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PHYLLOCHRON ESTIMATES ON AGRONOMIC POTENTIAL AND PHYSIOLOGICAL QUALITY OF MILLET

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Abstract

Millet is largely explored for a diversity of applications. The use of millet high-quality seeds is essential to increase grain yield. Accordingly, the purpose of this study was to evaluate the yield variability of millet plants from higher and lower-quality seeds in the expression of dry matter yield parameters. The study was conducted in the experimental and didactic area of IFRS - *campus* Ibirubá, Rio Grande do Sul, Brazil, with a completely randomized design. The treatments were plants from seeds of higher (HQS) and lower (LQS) quality and two season crops (2015/16 and 2017/18) in eight replications. The emergence speed was applied to identify plants from seeds of different qualities. The phyllochron, leaf number, height, stem diameter, number of nodes, and dry mass yield were the agronomic components evaluated for this study. Meteorological information was used to calculate phyllochron, water deficit, and average temperature. The collected data were submitted for analysis of variance and the Tukey test at a 5% probability of error. The HQS expressed lower phyllochron and most significant agronomic components. Furthermore, the 2015/16 crop had the lowest water deficit and obtained the best results.

Keywords: dry mass; *Pennisetum glaucum* (L.) R.Br; plant morphological characterization; thermal sum.

ESTIMATIVAS DO FILOCRONO NO POTENCIAL AGRONÔMICO E NA QUALIDADE FISIOLÓGICA DO MILHETO

Resumo

O milheto é amplamente explorado para uma diversidade de aplicações. O uso de sementes de milheto de alta qualidade é essencial para aumentar a produtividade de grãos. Nesse sentido, o propósito deste estudo foi avaliar a variabilidade da produtividade de plantas de milheto

provenientes de sementes de melhor e de menor qualidade na expressão dos parâmetros de produção de matéria seca. O estudo foi realizado na área experimental e didática do IFRS - campus Ibirubá, Rio Grande do Sul, Brasil, com delineamento inteiramente casualizado. Os tratamentos foram plantas provenientes de sementes de qualidade superior (SAS) e inferior (SQI) e duas safras (2015/16 e 2017/18) em oito repetições. A velocidade de emergência foi aplicada para identificar plantas a partir de sementes de diferentes qualidades. O filocrono, número de folhas, altura, diâmetro do caule, número de nós e rendimento de massa seca foram os componentes agronômicos avaliados para este estudo. As informações meteorológicas foram utilizadas para calcular o filocrono, o déficit hídrico e a temperatura média. Os dados coletados foram submetidos à análise de variância e ao teste de Tukey a 5% de probabilidade de erro. O SQS expressou menor filocrono e componentes agronômicos mais significativos. Ainda, a safra 2015/16 apresentou o menor déficit hídrico e obteve os melhores resultados.
Palavras-chave: massa seca; *Pennisetum glaucum* (L.) R.Br; caracterização morfológica das plantas; soma térmica.

Introduction

The millet is an annual summer Poaceae, with a C4 photosynthetic system, presents tolerance to drought and high temperatures, and shows high potential for animal feeding (PAVITHRA *et al.*, 2020). Its main purposes in production are for silage, grains, pasture, and straw for the no-tillage system (CROOKSTON *et al.*, 2020). Confinement and crop-livestock integration are applications to improve the annual income distribution of producers. Accordingly, millet is an interesting crop, since it is able to be cultivated with lower production costs, as well as being applied in ruminant feeding without altering consumption and animal performance (LAURIAULT *et al.*, 2021).

Attribution of financial resources solely used to maintain the productive potential of the cultivar, such as fertilization, phytosanitary treatment, weed control, and other cultural practices, are not capable of increasing the productivity characteristic of the genotype (GUPTA *et al.*, 2012). Genetic advancement is essential when it comes to raising the grain yield. Nonetheless, to reach higher grain yield performances, a significant attention must be established to the seed quality, as they will carry the potential selected by the breeding program (KEBA *et al.*, 2022).

The productive potential, resistance to diseases, insects, adverse environmental factors, product quality, response to inputs, and precocity are characteristics that influence the agronomic value of the cultivar (AUSIKU *et al.*, 2022). Appropriately, these variables can be interfered by the low seed quality. Seeds with high vigor have desirable characteristics for faster emergence and easier adaptation, such as faster translocation from seed reserves to seedling tissues (GUPTA *et al.*, 2022). Therefore, higher quality seeds can generate a considerable establishment of plants, consecutively, the stand will be more appropriate, and this condition is capable of interfering with production. Moreover, the exploration of high-quality seeds is an important parameter to increase the chance of successful cultivation. Vegetative development is extremely important for annual crops, especially for those whose purpose is biomass production (SALEEM, 2022). Contextually, techniques such as phyllochron determination, which is an important parameter to estimate plant development, are encouraged (RAKOCEVIC; MATSUNAGA, 2018).

The concept of phyllochron is defined by the interval between the emission of leaves with similar development on the same stem (SANTOS *et al.*, 2022). This parameter must be observed without the use of magnification or changing the way the leaf is displayed. The results can be expressed in units of thermal time (°C day^{-1}) and its influence on the sowing date is an important factor to verify the adaptation of cultivars, recommendations, and the proper crop management (SCHMIDT *et al.*, 2018).

Appropriately, the thermal sum is a concept of heat unit successfully applied in agricultural sciences. This component is calculated in its simplest form by subtracting the daily average temperature (Tave) by the lower base temperature (Tb), at which point the plant has zero or very low development (LIMA; SILVA, 2008). Since the phyllochron is directly related to the emission of leaves over time, the accumulated thermal sum is expressed in °C day $leaf^{-1}$ (CALVACHE *et al.*, 2020).

Moreover, there are different methods explored to estimate the thermal sum and the phyllochron. These strategies generally vary according to the application or not of optimal temperature and higher base additionally to the lower base temperature and in the form of using minimum, maximum, and average temperatures (KNAPP *et al.*, 2020). As observed by Rosa *et al.* (2009), in a study where different methodologies were compared to calculate the phyllochron, the method that obtained the lowest standard deviation, was indicated as the most suitable for performing the phyllochron calculation, as it uses the lower base temperature (Tb), optimal temperature (Topt) and upper base temperature (TB) for the development of the culture, in addition to those normally used in other methods, such as the minimum (Tmin), maximum (Tmax), and average (Tave) daily air temperatures.

Additionally, there are other methods to estimate plant development. The calculation methodology proposed by Wang and Engel (1998) consists of a non-linear model for evaluating plant development, where it is determined by means of beta distribution, with positive limits of 0 and 1 and with three biological coefficients (Tb, Topt, and TB) for the plant development. When the response of the function is 0, the development is extremely reduced by the extrapolation of the limits of Tb or TB. Contrastingly, when the response of the function is 1, the plant has the maximum development because the temperature is at optimal levels.

Nevertheless, the deficiency of research on millet crops means that data is significantly scarce. Correspondingly, research is required to promote knowledge related to the use of seeds of different qualities in millet crop yield. Accordingly, the purpose of this study was to evaluate the productivity of dry matter, phyllochron, height, main stem diameter, number of nodes, and leaves as a function of the use of higher and lower quality seeds in millet in distinct agricultural years.

Material and methods

Area characterization

The experiment was conducted in the experimental and didactic area of the Federal Institute of Education, Science and Technology of Rio Grande do Sul, Ibirubá, Brazil. The experimental area is located in the physiographic region of the Middle Plateau, Rio Grande do Sul (latitude (º) -28.656178, longitude (º) -53.112895, and 416 m above sea level). The Köppen climatic characterization is Cfa (humid subtropical). The soil was classified as a Typical Dystroferric Red Latosol (SANTOS *et al.*, 2018). The agronomic components determination and analyzes were conducted in the Didactic Laboratory for Research and Analysis of Seeds and Grains and in the Laboratory for Research on Annual Crops, Federal Institute of Education, Science and Technology of Rio Grande do Sul, Ibirubá, Brazil.

Experiment delineation

In the 2015/16 and 2017/18 crop seasons, the experiment was implemented in the direct seeding process using a certified lot of the ADR-500 cultivar. The desired population was 440,000 plants ha^{-1}, with row spacing of 0.34 m and the soil condition at the time of sowing was friable. The sowing depth used was 4 cm. The control of this factor and others that could interfere with the emergence speed of each seed, was performed at the sowing procedure, through visual evaluations. Appropriately, in the 2015/16 crop season, the crop was sown on 2015 April 11th. In 2016/17, the desired plant population was not reached, not allowing the experiment to be conducted in this season. In the 2017/18 agricultural year, millet was sown on 2017 March 11th.

The treatments consisted of plants from higher (HQS) and lower (LQS) quality seeds and the 2015/16 and 2017/18 crop seasons. The experimental design applied was completely randomized, consisting of eight replications for each seed quality within each season. Three plants were indicated per repetition. Therefore, an experimental unit constituted by the arithmetic mean between three plants and totaling 32 experimental units in the work.

To define the plants originating from higher and lower quality seeds, the methodology reported by Panozzo *et al.* (2009) and Schuch *et al.* (2009) was adopted. The first seedlings emerged, seven days after sowing, were considered as plants from higher quality seeds (HQS). Moreover, plants from lower quality seeds (LQS) were defined as the last seedlings to emerge, which occurred two days after emergence of HQS. This definition was possible because only one batch of certified seeds was used and in the same batch there are both higher and lower quality seeds.

Finally, between plant emergence and beginning of plant flowering period, the number of fully expanded leaves on the main stem (LN) was observed, with three evaluations every week. The last sheet issued was marked with the use of an elastic band, wrapping it.

Phillocron determination

To calculate the phyllochron, phenology data were used in association with climatic temperature data collected at the meteorological station of the Federal Institute of Education, Science and Technology of Rio Grande do Sul, Ibirubá, Brazil. The lower base temperature (Tb), optimal temperature (Topt), and upper base temperature (TB) of the millet were 10 °C, 33 °C, and 45 °C, respectively (SINGH *et al.*, 1998). The determination of the average temperature (Tave) was performed by collecting data from the campus meteorological station, then calculating the arithmetic mean between the minimum (Tmin) and maximum (Tmax) air temperatures on that day, with the following exceptions (ROSA *et al.*, 2009):

If $Tmin < Tb$, $Tmin = Tb$;

If $Tmax > TB$, $Tmax = TB$.

The phyllochron was determined according to the method suggested by Rosa *et al.* (2009) who obtained the least standard deviation, using the following equations to determine the thermal sum:

If $Tb < T\text{ave} \leq T\text{opt}$, $\text{TS}d = (T\text{ave} - Tb) \times 1\text{day}$;

If $T\text{opt} < T\text{ave} \leq TB$, $\text{TS}d = (T\text{opt} - Tb) \times (TB - T\text{ave}) \div TB - T\text{opt} \times 1\text{day}$.

Since TSd was accumulated from each plant emergence to the beginning of its maturation, this period resulted in the accumulated thermal sum (TSa): $\text{STa} = \sum \text{TSd}$. Linear regression was performed between LN and TSa for the mean of each repetition and the phyllochron was estimated as the inverse of the slope of this linear regression (MENDONÇA *et al.*, 2012).

Analytical procedures

When the identified plants reached physiological maturity, they were collected individually by cutting at the ground level. Afterward, the collected material was directed to the laboratory and the morphological characteristics evaluations were performed. In the collected plants, the variables height, stem diameter, the number of nodes in the main stem, and dry mass were determined.

For height analysis, the measurements were performed from the apex of the plant to the base, in centimeters. Using a digital caliper, Digimess Instrumentos de Preciso Ltda., the average diameter of the main stem was determined by measuring the smallest diameter of the center of the second internode. To determine the number of nodes in the main stem, it was necessary to directly count the plants already collected, considering only the nodes above the ground.

After the evaluations were conducted, the replicates were directed to drying using a paper bag in a forced air circulation oven at a temperature of approximately 65 °C. Accordingly, daily weighing was performed to observe when the sample reached constant weight. The repetition was destined for final weighing on an analytical balance with three decimal places of precision, this value was extrapolated to kg ha^{-1} and the dry mass productivity was obtained.

Finally, data from the National Institute of Meteorology meteorological station of the Federal Institute of Education, Science and Technology of Rio Grande do Sul were also applied to determine the water balance by the SISDAGRO system. According to the system, the option of corn was selected as a crop, due to the availability and higher proximity to the Poaceae used in this study, the cycle according to the average of the period that the plants remained in the field, and clay soil due to the similarity with the experimental area, resulting in an available soil water capacity value of 76.8 mm. The water balance calculations reproduced by the system are based on the methodology of Penman-Monteith (1998) and Thornthwaite and Mather (1955).

Statistical analysis

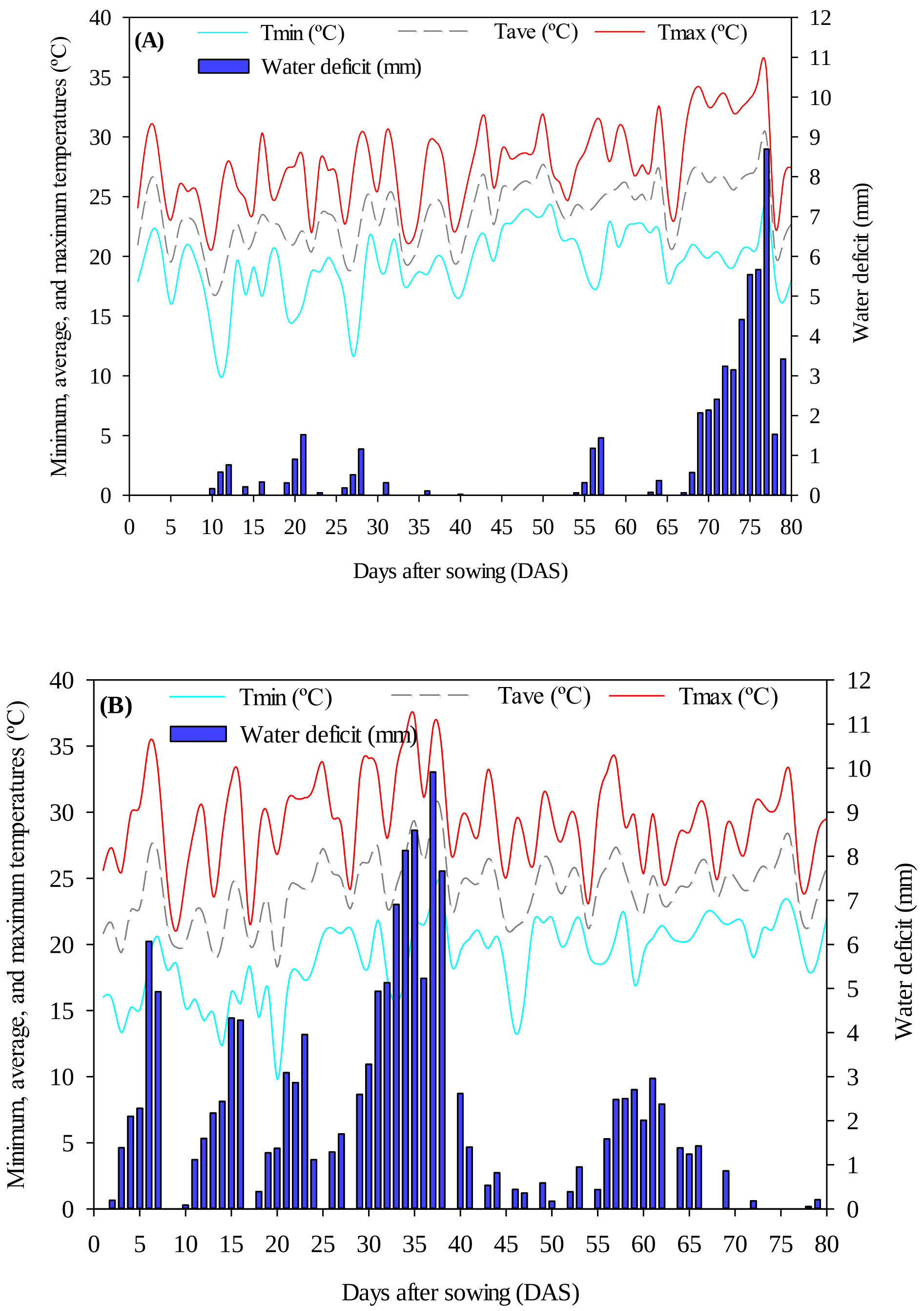
The data collected were tabulated, with the aid of the Sisvar® 5.6 statistical software package, submitted to analysis of variance, and, in case of significance, the Tukey test was applied at a 5% probability of error.

Results and discussion

The average emission of the plant reproductive structure in the 2015/16 crop season was on 2016 January 30th, 80 days after sowing (DAS) of the HQS and the dry mass collection was performed on 2016 March 12th (122 DAS). The reproductive stages and collection of millet HQS in the 2017/18 crop season occurred on average on 2018 February 5th (87 DAS) and 2018 February 28th (110 DAS), respectively.

For the first crop season (2015/16), the average minimum temperature was 19.8 °C, the average temperature was 23.6 °C, and the maximum temperature was 27.9 °C. These values in the 2017/18 crop season were 18.7 °C, 23.4 °C, and 28.9 °C, respectively. Accordingly, Figure 1 presents the meteorological data considering the (A) 2015/16 and (B) 2017/18 crop seasons.

Figure 1. Minimum (Tmin, °C), average (Tave, °C), and maximum (Tmax, °C) air temperatures and water deficit (WD, mm) in the (A) 2015/16 and (B) 2017/18 crop seasons.



During the millet crop development cycle in the 2015/16 crop season, there was a prolonged period of water deficit during the vegetative period. The accumulated water deficit was 68 mm over a period of 15 days, ending at the beginning of flowering (80 DAS). The total water deficit accumulated during the entire vegetative period was 75.0 mm in 36 days. In the 2017/18 crop season, water deficit occurred throughout the vegetative phase, observed in 63 days, which corresponds to 72.4% of the vegetative period and totaling an accumulated water deficit of 161 mm. Water deficit remained during the reproductive period in the 2017/18 crop season, which accounted for 38.8 mm accumulated in 19 of the 22 days of the phase, while in 2015/16 there were 12.5 mm in accumulated water deficit in 23 of the 44 days of the length of the reproductive period.

Rain indirectly affects the rate of the plant photosynthesis, as it interferes with soil moisture, which is a regulatory factor for all the plant metabolic processes, including the photoassimilates production. With low soil moisture, the plant will be induced to stomatal closure, reducing CO_2 fixation, therefore, delaying growth and development (DRIESEN *et al.*, 2020). The rainfall in the state of Rio Grande do Sul is variable, which impacts agricultural crops, as the irregularity of rainfall can expose plants to water deficit, reducing the performance of morphological characteristics, agronomic components, and grain yield (SELEIMAN *et al.*, 2021).

In both seasons, the final plant population obtained was approximately 440,000 plants ha^{-1}. There was a difference when the millet data was analyzed, the variables height and number of nodes in the main stem indicated an interaction between seed quality and crop season (Table 1).

Table 1. Height (cm) and number of nodes in the main stem of millet plants from the 2015/16 and 2017/18 crop seasons according to seed quality.

Quality	Height (cm)		Number of nodes	
	2015/16	**2017/18**	**2015/16**	**2017/18**
High	320 Aa	247 Ab	11.1 Aa	9.6 Ab
Low	297 Ba	186 Bb	11.1 Aa	8.0 Bb
Mean	262		9.9	
CV (%)	9.6		8.0	

Means followed by the same lowercase letter in the row or uppercase in the column did not differ from Tukey's test at 5% error probability.

For plant height, the HQS obtained higher values in the two years evaluated, the height reached in the 2015/16 crop season was 320 cm and in 2017/18, 247 cm. In relation to LQS, these results were 23 cm higher in the first crop season and 61 cm in the second, respectively.

Among the crop seasons, 2015/16 reached the highest height, regardless of seed quality, for the HQS the height was 320 cm, 30% more than in the year 2017/18, in the LQS of the first crop season, the height was 297 cm, 60% more than the second crop season. The interaction that obtained the highest height values were the climatic conditions of the 2015/16 crop season with the HQS, producing plants with an average height of 320 cm, compared to the worst treatment, composed of 2017/18 with LQS, this height increase was 72%.

Researching millet culture, Ijaz *et al.* (2016) obtained, through the collection of dry mass at 80 DAS, the highest productivity of green forage that reached 82.2 mg ha^{-1} and dry mass of 31.0 mg ha^{-1}, these results coincided with the highest height value observed, which totaled 230.12 cm. Furthermore, the leaf/stem productivity ratio was 0.24, indicating that the composition of the mass was mostly represented by the stem.

The morphological characteristic that is associated with height is the number of nodes, showing a positive correlation (HUSSAIN *et al.*, 2020). Considering this variable, in this study, there was only a difference for seed quality in the 2017/18 crop season, when in HQS the number of nodes was higher than in LQS and totaled 9.6 nodes, a difference of 17%. In the 2015/16 crop season, both seed qualities obtained 11.1 nodes in the main stem. Analyzing the reached average results of the crop season, 2015/16 values are 26% higher than in the second season.

Accordingly, phyllochron, main stem diameter, number of leaves, and dry mass, there was no interaction between plants from seeds of different qualities and crop seasons. Nonetheless, statistical differences were observed within each treatment (Table 2).

Table 2. Means of phyllochron (°C day leaf^{-1}), main stem diameter (cm), number of leaves, and dry mass (kg ha-1) of millet plants from higher and lower quality seeds and the 2015/16 and 2016/17 crop seasons.

Quality	**PL**	**SD**	**NN**	**DM**	**Crop season**	**PL**	**SD**	**NN**	**DM**
High	55.5 A	0.99 A	20.4 A	18,527 A	2015/16	57.2 A	1.15 A	19.3 A	16,701 A
Low	76.5 B	0.70 B	16.2 B	8,304 B	2017/18	74.9 B	0.55 B	17.2 B	10,130 B
Mean	66.0	0.85	18.3	13,416	Média	66.0	0.85	18.3	13,416
CV (%)	18.96	17.47	12.97	25.14	CV (%)	18.96	17.47	12.97	25.14

Means followed by the same capital letter in the column did not differ from Tukey's test at 5% error probability. PL: Phylochron (°C day leaf^{-1}); SD: Stem diameter (cm); NN Number of nodes; and DM: Dry mass (kg ha^{-1}).

The millet HQS, performed better phyllochron results, with an average value of 55.5 (°C day leaf^{-1}, lower than that observed in the LQS, which was 76.5 °C day leaf^{-1}, indicating that the requirement for thermal accumulation for the emission of a new leaf was lower, accelerating its development.

Other variables that obtained higher results for the HQS were the stem diameter, reaching 0.99 cm, while the LQS reached 0.70 cm, and the number of leaves in the main stem, 20.4 leaves and 16.2 leaves, respectively. All the additions in the dimensions or numbers of the morphological characteristics or development acceleration were of high importance to obtain the maximum performance in the production of dry mass in the HQS, which reached the productivity of 18,527 kg ha^{-1}, while the LQS obtained 8,304 kg ha^{-1}, a 123% increase in biomass provided by the use of seeds of better origin.

According to Schuch *et al.* (2009), higher performances using isolated soybean plants from higher quality seeds were observed for the morphological characteristics of height in the order of 11% more and a difference of 14% in stem diameter. According to the yield components, the performance was 22% higher for legumes per plant than those that came from higher quality seeds, 20% more biomass productivity per plant, and 25% higher in grain production per plant.

The use of more vigorous seeds was observed by Panozzo *et al.* (2009) as the treatment that obtained the highest results. The height reached was 5% higher than in the use of lower vigor seeds, the number of legumes per plant was 21% higher, the number of grains per plant 19% more, and both the grain yield per plant and the productivity were higher by 20.5%.

The results for the 2015/16 crop season were better compared to another crop evaluated. The first crop season (2015/16) had a phyllochron of 57.2 °C day leaf^{-1}, while the 2017/18 crop season reached 74.9 °C day leaf^{-1}. The SD was higher, totaling 1.15 cm, 60 more than the second crop season and it reached 19.3 leaves, 2.1 increase, positively affecting the plant dry mass, which generated productivity of 16,701 kg ha^{-1}, against 10,130 kg ha^{-1} in 2017/18 (Table 2).

Additionally, resistance to lodging is a characteristic of interest to growers and breeders, stem diameter is related to plant durability, since higher values of this morphological characteristic allow the accumulation of more reserves in the stem, increasing its resistance to mechanical actions (GAWŁOWSKA *et al.*, 2021).

Water limitation explains the high phyllochron of the 2017/18 crop season, indicating that the crop requires more °C day to develop a new leaf due to the lack of water in the medium. When water is no longer abundant in the soil, the plant will reduce the opening of the stomata or keep them closed, even when in sunny conditions. Moreover, the plant avoids suffering more from dehydration in exchange for less assimilation of the products of photosynthesis (MORAES *et al.*, 2020). Consecutively, the phyllochron explains the impact on the other variables, since it is an efficient way of evaluating the performance of plant development, indicating that it reduced the biomass productivity of each plant and influenced the production of aerial dry mass per hectare (SANCHÊS *et al.*, 2020). Similar results were indicated in the research performed by Bonfim-Silva *et al.* (2011), where the millet crop in soil moisture of 60% of field capacity, obtained twice the dry mass of moisture of 30%, and when observing the SPAD index of the three cultures evaluated (sorghum, millet, and corn) the highest chlorophyll content was observed in the field capacity of 60%, indicating that it was more photosynthetically active.

Conclusions

The study provided that the exploration of higher quality seeds produces millet plants that obtain better results in dry mass productivity and morphological characteristics. Finally, the millet is a species widely applied for many purposes and the seed quality is crucial for the plant to reach its maximum yield potential.

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