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LEAF APPEARANCE RATE AND PHYLLOCHRON ON MILLET SOWING DATES

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ABSTRACT – This study aimed to determine the leaf appearance rate and phyllochron affected by millet sowing dates. The experiment with millet (*Pennisetum glaucum* L.), cultivar BRS 1501, was conducted with six sowing dates (11/28/2019, 12/03/2019, 12/10/2019, 12/17/2019, 12/30/2019 and 01/14/2020). The sowing was performed in plots with six rows of 2 m in length, spacing 0.25 m between rows. After emergence, five plants were marked for each sowing date, and the number of leaves (NL) was counted twice a week until flowering. For each plant relative to each sowing date (30 plants), the NL, leaf appearance period (LAP, in days), accumulated thermal sum (TSa, in ºC day), leaf appearance rate (LAR, on days $leaf^{-1}$), and phyllochron in °C day $leaf^{-1}$ were determined. Among the sowing dates, there was no significant variation in the NL, with an average of 18.07. LAP varied between 49 and 88 days, TSa between 697.57 and 1299.47 °C day, LAR between 3.26 and 5.40 days $leaf^{-1}$, and phyllochron between 45.05 and 80.81 °C day $leaf^{-1}$. Millet shows faster vegetative development (lower LAP, TSa, LAR, and phyllochron) in later sowings (12/17/2019, 12/30/2019, and 01/14/2020) compared to early sowings (11/28/2019, 12/03/2019 and 12/10/2019).

Keywords: *Pennisetum glaucum* L.*,* Cover crop, Number of leaves, Leaf appearance period, Thermal sum.

TAXA DE EMISSÃO FOLIAR E FILOCRONO EM DATAS DE SEMEADURA DE MILHETO

RESUMO - O objetivo deste trabalho foi determinar a taxa de emissão foliar e o filocrono em datas de semeadura de milheto. O experimento com milheto (*Pennisetum glaucum* L.), cultivar BRS 1501, foi conduzido em seis datas de semeadura (28/11/2019, 03/12/2019, 10/12/2019, 17/12/2019, 30/12/2019 e 14/01/2020). As semeaduras foram realizadas em parcelas, com seis fileiras de 2 m de comprimento e espaçadas 0,25 m entre fileiras. Após a emergência, para cada data de semeadura, foram marcadas cinco plantas e foi contado o número de folhas (NF), duas vezes por semana, até o florescimento. Para cada planta em cada data de semeadura (30 plantas) foi determinado o NF, o período de emissão foliar (PEF, em dias), a soma térmica acumulada (STa, em ºC dia), a taxa de emissão foliar (TEF, em dias $folha^{-1}$) e o filocrono, em °C dia $folha^{-1}$. Entre as datas de semeadura não houve variação do NF, com média de 18,07 folhas. O PEF variou entre 49 e 88 dias; a STa entre 697,57 e 1299,47°C dia; a TEF entre 3,26 e 5,40 dias $folha^{-1}$; e o filocrono entre 45,05 e 80,81°C dia $folha^{-1}$. O milheto apresenta desenvolvimento vegetativo mais rápido (menores PEF, STa, TEF e filocrono) nas semeaduras mais tardias (17/12/2019, 30/12/2019 e 14/01/2020) em comparação com as semeaduras antecipadas (28/11/2019, 03/12/2019 e 10/12/2019).

Palavras-chave: *Pennisetum glaucum* L.*,* Planta de cobertura, Número de folhas, Período de emissão foliar, Soma térmica.

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Millet (*Pennisetum glaucum* L.) is an annual grass of tropical climate, and its center of origin is North Africa. The crop has several purposes of use, including the production of grains and silage. It is considered a forage of high nutritional value (Buso et al., 2014), with a high percentage of crude protein (22.3%) (Görgen et al., 2016).

Millet crop has a root system with many roots, with fast and continuous growth (Delazeri et al., 2020), giving the soil characteristics of lower density and greater porosity (Silva et al., 2017). The leaves are long and smooth and have hairy surfaces and ligules. The leaf blades are lanceolate and sometimes 90-100 cm or more long and 5-8 cm wide (Magalhães & Durães, 2009). Its dry biomass production is high, ranging from 3,667.2 kg ha^{-1} (Vuicik et al., 2018), 5,900 kg ha^{-1} (Bertolino et al., 2021), 6,396 kg ha^{-1} (Simão et al., 2015) to 8,917 kg ha^{-1} (Boldrin et al., 2022), promoting suppression of weeds.

Despite the excellent adaptability of the crop to climatic conditions, forage productivity and quality may vary depending on the sowing date (Simão et al., 2015), cutting date (Görgen et al., 2016), and genotype (Boldrin et al., 2022). Therefore, changes in temperature and rainfall conditions between sowing dates, locations, and years, that is, between cultivation environments, can influence the appearance of leaves in the plant. Thus, identifying the best sowing date and its effects on the vegetative development of plants is a way to increase production and improve millet crop management.

Given the importance of the crop, it is necessary to know its development. However, the use of the number of days as a criterion of cycle duration is incoherent because the duration of the subperiods of the plant is associated with environmental conditions (Martins et al., 2012), including temperature, photoperiod, and water regime (Simão et al., 2015). One way to monitor the development of plants is by counting the number of leaves that emerge. That is, leaf appearance is the most indicated way to evaluate the physiological time of the plant, and phyllochron represents the time interval required for the appearance of two consecutive leaves on the stem (Wilhelm & McMaster, 1995).

Air temperature is the abiotic factor that directly influences plant development, with different intensities in different stages of development. Several are the methods for determining the thermal sum. However, the difference between the average daily air temperature and the base temperature (Tb) is accumulated in the most straightforward method. The Tb is the temperature below which the development is null or negligible (Arnold, 1960; McMaster & Wilhelm, 1997).

Studies related to leaf appearance rate, phyllochron, and sowing dates were conducted with maize (*Zea mays* L.) (Streck et al., 2009; Martins et al., 2012; Santos et al., 2022), escarole (*Cichorium endivia*) (Schmidt et al., 2018), sorghum (*Sorghum bicolor* L. Moench) (Bandeira et al., 2018), okra (*Abelmoschus esculentus*) (Nunes et al., 2019) and quinoa (*Chenopodium quinoa*) (Munareto et al., 2021). These studies have found different responses of plants under environmental variations.

However, few studies are available in the literature on the variation of leaf appearance rate (LAR) and phyllochron as a function of millet sowing dates. It is assumed that in the millet crop, there is variation in LAR and phyllochron between sowing dates. Thus, this study aimed to determine the leaf appearance rate and phyllochron affected by millet sowing dates.

Material and Methods

The experiment with millet (*Pennisetum glaucum* L.), BRS 1501 cultivar, was conducted in the agricultural

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year 2019/2020 in the experimental area of the Plant Science Department of the Federal University of Santa Maria, located at 29º42'S, 53º49'W and 95 m altitude. The climate is classified as humid subtropical - Cfa (Alvares et al., 2013) and soil as *Argissolo Vermelho distrófico arênico* (Ultisol) (Santos et al., 2018). The chemical analysis of the soil was performed at 0-20 cm depth, which revealed: pH $water_{1:1}$: 5.2; Ca: 4.8 $cmol_c$ dm^{-3}; Mg: 1.5 $cmol_c$ dm^{-3}; Al: 0.3 $cmol_c$ dm^{-3}; H+Al: 8.7 $cmol_c$ dm^{-3}; SMP index: 5.4; organic matter: 2.3%; clay content: 24.0%; S: 15.3 mg dm^{-3}; P (Mehlich): 43.9 mg dm^{-3}; K: 0.593 $cmol_c$ dm^{-3}; CEC_{pH7}: 15.6 $cmol_c$ dm^{-3}; Cu: 1.77 mg dm^{-3}; Zn: 1.04 mg dm^{-3}; and B: 0.3 mg dm^{-3}.

The experiment was conducted in a randomized block design, with six sowing dates (11/28/2019, 12/03/2019, 12/10/2019, 12/17/2019, 12/30/2019, and 01/14/2020), seeking to contemplate wide variability in cultivation conditions, and five replicates (plants). On each date, sowing was performed in a plot composed of six rows of 2 m length spaced 0.25 m between rows. Sowing was performed with a density of 18.75 kg of seeds ha^{-1}, aiming at a population of 164,930 plants ha^{-1}.

For each sowing date, after emergence, five plants were randomly selected. In each plant, the number of expanded leaves (NL) was counted twice a week until flowering. The leaf appearance period (LAP, in days) was calculated from seedling emergence to the flowering of each plant (last evaluation).

Data on daily rainfall and minimum and maximum air temperatures were recorded at the Automatic Weather Station, belonging to the 8th Meteorological District of the National Institute of Meteorology located 100 m away from the experimental area. The accumulated thermal sum (TSa, in ºC day) was calculated for each evaluation using the expression TSa = Σn [(Tavg-Tb).1day] (Arnold, 1960), where Tb is the base temperature, considered as Tb = 10 °C (Norman et al., 1995; Lozada & Angelocci, 1999), and Tavg is the average daily air temperature. Tavg was calculated from the minimum and maximum air temperatures for each hour and each day.

Leaf appearance rate (LAR, in days $leaf^{-1}$) and phyllochron (°C day $leaf^{-1}$) were determined for each plant and sowing date (30 plants). LAR was calculated by the inverse of the angular coefficient of the linear regression (y = a + bx) of the number of leaves (NL, y) as a function of the number of days after emergence (DAE, x) (LAR = 1/b). Phyllochron was calculated by the inverse of the angular coefficient of the linear regression (y = a + bx) of the number of leaves (NL, y) as a function of the accumulated thermal sum (TSa, x) (phyllochron = 1/b).

Variance and F test analysis was performed at a 5% significance level for NL, LAP, TSa, LAR, and phyllochron. The means of sowing dates were grouped by the Scott-Knott test at a 5% significance level. The calculations were performed using Microsoft Office Excel® and Genes software (Cruz, 2016).

Results and Discussion

In the leaf appearance period of the millet crop (12/08/2019 to 03/17/2020), the minimum (15.91 °C) and maximum (29.95 °C) temperatures occurred on 02/22/2020 and 12/29/2019, respectively (Table 1). The temperatures were higher than the regular minimum and maximum annual temperatures, with 14.6 °C and 25 °C values, respectively (Heldwein et al., 2009). The means of Tavg in the leaf appearance period for sowings carried out on 11/28/2019, 12/03/2019, 12/10/2019, 12/17/2019, 12/30/2019, and 01/14/2020 were 24.50 °C, 24.76 °C, 24.60 °C, 24.11 °C, 24.20 °C and 24.14 °C, respectively, which were higher than the average temperature for the

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months from December to March, equal to 23.78 °C (Heldwein et al., 2009).

For the sowings on 11/28/2019, 12/03/2019, 12/10/2019, 12/17/2019, 12/30/2019, and 01/14/2020, cumulative rainfall was 380.20 mm, 377.00 mm, 366.00 mm, 307.20 mm, 341.40 mm and 205.20 mm, respectively (Table 1), that is, there was a gradual decrease with the delay in the sowing date. The cumulative rainfall in the experimental period (11/28/2019 to 03/17/2020) was 404.8 mm (Figure 1). This volume was lower than the average cumulative rainfall from December to March (553.90 mm) (Heldwein et al., 2009).

The coefficients of determination (R^2) ranged from 0.92 to 1.00, with an average of 0.98, for leaf appearance rate (Figure 2) and from 0.94 to 1.00, with an average of 0.98, for phyllochron (Figure 3). This result demonstrates that at least 92% of the number of leaves (NL, y) was explained by the variation in the number of days after emergence (DAE, x). It also reveals that at least 94% of the variation in the number of leaves (NL, y) was explained by the variation in the accumulated thermal sum (TSa, x). Coefficients of determination of high magnitudes have also been verified in maize ($R^2 \geq 0.96$) (Martins et al., 2012) and ($R^2 \geq 0.95$) (Santos et al., 2022), okra ($R^2 \geq 0.94$) (Nunes et al., 2019), and quinoa ($R^2 \geq 0.92$) (Munareto et al., 2021).The F test of the analysis of variance showed no significant difference in the number of leaves (NL) between the sowing dates. For the leaf appearance period (LAP, in days), accumulated thermal sum (TSa, in ºC day), leaf appearance rate (LAR, in days $leaf^{-1}$), and phyllochron, in °C day $leaf^{-1}$, there were significant effects ($p \leq 0.05$), which demonstrates that there was variability between the sowing dates (Table 2).

Regarding NL, as expected, no groups were formed in the Scott-Knott clustering test, that is, a non-significant effect of sowing dates was confirmed. Among the sowing dates, NL ranged from 16.20 (01/14/2020) to 19.60 (12/30/2019) (Table 3), with an average of 18.07 leaves (Table 2). Bandeira et al. (2018) also found no interference of sowing date in the final number of leaves of the sorghum genotype BRS 506.

Concerning to LAP, four groups of means were formed by the Scott-Knott test. LAP varied between 49 days (01/14/2020) and 88 days (12/10/2019) (Table 3), with an average of 65.70 days (Table 2). A decrease

Table 1. Sowing, emergence and flowering dates, minimum air temperature (Tmin, in °C), maximum air temperature (Tmax, in °C), average air temperature (Tavg, in °C) and cumulative rainfall for the period from emergence to flowering of millet plants.

Sowing	Emergence	Flowering [(1)]	Tmin (°C)	Tmax (°C)	Tavg (°C)	Rainfall (mm)
11/28/2019	12/08/2019	03/03/2020	15.91	29.95	24.50	380.20
12/03/2019	12/18/2019	02/25/2020	15.91	29.95	24.76	377.00
12/10/2019	12/20/2019	03/17/2020	15.91	29.95	24.60	366.00
12/17/2019	01/06/2020	03/03/2020	15.91	28.01	24.11	307.20
12/30/2019	01/10/2020	03/17/2020	15.91	29.26	24.20	341.40
01/14/2020	01/21/2020	03/17/2020	15.91	29.26	24.14	205.20

[(1)] Date of flowering of the last plant among the five plants evaluated for each sowing date.

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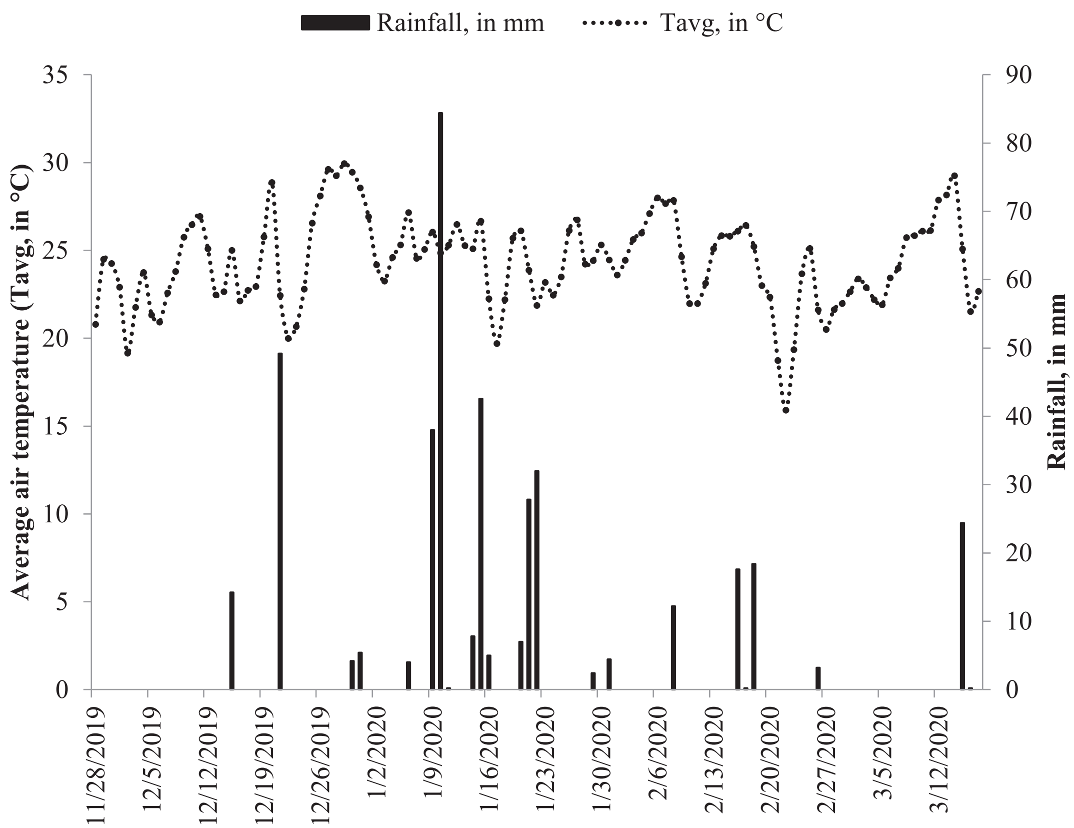

Figure 1. Daily values of the average air temperature (Tavg, in °C) and cumulative rainfall, in mm, for the period from emergence to flowering, for six sowing dates of millet crop.

was observed in LAP due to high temperatures and low rainfall volume. LAP decreased due to high temperatures and low rainfall during sowings between 12/17/2019 and 01/14/2020. A similar result was reported by Simão et al. (2015), who observed a shortening of the vegetative cycle of plants in millet cultivars sown on different dates.

The Scott-Knott test separated TSa into five groups. The TSa varied between 697.57 °C day (01/14/2020) and 1299.47 °C day (12/10/2019) (Table 3), with an average of 966.46 °C day among the six sowing dates (Table 2). Higher LAR values were observed for sowings on 11/28/2019 (5.40 days leaf^{-1}) and 12/10/2019 (5.24 days leaf^{-1}), and lower LAR values were observed for the other four sowing dates. LAR ranged from 3.26 days leaf^{-1} (01/14/2020) to 5.40 days leaf^{-1} (11/28/2019) (Table 3), with an average of 4.05 days leaf^{-1} (Table 2). The highest LAR values are concentrated in the treatments with the earliest sowing dates, indicating less plant development, as they took longer to produce their leaves.

Regarding the phyllochron, the Scott-Knott test formed two means groups (Table 3). The first group, with higher values of phyllochron, was formed by the sowings on 11/28/2019 and 12/10/2019, and the second group, with lower values of phyllochron, consisted of the other four sowing dates. Phyllochron ranged from 45.05 °C day leaf^{-1} (01/14/2020) to 80.81 °C day leaf^{-1}

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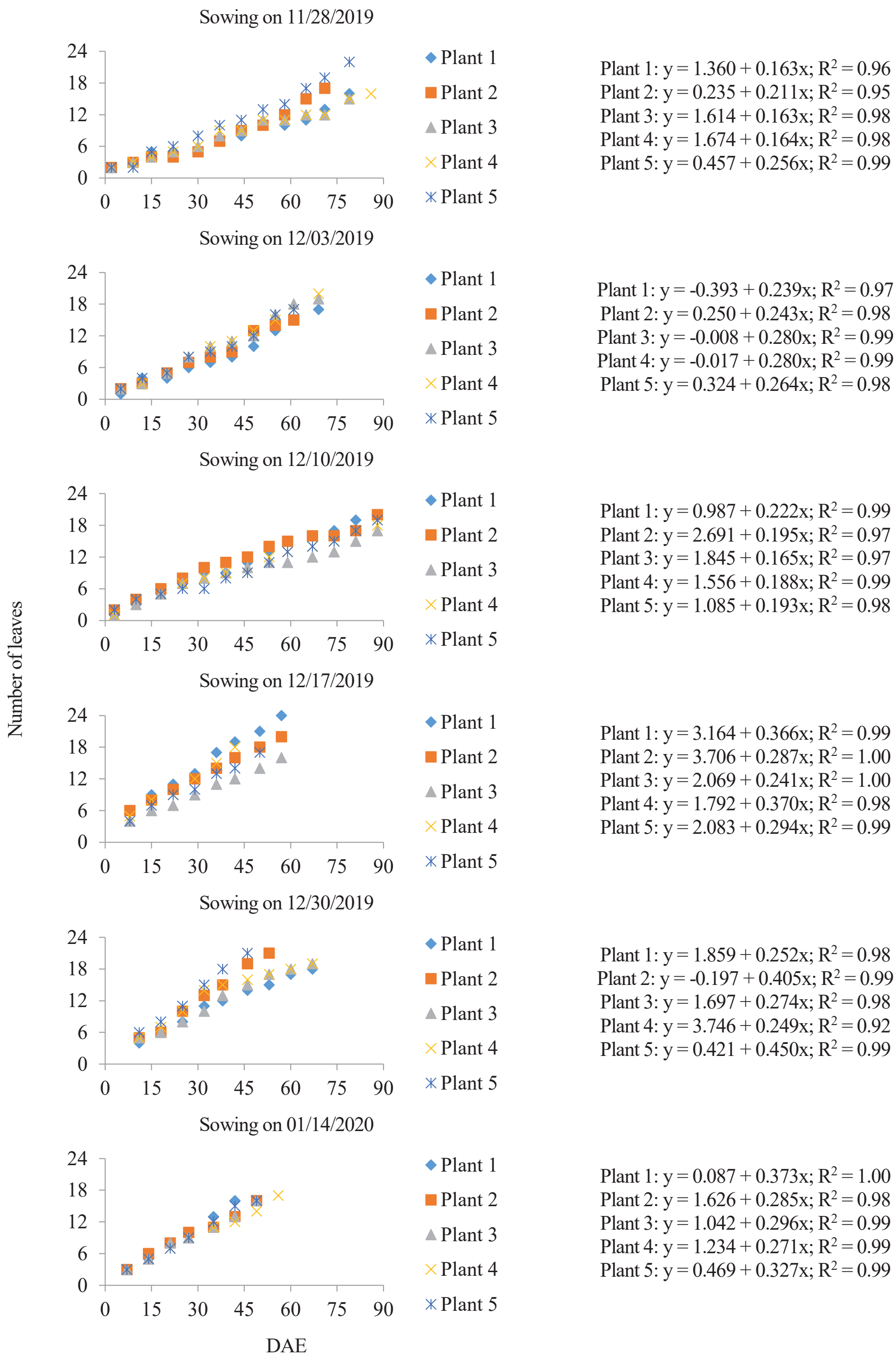

Figure 2. Relationship between the number of leaves on the main stem (NL) and the number of days after emergence (DAE) used to estimate the leaf appearance rate (LAR, in days leaf^{-1}), for six millet sowing dates.

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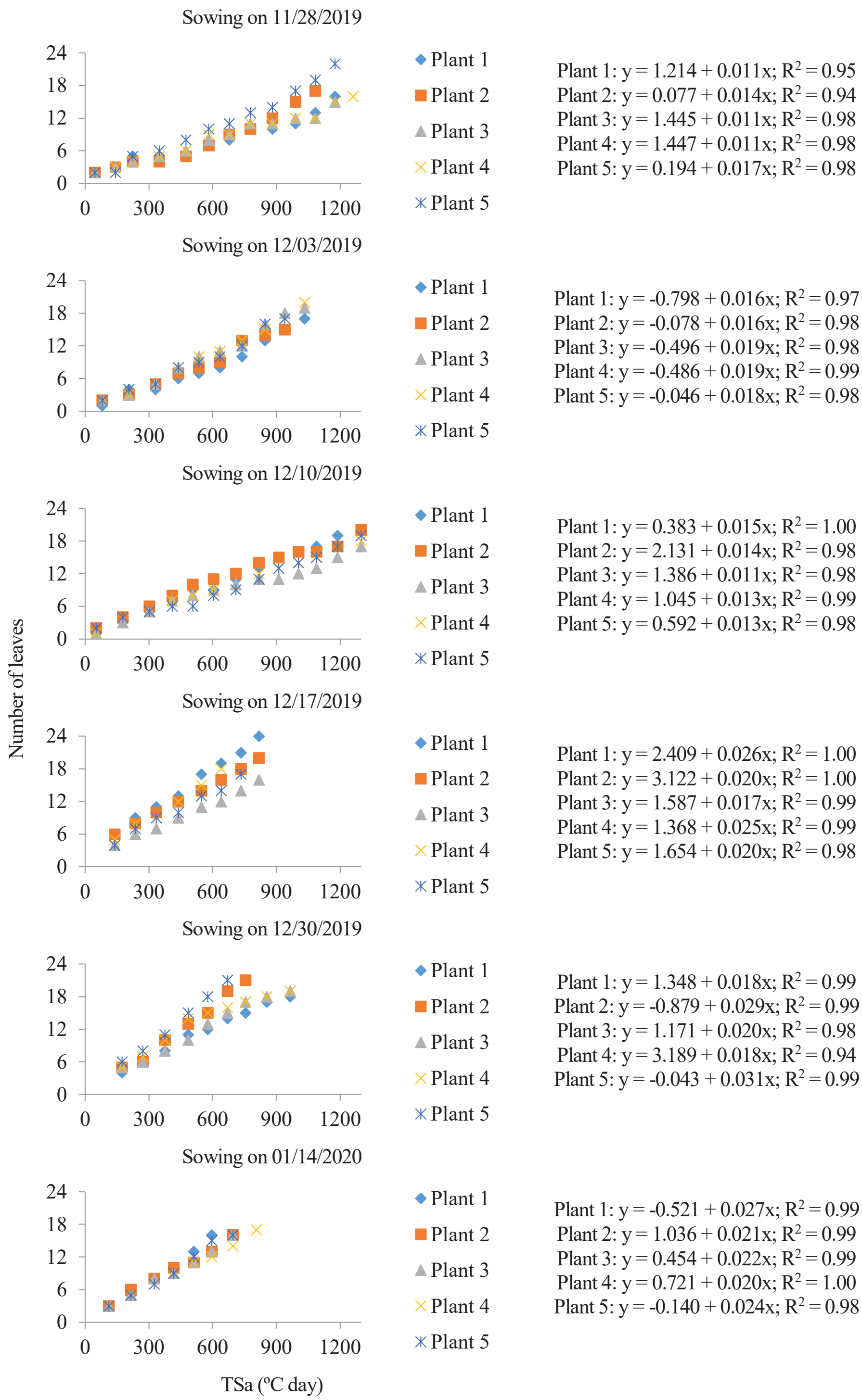

Figure 3. Relationship between the number of leaves on the main stem (NL) and the thermal sum accumulated after emergence (TSa, in ºC day) used to estimate the phyllochron, in °C day leaf[1], for six millet sowing dates.

Table 2. Summary of the analysis of variance with the number of degrees of freedom (DF) and mean square for the sources of variation (sowing date and residual), mean, coefficient of variation (CV) and F value calculated for sowing date (Fc), for the number of leaves (NL), leaf appearance period (LAP, in days), accumulated thermal sum (TSa, in ºC day), leaf appearance rate (LAR, on days leaf^{-1}) and phyllochron, in °C day leaf^{-1}, for six millet sowing dates.

SV	DF	NL	LAP	TSa	LAR	Phyllochron
		-------------------------------------Mean Squares-------------------------------------				
Date	5	8.21ns	1151.90*	277995.21*	5.11*	1258.30*
Residual	24	4.20	35.70	6402.34	0.45	89.94
Mean		18.07	65.70	966.46	4.05	58.62
CV (%)		11.34	9.09	8.27	16.59	16.18
Fc		1.96	32.27	43.42	11.31	13.99

*Significant effect by F test at 5% significance level. ^{ns} not significant.

Table 3. Means of number of leaves (NL), leaf appearance period (LAP, in days), accumulated thermal sum (TSa, in ºC day), leaf appearance rate (LAR, in days leaf^{-1}) and phyllochron, in °C day leaf^{-1}, for six millet sowing dates.

Sowing dates	NL	LAP	TSa	LAR	Phyllochron
11/28/2019	17.20 a	78.80 b	1174.84 b	5.40 a	80.81 a
12/03/2019	17.60 a	65.80 c	996.02 c	3.84 b	57.50 b
12/10/2019	18.80 a	88.00 a	1299.47 a	5.24 a	75.45 a
12/17/2019	19.00 a	52.60 d	766.03 e	3.29 b	47.10 b
12/30/2019	19.60 a	60.00 c	864.83 d	3.27 b	45.79 b
01/14/2020	16.20 a	49.00 d	697.57 e	3.26 b	45.05 b

Means not followed by the same letter in the column differ by the Scott-Knott test, at 5% significance level.

(11/28/2019) (Table 3), with an average of 58.62 °C day leaf^{-1} among the six sowing dates (Table 2). Therefore, plants respond differently to the environmental cultivation conditions of each sowing date (Table 1 and Figure 1). These values were higher than the phyllochron of the sorghum crop, which ranged from 63.04 °C day leaf^{-1} to 46.76 °C day leaf^{-1} in November and December, respectively (Bandeira et al., 2018). For maize crop, the phyllochron means obtained were 55.7 °C day leaf^{-1} in the agricultural year 2005/2006 and 53.9 °C day leaf^{-1} in the agricultural year 2006/2007 (Streck et al., 2009), 40.2 °C day leaf^{-1} (Martins et al., 2012), and 51.5 °C day leaf^{-1} (Santos et al., 2022). These divergences can be attributed to the genotypes and environmental conditions in the years of cultivation.

No significant differences were found between the sowing dates for the number of leaves. However, there was a gradual decrease in LAP, TSa, LAR, and phyllochron with the delay of sowing, that is, toward sowings in November, December, and January. This result demonstrates that, for the first sowing dates (11/28/2019, 12/03/2019, and 12/10/2019), the plants continued producing leaves for longer (> LAP), accumulated more thermal sum (> TSa), consequently took longer to produce a leaf (> LAR) and required more °C day to produce a new leaf (> phyllochron). Conversely, for the last sowing dates (12/17/2019, 12/30/2019, and 01/14/2020), the plants showed faster vegetative development, producing a similar number of leaves (NL) as the earlier sowing dates but with lower LAP, TSa, LAR and phyllochron.

Conclusions

The study found that millet exhibits faster vegetative development, characterized by a lower leaf appearance period, accumulated thermal sum, leaf appearance rate, and phyllochron, in later sowing dates (12/17/2019, 12/30/2019, and 01/14/2020) as compared to earlier ones (11/28/2019, 12/03/2019, and 12/10/2019).

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