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Thermal time in nitrogen and boron application on irrigated Mombaça grass "Guinea grass"

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Abstract
This study aims to evaluate the correlation among growing degree-days (GDD), canopy height (CH), and leaf area index (LAI) for Guinea grass irrigated, considering the different combinations of the nitrogen and boron rates and cycles of regrowth. The experiment was carried out from August/2017 to August/2018 in a field experiment, and the climate of the region is classified as subtropical. A randomized block design arranged in a factorial scheme (4x3x11) with four replications was used. The treatment was (i) boron fertilization: 0, 1, and 2 kg ha^{-1}; and (ii) nitrogen fertilization: 250, 500, 750, and 1,000 kg ha^{-1} distributing to 11 growth/cutting cycles. We observed the high correlation between GDD and the parameters evaluated of CH and LAI. The nitrogen results showed a low influence on canopy height and the leaf area index, and boron results did not influence these parameters.

Keywords: degree-days; pasture irrigation; carrying capacity; animal stocking rate; forage yield.

Tiempo térmico en la aplicación de nitrógeno y boro en pasto Mombaça de regadío "pasto Guinea"

Resumen
El objetivo fue evaluar la correlación entre los grados-día de crecimiento (GDC), altura del dosel (AD) y índice de área foliar (IAF) para el pasto Guinea irrigado considerando la diferente combinación de las tasas de nitrógeno y boro y los ciclos de rebrote. El experimento se llevó a cabo de agosto/2017 a agosto/2018, en un experimento de campo y la región climática se clasifica como subtropical. Realizó un experimento factorial (4x3x11), con cuatro repeticiones y corrido en un diseño de bloques completamente aleatorio. Tratos: fertilización con boro: 0, 1 y 2 kg ha^{-1}; fertilización con nitrógeno: 250, 500, 750 y 1,000 kg ha^{-1} distribuidos en 11 ciclos de crecimiento/corta. Hemos observado la alta correlación entre GDC y los parámetros evaluados para AD y IAF. Los resultados de nitrógeno mostraron una baja influencia en la altura del dosel y el índice de área foliar, y los resultados de boro no presentaron influencia en estos parámetros.

Palabras clave: grados-días; riego de pastos; capacidad de carga; tasa de carga animal; rendimiento de forraje.

1. Introduction

The beef consumption for human beings started in the early ancestor Aurochs, during the Egyptian era in the Nile River valley around 3,000 BC. In the Brazilian context, meat and leather became essential export goods around the end of century XVIII. Nowadays, the country is one of the main global players exporting to destinations like Russia and China [15].

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Although Brazilian beef cattle production uses extensive systems, the proper handling of pasture is a challenge for the farmers due to the growth of pasture influenced by climatic variables that involve energy flow into the environment [6]. In tropical areas, higher temperatures contribute to forage plants growing, and associate with correct pasture handling, it is possible to provide a higher production [8,10,16]. Nevertheless, during the winter, the irrigation application under mild temperature reduces pasture production due to the productivity of tropical grasses, mainly influenced by photoperiods that stimulate floral induction [2].

Currently, pasture handling is based on the determination of biometrics parameters, such as the height of the grass. Therefore, acknowledging the crop phenological cycle is crucial to adopting correct pasture handling [14].

The thermal accumulation of thermal time, also called by growing degree-days (GDD), has been used to define the answer of plant development under temperature [1,4]. Temperatures below the crop pattern directly impact metabolic processes that result in low rates and affect plant development. Several studies about tropical forage pattern temperature have indicated a value of around 15 ºC as an adequate temperature [12].

A previous study from [15] reported a high correlation between the height of the plant and the thermal time. The authors observed that growing degree-day accumulation was slightly lower in a cut cycle during autumn/winter with 12 days more than spring/summer cut cycles. They observed a significant correlation between GDD and canopy height and the GDD and IAF. Thus, applying to the GDD concept allows adequate grazing growth management and animal handling due to climate data obtained from seasons of the year.

With these ideas in mind, this paper aims to analyze the correlation among the thermal sum with the canopy height (CH) and the leaf area index (LAI) of the Guinea grass *Megathyrsus Maximus* (Syn. Panicum maximum cv. Mombaça).

2. Material and methods

2.1 Experimental site and forages

The experiment was carried out from August 2017 to August 2018, in the Luiz de Queiroz College of Agriculture (ESALQ/USP), located in Piracicaba city, SP (Latitude 22º 42' 14.6" South; Longitude 47º 37' 24.1" West; altitude 569 m). The local soil of the experiment field is classified as Clayey Oxisol (Nitossolo Vermelho Eutroférrico Latossólico, in Brazilian classification) [9]. It presents the particle-size characteristic of 32.5% sand, 18.9% silt, and 48.6% clay. According to Köppen classification, the region climatic is Cwa – subtropical or tropical of altitude, hot summer, low frequency of frost, and rain concentration during the summer period [13].

Four replications were conducted, and the 12 plots measured 2.3 x 2.75 m, 3.33 m² each, resulting in a useful field of 303.6 m² and an entire field of 440 m², including the borders. A randomized block design arranged in a factorial scheme (4x3x11) with four replications was used. The treatment was (i) boron fertilization: 0, 1, and 2 kg ha^{-1}; (ii) nitrogen fertilization: 250, 500, 750, and 1,000 kg ha^{-1}; (iii) 11 growth/cutting cycles, throughout the seasons of the year.

The forage species used was the Mombaça grass "Guinea grass" *Megathyrsus Maximus* (Syn. Panicum maximum cv. Mombaça). The 11 collect cycles during one experimental year were split into five cycles during autumn/winter and six cycles during spring/summer.

The experiment was beginning in 2017 in the experimental field that already contained the forage implanted since 2015. The soil preparation included plowing, harrowing, control of invasive plants, pH correction with the application of the dolomitic limestone with a dose of the 2 Mg ha^{-1} and the fertility with fertilization of the 250 kg ha^{-1} of Super Single (18% of P2O5), and 300 Kg ha^{-1} of the Potassium Chloride (60% of K2O). The seeding of the Mombaça grass occurred from October to November 2015. In 2017, the new ground chemical analysis was processed, and the necessity of acidity soil correction was noticed with 2 Mg ha^{-1} of dolomitic limestone before the beginning of the experiment.

On August 11, 2017, the plots proceeded with the forage standardization cut, and the experiment was started. During the experimental period, the temperature range was from

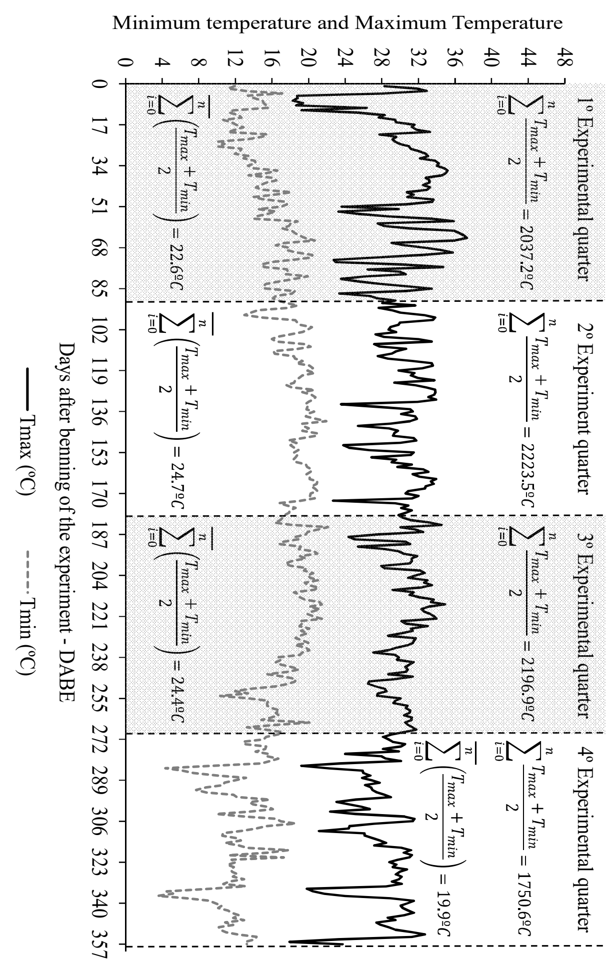

Figure 1. Minimum (Tmin) and maximum (Tmax) temperatures during the experimental period, from 08/2017 to 08/2018. Piracicaba-SP, Brazil.
Source: The Authors.

a minimum of 3.6 ºC to a maximum of 37.3 ºC. In the last quarter of the experimental year was observed the lower temperature, with a thermal time of 1,750.6 ºC (Fig. 1).

2.2 Irrigation system

The plots irrigation was carried out using the irrigation system by conventional sprinklers with low flow and sectoral devices. The sprinklers were fit to work at 90º angle (each plot segregated the irrigation system), and the service pressure used was 250 kPa (25 mca) and flow rate of 0.584 m^3 h^{-1}, installed considering a space of 11 x 8 m (sprinklers x lines), resulting in an application intensity (Ia) of 17.1 mm h^{-1}. The irrigation was performed in rotation fixed (04 days) and variable water blade, according to the measuring of the crop water consumption through tensiometers installed in the experimental field.

The water depth (LI) was determined from the averages of matric potential (Ψm, bar), calculated from tensiometer readings installed in the crop root zone. Values of Ψm it was correlated with the soil water retention curve to obtain the current volumetric humidity (θa in mm) and the current storage of water in the soil (ARMa, mm), and it was considered an effective roots depth (Z) equal to 0.4 m.

Current humidity values (θa) were estimated from the soil water retention curve obtained with the tension table and Richards extractor in the Soil and Water Quality Laboratory in ESALQ/USP. It was adjusted using the [20], Eq.1.

$$\theta_a=0.2938+\left[\frac{(0.4934 - 0.2938)}{\left[1+(0.113\Psi m_a)^{1.3211}\right]^{0.2431}}\right];\ (R^2=1.00;\ P<0.01) \quad (1)$$

θa – current volumetric humidity (cm^3 cm^{-3}); Ψma – current soil matric potential (bar).

The humidity values to field capacity (θcc) and to permanent wilting point (θpmp) corresponding to matric potential values Ψmcc = 10 kPa (0.1 bar) [5] and Ψmpmp = 1,500 kPa (15 bar).

The maximum interval between irrigation was previously established based on a minimum value of the storage capacity of water in the soil, such as to maintain the critical humidity up to 60% of the capacity of water available (CAD, mm – humidity between field capacity and the permanent wilting point) (θ60 = humidity to 60% CAD).

2.3 Experimental Management

Each experimental plot was performed successive cut cycles up to August 2018, about one year. We adopted a post-cut height (residue) of 0.3 m to Mombaça grass "Guinea grass", following the literature recommendation [18].

Cutting cycles and forage collection were variables concerning the season of the year: autumn/winter, 40 days; and spring/summer, 28 days. During the cycles was determined (i) luminous interception (IL, %), measured from using the apparatus LAI 2000 Plant Canopy Analyzer (LI-COR®); (ii) leaf area index (LAI, m^2 m^{-2}), estimated from IL; and (iii) the canopy height (CH, cm), based on a graduated ruler with amplitude from 0 to 150 cm, in a leaf base support.

We used the biometric parameters (LAI and CH) to establish the correlation with the growing degree-days accumulation (GDD, ºC d^{-1}). It was applied the measuring interval pattern in 04 days for all experimental plots. The luminous interception reading (IL) by forage dossal proceeded simultaneously with biometric parameters in a period with low solar radiation (before sunset). To measure the canopy height (CH), we carried out six-point in each plot, and the height measurements were obtained from the ground to the last expanded leaf curvature.

The GDD was calculated concerning period variables by curt cycle, according to the indication of luminous interception, with a limit of GDD where IL = 95%, that it is considered the ideal time to cut, or grazing started [7].

2.4 Statistical analysis

The growing degree-days (GDD) was estimated following the recommendation of the [3], Eq.2.

$$GDD=\sum\left[\frac{(TM+Tm)}{2}-Tb\right] \quad (2)$$

TM – maximum daily temperature (ºC); Tm – minimum daily temperature (ºC); Tb - lower base temperature (ºC).

Generally, the lower base temperature (Tb) of the tropical grasses will be from 12 to 15 ºC [1,6,12]. However, to obtain data more precisely, the Tb was determined considering the lower standard deviation in degree-day [21], Eq.3.

$$Tb=\frac{\sum_{i=1}^{n}(Ti\times di)\sum_{i=1}^{n}di-n\sum_{i=1}^{n}(di^2\times Ti)}{(\sum_{i=1}^{n}di)^2-n\sum_{i=1}^{n}di^2} \quad (3)$$

Tb – lower base temperature (ºC); Ti – the average temperature of each specific period; n – number of the cut cycles; di – number of the days to meets the development stage in each cutting series or cycle.

Thus, the lower base temperature to Mombaça grass was 14.1 °C. Data analysis has proceeded with the normal distribution, variance F test, and descriptive statistics using MS Excel® electronic sheet and the ActionStat supplement.

1) Data were split by season (autumn/winter and spring/summer) to identify differences from GDD, LAI, and CH parameters assessment in each season of the year; also, we clustered the data according to treatment (nitrogen and boron);
2) Anderson-Darling test was applied to verify if the data was adjusted in the Normal Distribution;
3) To analyze the variance among data, we proceeded the F test, and after we followed in selecting the adequate tests;
4) To test differences between treatments from two-sample, we carry out the T-test.

To conclude, we used the MS Excel® electronic sheet to carry out the regression curve models.

3. Results and discussion

Based on pasture growth that is characterized by vigor growth during rainy periods and the lower growth during the cold and dry periods (known as production off-season), the data was divided: autumn/winter (dry season) and spring/summer (rainy season). All data showed normal distribution by the Anderson-Darling test; therefore, there was no necessity to applying data transformation. No significant effect was demonstrated by boron rates on tests performed.

The F Test values were higher than the critical F value (Fcritical value = 0.05) for the season of the year considering evaluated parameters, resulting in similar variances with homoscedastic T-test without difference between the average of the GDD (growing degree-days) and CH (canopy height). To leaf area index (LAI) showed the T-Test value lower than the critical T-Test (Pcritical value = 0.05) at the significant level of 95%, [P (T<=t) = 0.0037] and it was observed difference between averages.

The T-Test applied to a similar variance of the treatments with nitrogen rates showed differences among samples according to accumulated degree-days of the season of the year, a significant level of 95% ($P<0.05$). Results to nitrogen rates N1, N2, N3 and N4 were P (T<=t) = 0.001, 0.002, 0.001, and 0.001, respectively. However, we do not observe significant differences among averages to samples of the LAI considering nitrogen rates N1, N2, N3 and N4, P(T<=t) = 0.149, 0.128, 0.125, and 0.149, respectively.

According to [14], the pasture growing depends on active photosynthetic radiation (PAR), which directly affects several elements, such as the higher GDD in the rainy period. The authors observed cycles of 35 days (rainy period) and 48 days (dry period) and a similar GDD accumulation. Our results showed the accumulated values to each cycle were similar (Figs. 2a and 2b), with 289.9 and 291.1 GDD, autumn/winter (cycle 40 days), and spring/summer (cycle 28 days), respectively.

The average daily thermal sum was 7.2 GDD d^{-1} during the autumn/winter period, and 10.4 GDD d^{-1} during the spring/summer period (Figs. 2c and 2d), with 31% less than the daily thermal sum in-season dry. Similar results were observed by [17], with GDD daily accumulations higher in the spring/summer to Guinea grass with 36% (6.6 GDD d^{-1} in the autumn/winter, and 10.2 GDD d^{-1} spring/summer).

The graphic of leaf area index (LAI) and the canopy height (CH) of Guinea grass showed that, in a similar climate condition like of the experiment, pasture with this forage present linear growing of LAI and CH according to thermal sum (GDD), (Fig. 2). In the study conducted with Brachiaria brizantha grass (cv. Piatã), the direct relation of growing with LAI was observed, resulting in a linear relation between them [6].

Although the dry cycles were longer than rainy cycles (Figs. 2c and 2d), both periods, with values of a similar thermal sum around 290 GDD, the crop reached the cut point or grazing with Luminous Interception Index by maximum leaves (LI = 95%) [6,8,14]. [17], noticed the same resulting to Guinea and Bermuda grasses (Cynodon genus) and concluded that it is possible to obtain correlation among CH, LAI, and GDD.

We noticed a direct relationship between growing (CH) and thermal sum (GDD), and the basal temperature (Tb) as a limiting factor to GDD accumulation, with the lowest air temperature, it was 3.6 ºC at the last quarter of the experiment (Fig. 1). A study [4] about basal corn temperature observed

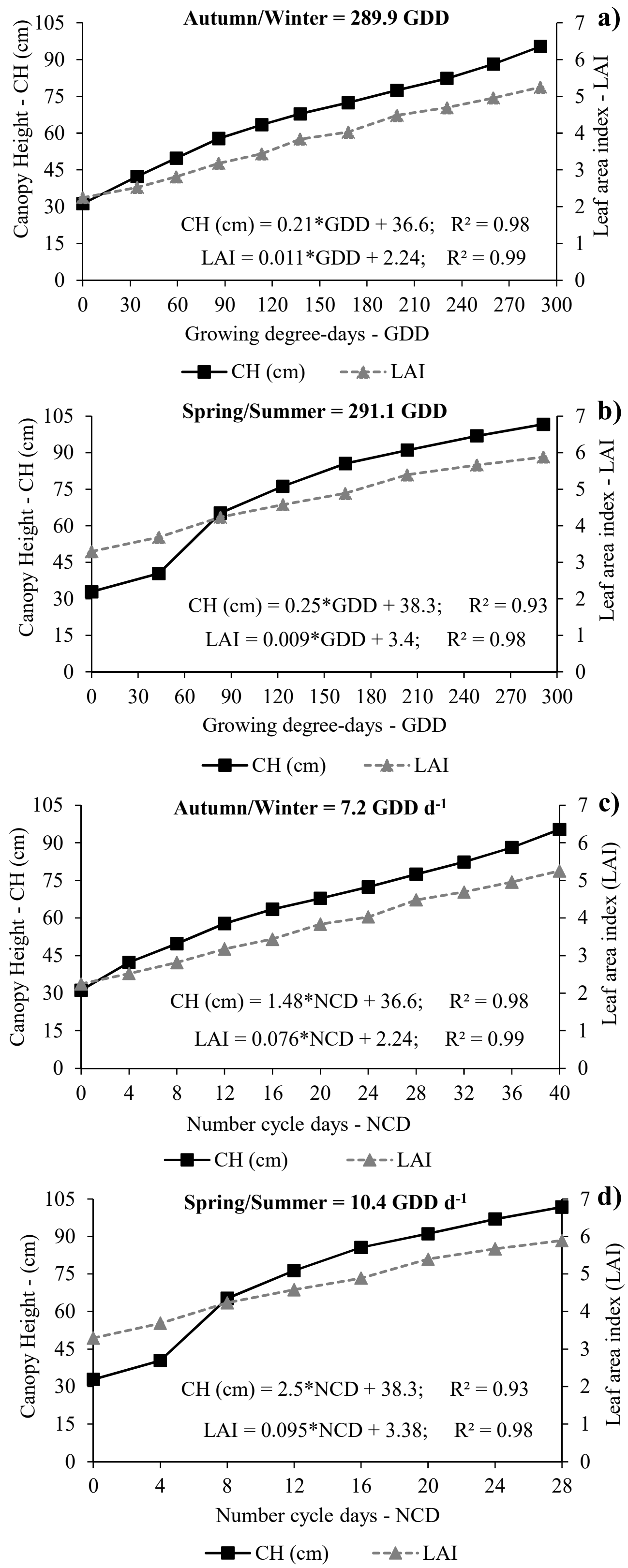

Figure 2. Guinea grass: empirical models for estimation of canopy height (CH, cm) and leaf area index (LAI, m^2 m^{-2}) as a function of growing degree-days (GDD): (a) autumn/winter (b) spring/summer; and as a function of number cycle days (NCD): (c) autumn/winter (d) spring/summer. Piracicaba-SP, Brazil, 2017/18.
Source: The Authors.

that air temperature variation promoted plant morphological changes, modifying tiller density and impacting LAI and CH growth. It is possible to verify the smallest sum (1,750.6 ºC) and average (19.6 ºC) of the air temperature at the last quarter of the experiment (dry period), consequently resulting in the smallest thermal accumulation.

Linear models helped explain the temperature effect on forage accumulation—moreover, submodels based on temperature and GDD to simulate plant growth. No grown is expected for tropical grasses when temperatures are between 10 and 15 ºC [12]. However, our results observed growth in autumn/winter, with 15 days with the minimum temperature below 10 ºC (Fig. 1).

Among the characteristics of the Megathyrsus genus (Syn. Panicum), highlight the large size, reaching a height between 1.5 and 1.8 m. Although from a certain point, the canopy height (CH) increasing mainly by culm stretching. [7] and [18] observed that from Heights between 85 and 95 cm with 95% of luminous interception (LI), the leaf production was not significant concerning the loss from the lower third of the plant. Therefore, it established the ideal height when the grass reaches LI = 95%, with CH ≈ 0.95 m and LAI ≈ 6.0 (Fig. 2).

When we compared nitrogen rates (250, 500, 750, and 1,000 kg ha^{-1} year^{-1}), results showed similar growth to CH and LAI. Values from the N4 dose were slightly higher than others (Fig. 3). Thus, we can infer that CH and LAI are not exclusive parameters to evaluate the forage production, even though they are significant indicators of the entry handling of the animals in pasture paddocks.

Results observed [11] appointed that the leaf stretching rates Panicum maximum (Syn. *Megathyrsus maximus*) cv. Massai grew up to second nitrogen dose (N 450 mg dm^{-3} of soil), and after this moment, the authors did not observe any effect. Our results showed a CH average difference of approximately 15 cm during the season of the years between N1 (250 kg of N) and N4 (1,000 Kg of N) rates (Figs. 3b and 3d) and comparing the productivity (CH = 95 cm) we found a difference of 16%, that resulting in a production difference of 22 Mg ha^{-1} year^{-1}, presenting satisfactory adjustments and contributing to improvements in crop water management [19].

We noticed a higher growth of up to 90 GDD during both periods (autumn/winter and spring/summer), corresponding from 6 to 16 ºC days of the cycle (Figs. 4b and 4d). Thus, this could be relating to nitrogen cover fertilization, applied after the forage cut, and the peak of Guinea grass growth that occurs in the first days after the cut [17].

The LAI reached higher values during the spring/summer period between nitrogen highest and lowest rates (1,000 and 250 kg ha^{-1} year^{-1}, respectively). From the dry to rainy period, we observed that upper borderline average values of LAI vary from 5.3 to 6.3 m^2 m^{-2}, respectively.

Assessing the LAI in the different seasons of the year, [19] also observed the same variations in the indexes. For the authors, a standard rest (fixed cycle days) period is not effective in defining grazing management in field conditions since herbage accumulation rates of *Panicum maximum* cv. Mombaça varies significantly throughout the year.

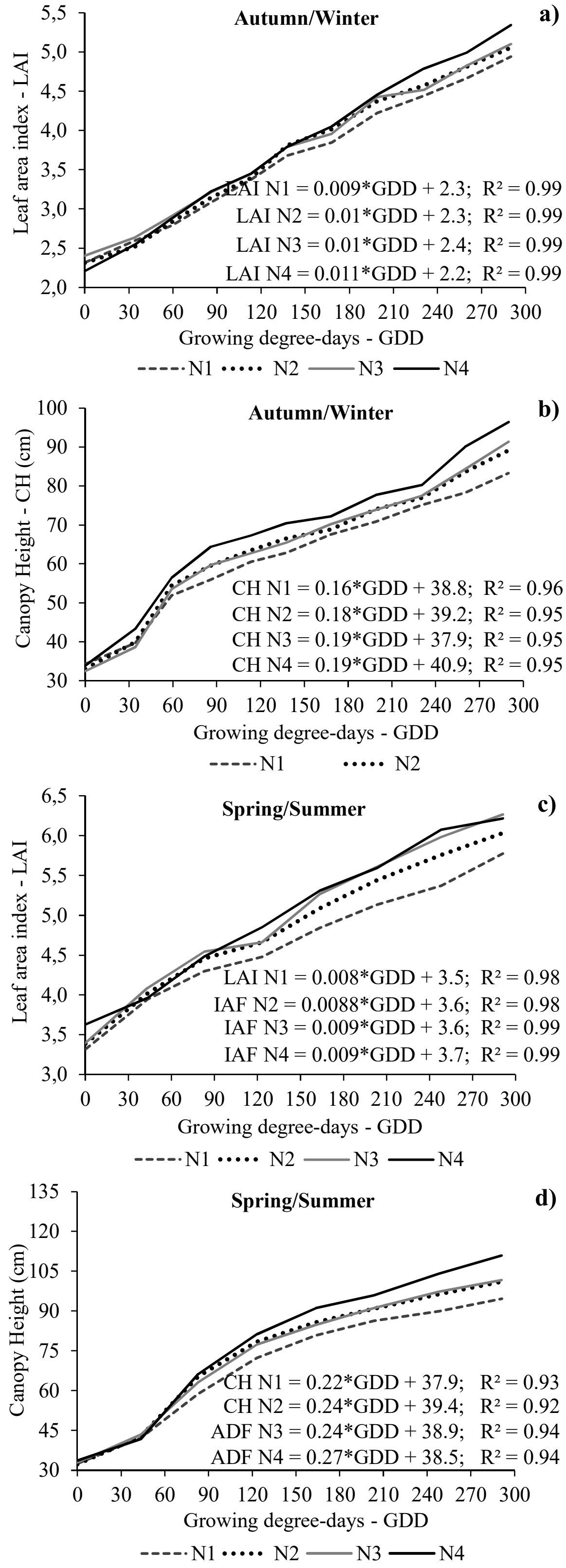

Figure 3. Guinea grass: empirical models for estimation of leaf area index (LAI) and canopy height (CH) as a function of growing degree-days (GDD) for the different nitrogen rates: a) LAI autumn/winter, b) CH autumn/winter, c) LAI spring/summer and d) CH spring/summer. Piracicaba-SP, Brazil, 2017/18.
Source: The Authors

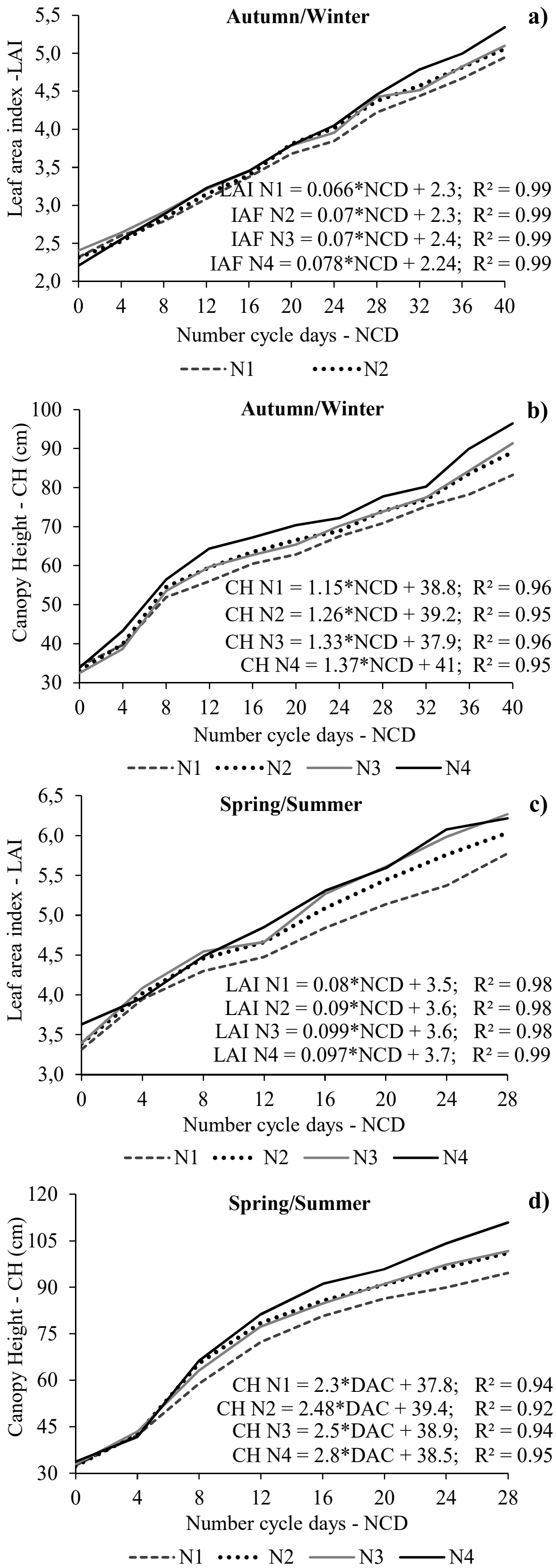

Figure 4. Guinea grass: empirical models for estimation as a function Number cycle days (NCD) for: (a) LAI autumn/winter, (b) CH autumn/winter, (c) LAI spring/summer and (d) CH spring/summer. Piracicaba-SP, Brazil, 2017/18.
Source: The Authors.

4. Conclusions

Empiric models with linear regression adjusted, and a higher correlation coefficient for all treatments have resulted from the correlation between the canopy height (CH), the leaf area index (LAI), and growing degree-days.

The Guinea grass showed high growth in the first 15 days of the cycle, and the forage dossal reached luminous interception LI = 95% in cycles from 28 days (spring/summer) to 40 days (autumn/winter).

When applied adequately, the thermal sum (GDD) is helpful to estimate the LAI and CH, consequently, the animal handling in rotational grazing systems.

The nitrogen rates showed a low influence on biometrics parameters addressed. The boron rates were not evaluated because it was not observed effect on pasture growth and production variation.

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