In addition, photo-assimilates are directly exude through the roots and are rapidly used by mycorrhizae and microorganisms inhabiting the rhizosphere and, thus, contributing to soil CO_2 formation (Merbach et al., 1999, Kuzyakov et al., 2003).

The contribution of CO_2 resultant from roots and rhizomicrobial respiration, known as CO_2 derived from root, is extremely elevated, reaching up to 90% of total soil CO_2 (Hanson et al., 2000). Several studies revealed that root CO_2 contribution decreased in periods of dormancy compared to the growing season (Dorr and Munichich, 1986; Rochette and Flanagan, 1997). This may be explained by the fact that these respiration types are closely related to plant assimilates supply into rhizosphere, therefore, directly dependent on photosynthesis.

Whichever factors that affect photosynthesis or the substrate supply to roots and rhizosphere microorganisms, such as solar radiation, leaf area index, water stress and nutritional status, represent an important determinant of root derived CO_2 efflux and therefore a contributing factor of soil CO_2 total efflux.

There is a highly variable time interval between carbon assimilation by photosynthesis and subsequent efflux of soil CO_2. This depends on physiology, stage of plant growth and environmental conditions. In literature, delays of about 13 days for grasses and around 4-5 days for mature forest trees are found. Kuzyakov & Gavrichkova (2010) firmly discussed that soil CO_2 efflux models should incorporate parameters related to photosynthesis, as this variable represents one of the main drivers of carbon flows.

Our results combined with França da Cunha et al. (2012), strengthen the evidence that the lack of water in central and northern regions of Brazil may be the most important climatic factor for seasonal reduction of *B. brizantha* production. It is well known that seasonal variability accounts for 60% of the variation in annual production, while the interannual variability represents only 2.6% (Demanet et al., 2015). It is important to note that after the winter period, the availability of water in rivers for irrigation practices is minimal or null, whereas rivers and surface water sources are still abundant in the summer-fall period.

Considering irrigation of large areas of pasture, this process seems to be unfeasible, in spite of the occurrence of elevated evapotranspiration and significantly low precipitation in winter months, as shown in Table 1. However, discard the entire irrigation does not necessarily seem to be the most qualified strategy, considering the large reduction of low-cost food for livestock. Therefore, finding a half-term that guides on the amount and frequency of irrigation, when there is still water availability in the rivers, and whether that is economically viable in the annual balance of profitability of cattle production appear as interesting next steps. On the other hand, it will also be necessary to assess in what magnitude the irrigation or regional changes in the pluviometric regime can influence on annual carbon flow of these ecosystems with *B. brizantha*. Moreover, it would be important to elucidate whether the monoculture and current management techniques of Brachiaria pasture lands are taking into account productive sustainability.

Dantas et al., 2016, found similar results for the same cultivar of Brachiaria in São Paulo State-Brazil. These authors verified that the 100% replacement of the evapotranspiration or the maintenance in 50% of the water available in the soil, allows to effectively obtaining high production during the winter. Other results in irrigated conditions also showed increases of *B. brizantha* cv. Marandu of 1.65, 1.70 and 2.9 times in May, August and September, respectively, compared to the lowest production in April (Silva and Silva Junior, 2009). This can thus allow the rapid recovery and pasture production after the coldest (July) and dried period of the year (July to October).

Our results show that only the equivalent of 50% of the evapotranspiration could be needed since the irrigations are done during the Fall when there is still enough water in the reservoirs. Maintaining the amount of water available in the soil slightly above of 35% can be a generalized criterion to increase the productivity of *B. brizantha* cv Marandu during autumn and winter, and consequently increase annual productivity.

The experiment in lysimeter allowed observing the pre-eminence of the water deficit over temperature not crescimento da brachiaria. The interaction of the two factors, deepening of the dry and low temperatures strongly limited the increase of biomass during the winter, mainly in treatments with high water deficiency. This effect can also be inferred that both factors interfere with photosynthesis and the metabolism of plants by different mechanisms, resulting in lower growth rates, and with the effect of drying much longer and more intense than low temperatures

4. Conclusions

There was differential influence of climatic factors, regarding time of year, on the soil respiration cultivated with *Brachiaria brizantha* cv. Marandu. Even at low and moderate temperatures, precipitation was crucial to increase the soil CO_2 efflux. Moreover, the growth rate of dry matter was influenced by rainfall events. Thus, a potential irrigation management in the period after August 15, when minimum temperatures increased, could influence the growth curve enabling more elevated growth rates. This would reduce the cycles of harvest and enhance forage productivity during the year either for grazing or silage.

There was a differential influence of climatic factors on the respiration of the soil cultivated with *Brachiaria brizantha* cv. Marandu depending on the year period. The most important climatic factor for NCER variation was precipitation taking into account the preeminent correlation with efflux, mainly in the driest period of the year (May to August). Furthermore, soil temperature also impact on CO_2 efflux variation, since adequate moisture was presented in the soil.

Although precipitation exhibited more significant correlation with CO_2 efflux, the isolation of a single determining factor in CO_2 efflux variation is not correct, considering that all elements act in conjunction with Marandu cultivar development in soil respiration.

The controlled variation of soil moisture at low temperatures (Lysimeter experiment) allowed for a more precise characterization of the response of the biomass and CO_2 efflux from the soil, and consequently, to define a management proposal to mitigate seasonality on pasture production. The results of the lysimeter test contributed to determine the soil moisture hierarchy on the low temperatures during the winter, and these findings were fundamental to define the management strategy aiming at the mitigation of the seasonality on the production of grass.

Based on the results of 2014 and the new findings in the evaluation of lysimeter in 2016, we can define a strategy for the mitigation of seasonality in the availability of food for livestock. We consider it necessary to irrigate during the fall, when water is still available for irrigation in rivers and reservoirs. This would avoid the continuous drying of the soil and a faster reaction of the plants with the beginning of the first precipitations of the new water cycle accompanied by higher temperatures. This strategy, although it cannot be generalized, would reduce the effects of the winter period on the annual Brachiaria harvest cycles, which would contribute to improving the productive management of the pastures.

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Table 1: Viçosa climate series of 1980-2013, 2014 and 2016 year growing seasons

Climate factor	Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Summer			Fall			Winter			Spring		S
Climatological serial data												
T_{max} °C	28.6	29.6	28.6	27.3	25.2	24.2	24.2	25.5	26.2	27.2	27.3	27.9
T_{min} °C	19.0	18.8	18.4	16.8	14	11.9	11.2	12	14.2	16.4	17.7	18.6
Pp (mm)	198.8	129.6	156.2	64.4	37.3	17.5	11.1	16.3	56.5	101.4	174.4	198.3
ETo (mm)	122.8	119.6	111.1	89.6	72.1	61.1	69.8	88.0	98.3	114.1	111.5	116.5
ETo/pp	0.6	0.9	0.7	1.4	1.9	3.5	6.3	5.4	1.7	1.1	0.6	0.6
Meteorological data – 2014												
T_{max} °C	30.9^{+}	30.9^{+}	28.1^{-}	27.3	25.8^{+}	24.9^{+}	23.8^{-}	26.1^{+}	28.3^{+}	28.8^{+}	28.5^{+}	29.3^{+}
T_{min} °C	23.4^{+}	18.3^{-}	18.2^{-}	17.1^{+}	13.4^{-}	12.7^{+}	12.8^{+}	11.6^{-}	13.9^{-}	15.4^{-}	18.0^{+}	18.8^{+}
Pp (mm)	72.2^{-}	23.8^{-}	182.8^{+}	84.4^{+}	8.4^{-}	2.2^{-}	11.1	6.9^{-}	18.8^{-}	23.6^{-}	203.0^{+}	167.2^{-}
ETo (mm)	131.7^{+}	126.9^{+}	102.1^{-}	85.3^{-}	93.3^{+}	66.9^{+}	72.7^{+}	92.9^{+}	114.6^{+}	129.4^{+}	111.9^{+}	125.5^{+}
ETo/pp	1.82^{+}	5.33^{+}	0.56^{-}	1.01^{-}	11.10^{+}	30.39^{+}	6.55^{+}	13.47^{+}	6.10^{+}	5.49^{+}	0.55^{-}	0.75^{+}
Meteorological data – 2016												
T_{max} °C	28.0^{-}	31.0^{+}	29.1^{+}	29.5^{+}	25.5^{+}	22.7^{-}	25.0^{+}	26.3^{+}	27.7^{+}	26.8^{-}	26.9^{-}	28.4^{+}
T_{min} °C	19.0	18.7^{-}	18.5^{+}	16.0^{-}	14.2^{+}	12.1^{+}	10.9^{-}	10.8^{-}	14.1^{-}	16.7^{+}	17.4^{-}	17.9^{-}
Pp (mm)	352.6^{+}	81.2^{-}	106.6^{-}	30.2^{-}	24.8^{-}	72.6^{+}	0.4^{-}	11.8^{-}	26.8^{-}	85.8^{-}	125.0^{-}	235.8^{+}
ETo (mm)	99.1^{-}	118.5^{-}	97.5^{-}	95.4^{+}	68.5^{-}	52.0^{-}	68.9^{-}	91.0^{+}	96.8^{-}	92.3^{-}	90.9^{-}	113.2^{-}
ETo/pp	0.3^{-}	1.5^{+}	0.9^{+}	3.2^{+}	2.8^{+}	0.7^{-}	172.3^{+}	7.7^{+}	3.6^{+}	1.1	0.7^{+}	0.5^{-}

Values followed by (+) and (-) signifies superior and inferior values to Normal Climatological conditions (NC), respectively.

Table 2. Pearson linear correlation of CO_2 efflux values in the soil (NCER) regarding soil temperature and moisture in treatments with 100% (L1), 75% (L2), 50% (L3) and 25% (L4) of evapotranspiration reposition of accumulated crop (ETc ac.).

Treatment	Soil temperature	Soil moisture
L1	0.84**	-0.39
L2	0.64*	0.12
L3	0.56*	0.71**
L4	0.60*	0.86**

**Significant correlation at 1% level 1% (p<0.01)

* Significant correlation at 5% level (p<0.05)

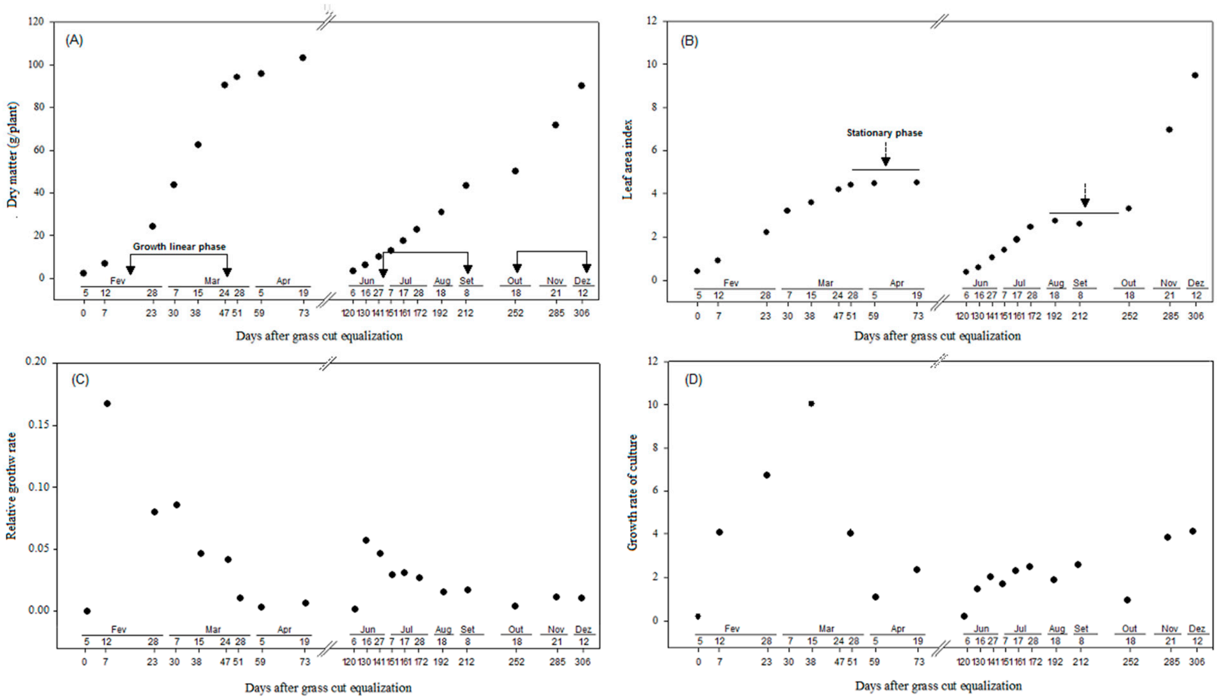

Figure 1. Dry matter (A), Leaf area index (B), Relative (C) and Culture (D) growth rates of *Brachiaria brizantha* cv Marandu, in two growth seasons of 2014. Solid arrow shows the initial and final linear phase on each curve. Dotted arrows represent the onset or stationary phase of curves.

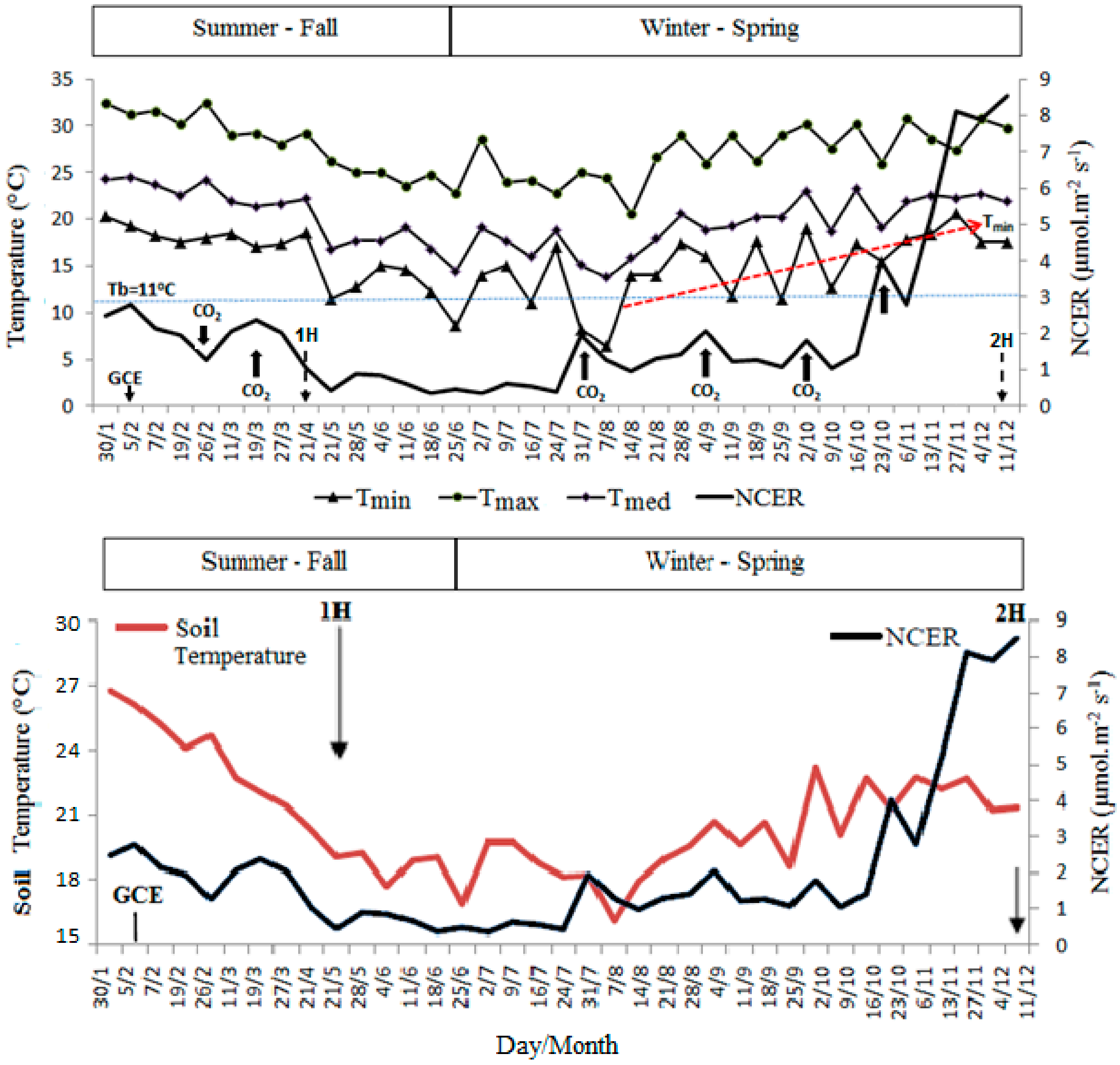

Figure 2. Temperatures of air (A), soil (B) and NCER evolution on both evaluated growth seasons. The black arrows denote change points in biomass management (GCE=grass cut equalization, 1H=First harvest, 2H=Second harvest). The dotted red line shows the increase of the minimum temperatures from 14 / Aug and the fine dotted blue line shows the minimum cardinal temperature (T_b) for the cv. Marandu (A).

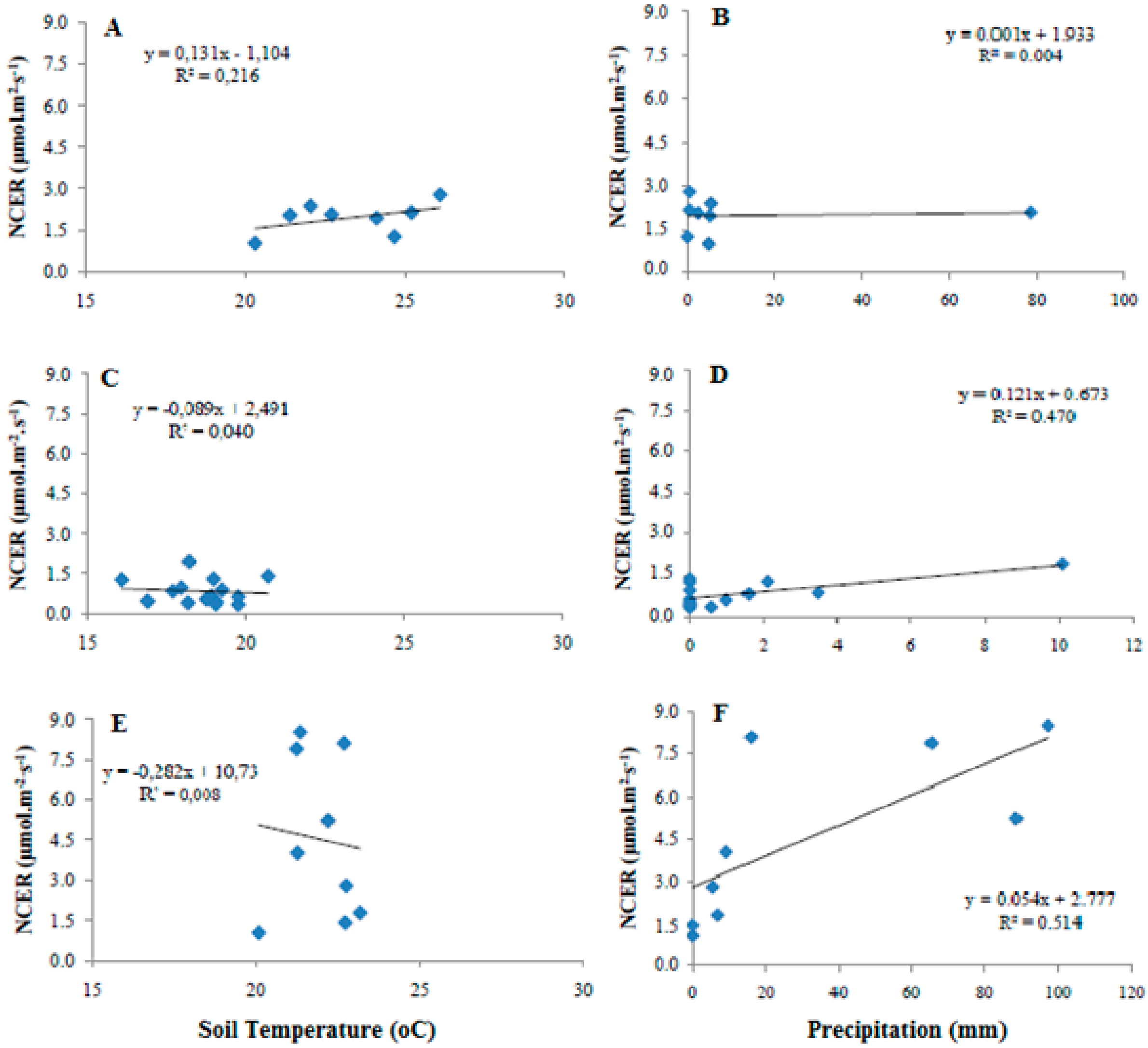

Figure 3. Correlation ($P<0.05$) between NCER (CO_2 efflux) with Soil Temperature (A, C, E) and between NCER and Precipitation (B,D,E) at February to April (A,B), May to August (CD, dry period) and October to December (E,F, rainy period).

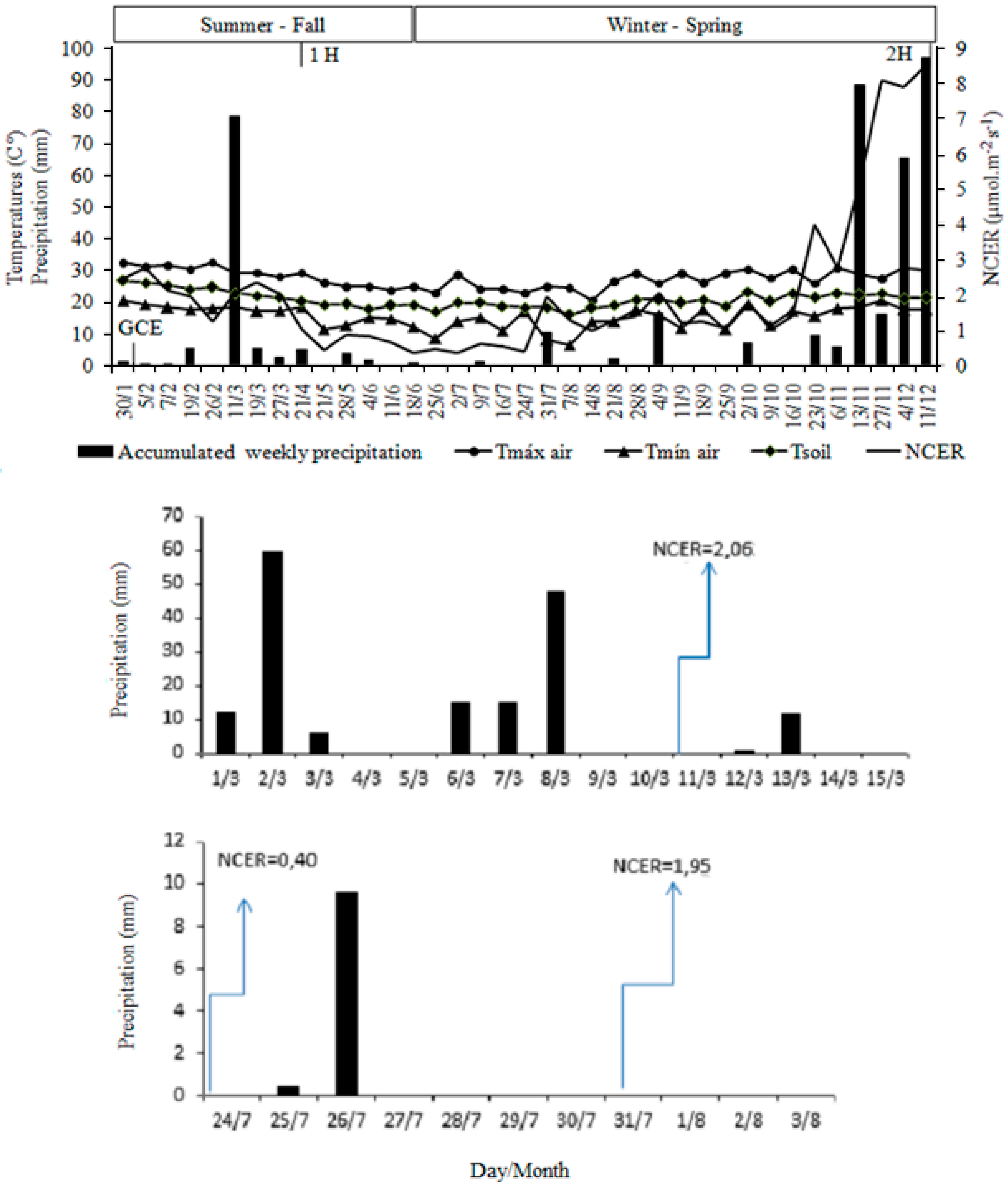

Figure 4: NCER (CO_2 efflux) evolution compared to precipitation, air and soil temperatures on growth seasons (up). Response time to NCER after rain event in contrast season, summer (medium) and winter (down). Blue arrows point out the day where ascension of CO_2 after rain events was found.

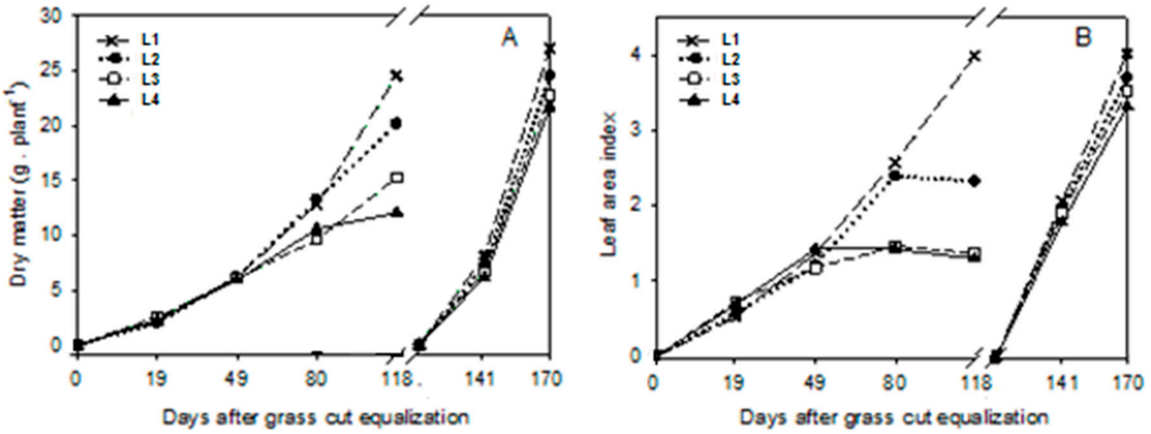

Figure 5. Dry matter accumulation (A) and leaf area index (B) from the standardization of *Brachiaria brizantha*, cv Marandu until the end of experimental period in treatments with 100% (L1), 75% (L2), 50% (L3) and 25% (L4) of evapotranspiration reposition of accumulated crop (ETc ac.).

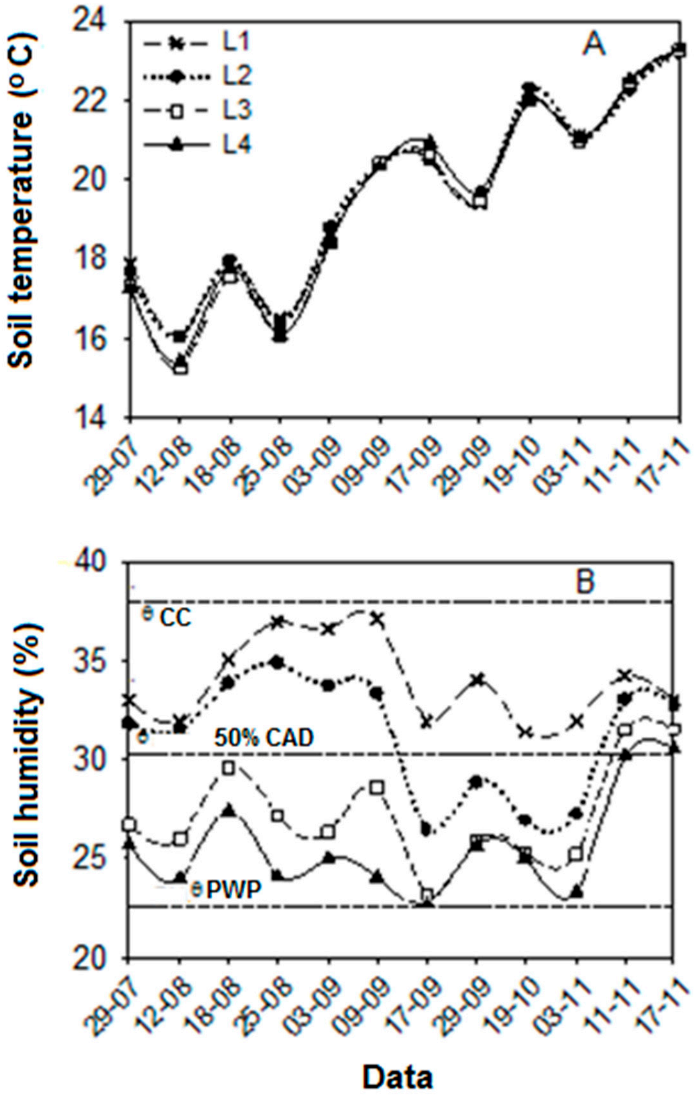

Figure 6. Soil temperature and moisture in the 0-5 cm layer of areas containing *Brachiaria brizantha*, cv Marandu, submitted to treatments with 100% (L1), 75% (L2), 50% (L3) and 25% (L4) of accumulated culture evapotranspiration reposition (ETc ac.) (A). θ_{CC} = soil volumetric moisture in field capacity; $\theta_{50\%\ CAD}$ = 50% of available water capacity (AWC); θ_{PMP} = soil volumetric moisture at the permanent wilting point (B).

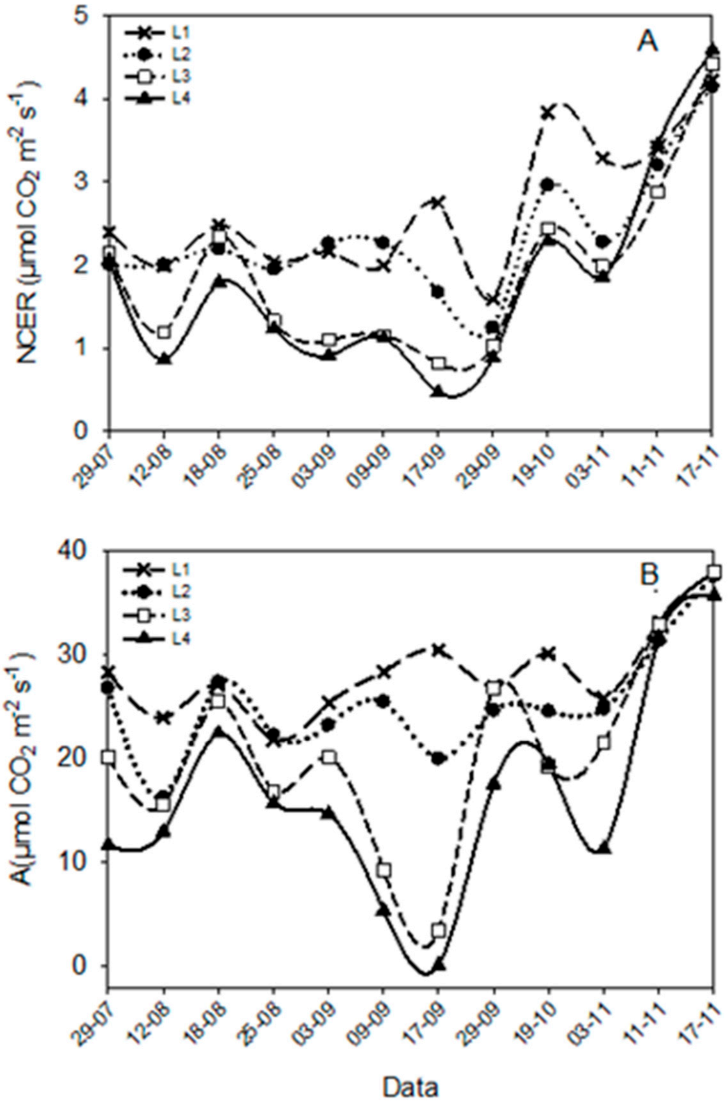

Figure 7. Soil CO_2 efflux (NCER) in areas with *Brachiaria brizantha*, cv Marandu, submitted to treatments with 100% (L1), 75% (L2), 50% (L3) and 25% (L4) of accumulated culture evapotranspiration reposition (ETc ac.) (A). Leaf net assimilation of CO_2 (*A*) in areas of *Brachiaria brizantha,* cv Marandu, submitted to treatments with 100% (L1), 75% (L2), 50% (L3) and 25% (L4) of evapotranspiration reposition of accumulated crop (ETc ac.) (B).