



Article

Growth Performance of Sabia Grass Irrigated by Drippers Installed in Subsurface

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Abstract: Studies to improve the use of subsurface drippers in pasture formation are needed. Therefore, the objective of this study was to evaluate the germination and emergence of Sabia grass as a function of drippers installed at different depths. The study was conducted in pots in Viçosa, Minas Gerais State, Brazil. The experiment was conducted using a completely randomized design with four replicates. The experimental layout featured split plots over time, where the main plots consisted of three cultivation cycles and the subplots represented various dripper installation depths. The three sowing dates were 26 March, 12 April, and 29 April 2022. Drip tapes were installed at seven different depths: 0 (superficial), 5, 10, 15, 20, 25, and 30 cm. The results showed that the reduction in water potential, associated with increased temperature, resulted in lower performance of Sabia grass seeds. Seed germination and parameters related to germination speed were negatively impacted by the increase in dripper installation depth, with a 30–40% reduction in germination speed observed at depths greater than 15 cm. Drippers installed at 15–20 cm depth in clayey soil were ideal, providing a balance between reducing soil water evaporation and maintaining seedling emergence rates. Compared to surface installation, this depth improved seed performance by up to 25%, while enhancing operability and minimizing water loss. It is recommended to install drippers at a depth of 15–20 cm in subsurface drip irrigation systems in clayey soil areas to achieve benefits such as decreased soil water evaporation and improved operability compared to surface systems.

Keywords: germination speed; hybrid *Urochloa* cv. Sabia; pasture formation; seed emergence; seed physiology; subsurface irrigation; water potential



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1. Introduction

Cattle ranching is one of the most important sectors of Brazilian agribusiness. In 2018, Brazil had the world's second-largest cattle herd, with around 214.69 million head of cattle. That same year, the country was the largest exporter of beef, with 2 million tons per year, and the second-largest producer of meat, with 11 million tons per year [1], thus occupying a prominent position in the global livestock industry. Using technologies to increase productivity throughout the livestock sector is critical to meeting the growing demand for animal products. However, these technologies must minimize the sector's impact on the environment and natural resources [2].

Water is one of the limiting factors in the production of grazing animals [3,4], so irrigation presents itself as a promising practice for intensifying meat and milk production in regions where rainfall is scarce or irregularly distributed [2]. Forage crops that receive an adequate supply of water are more productive and have characteristics that favor animal production, such as higher crude protein content and higher digestibility [4–6].

Using pastures as the main source of nutrients in traditional milk production systems in Brazil is common, because it is considered the most economical way to feed herds, mainly

due to the high price of concentrates. According to the IBGE [7], pasture is also the basis of support for Brazilian beef cattle. Thus, it is important to choose the forage crop that best adapts to soil and environmental conditions in order to use it in a planned way, aiming to optimize its use, enhance productivity, and improve utilization by animals [8,9].

Currently, the national market has a wide variety of forage grass cultivars belonging to the genus *Urochloa*. However, many of them have not yet had their production characteristics fully elucidated, as is the case of Sabia grass (hybrid *Urochloa* cv. Sabia). Therefore, evaluating a new *Urochloa* cultivar makes it possible to identify suitable forage grasses to be sown [10]. Sabia grass was released in the Brazilian market by the company Barenbrug and has the characteristics of easy management and intense tillering, resulting in greater forage mass production. This grass has upright growth, moderate soil fertility requirements, should be grown in well-drained soils, and has a good response to fertilization. Sabia grass is suitable for grazing and silage production and is well accepted by animals [11].

In pastures, the most widely used irrigation technique in Brazil is the sprinkler method [3,12]. However, there is a tendency for the agricultural industry to adapt to more efficient irrigation systems, such as localized ones, especially in terms of use of water resources. The use of subsurface drip irrigation has expanded in recent decades [13]. This system applies water directly to the root zone of the plants, significantly reducing losses due to evaporation and surface runoff compared to sprinkler irrigation methods [14,15]. Moreover, subsurface drip irrigation allows for more precise and controlled application, meeting the water needs of the plants more efficiently and preventing water wastage [16,17]. It also offers other advantages, such as enabling soil management without the need to remove the drip lines, whether during soil preparation, mechanical weeding, or seed harvesting [4,16]. In the context of pastures, the use of subsurface drip irrigation also has the advantage of not wetting the soil surface layer, thus reducing the susceptibility to compaction caused by animal trampling.

As it is a relatively new technology, more detailed studies on some points are lacking [13]. When it comes to irrigated forage crops, there is a lack of information that could assist technicians and livestock farmers in the proper management of water application in relation to crop establishment (germination) and development (production) [4,18]. The superficial soil layer (0–10 cm), where seeds are deposited, can become dry due to evaporation and tillage prior to sowing. In addition, in the case of water replacement by a buried emitter, capillary rise may not be sufficient to moisten the volume of soil where the seed is located [6,19]. This problem can lead to delays in emergence or crop failure [20].

The installation depth of drip emitters is a critical factor for irrigation efficiency and the successful establishment of crops. Installing emitters at inappropriate depths can lead to uneven water distribution, which affects seed germination and seedling emergence [21,22]. An appropriate emitter depth facilitates the capillary rise of water to the soil's surface layer, where the seeds are located, ensuring sufficient moisture for germination without excessive water waste [23]. This also helps maintain soil structure and minimizes the formation of surface crusts that could hinder seedling emergence [24]. Therefore, correctly adjusting the depth of the emitters is essential not only to improve water use efficiency but also to promote healthy and vigorous forage growth.

Reducing the depth of drip lines (less than 20 cm relative to the soil surface) can promote more uniform seed germination [21,22]. Alternative strategies, like using soil correctives or applying water in pulses, were deemed unsatisfactory [25]. However, Lamm et al. [26] found different results when applying subsurface pulse irrigation, as they observed an improvement in soil water redistribution and improvements in crop germination and establishment.

Some researchers suggest placing drip tubes above an impermeable layer to encourage upward soil water movement. However, the effectiveness of this method has been inconsistent, and the associated costs are relatively high [27–29]. In a study analyzing agronomic and production characteristics of maize crop, Rocha et al. [13] concluded that a drip line installed at 30 cm depth in the soil led to better results for these variables. Thus, it can be

said that drip line installation depths and water application intensities for better agronomic and physiological responses of the crop of interest are problems pertaining to the use of this system in pasture [6,12].

Given the economic significance of Sabia grass, it is essential to identify the optimal water availability conditions to ensure successful seed germination, and seedling emergence. Thus, studies are needed to find the best management and installation of emitters in subsurface drip irrigation, enabling improvement in the formation of Sabia grass pastures. The aim of this study was to assess the germination and emergence of Sabia grass under irrigation using drippers installed at varying soil depths.

2. Materials and Methods

The experiment was conducted in the experimental area of the Hydraulics Laboratory at the Reference Center for Water Resources (CRRH) of the Federal University of Viçosa (UFV), located in Viçosa, Minas Gerais, Brazil. The site is situated at a latitude of $20^{\circ}46'19''$ S and longitude of $42^{\circ}52'28''$ W, with an average altitude of 662 m. The regional climate is classified as Aw, featuring hot, rainy summers and cold, dry winters [30]. The area experiences an average annual temperature of 21.8°C and an annual rainfall of 1345 mm, with December being the wettest month and July the driest.

Meteorological data were collected using a DAVIS Vantage Pro II automatic weather station that was previously installed in the experimental area. This station has sensors that provide air temperature ($^{\circ}\text{C}$), solar radiation ($\text{MJ m}^{-2} \text{d}^{-1}$), relative humidity (%), wind speed (m s^{-1}), and rainfall (mm) data with 5 min temporal resolution. The average daily values of air temperature, solar radiation, and relative humidity were 22.3 , 19.9 , and 19.3°C , 14.93 , 17.34 and $14.11 \text{ MJ m}^{-2} \text{d}^{-1}$, and 84.5 , 80.8 , and 83.1% for cycles 1, 2, and 3, respectively (Figure 1). In the figure, it can be observed that solar radiation and relative humidity exhibited an inverse relationship, with peaks in solar radiation corresponding to minimal relative humidity and vice versa, due to the direct influence of evaporation on air moisture.

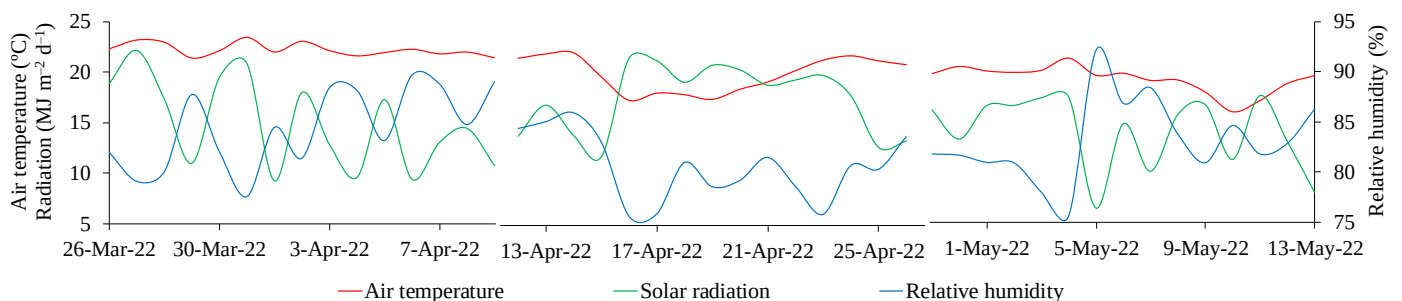


Figure 1. Daily values of mean air temperature ($^{\circ}\text{C}$), solar radiation ($\text{MJ m}^{-2} \text{d}^{-1}$), and mean relative humidity (%) in three cycles of initial development of Sabia grass. Viçosa, MG, Brazil, DEA-UFV, 2022.

Sabia grass (hybrid *Urochloa* cv. Sabia) was cultivated in three cycles in the germination and emergence stages. Each cycle lasted 15 days, allowing for detailed monitoring and evaluation of the grass development under different periods and conditions. The three sowing dates were 26 March, 12 April, and 29 April 2022. The Sabia grass seeds used in the study were from the Barenbrug brand with minimum purity of 95% and treated with fungicide and insecticide. For sowing, a circular furrow 10 cm in radius and 2 cm deep was opened in each pot, and 60 seeds were evenly distributed along the furrow.

The experiment utilized cylindrical pots measuring 40 cm in diameter, 55 cm in height, and with a volume of 70 L. The pots were filled with soil collected from a slope on the UFV campus. The soil was classified as dystrophic red–yellow latosol [31]. To achieve soil stability and moisture distribution similar to natural conditions, the soil was passed through a 2 mm sieve, homogenized, and allowed to rest for seven days before initiating the irrigation events. This process ensured that moisture content was relatively uniform

across all replicates. Soil samples were collected to assess the physical, hydraulic, and chemical properties (Table 1). Each pot was filled with 70 kg of dry soil, resulting in an approximate volume of 66 dm³. As a result, the soil surface was 3 cm below the top edge of the pot.

Table 1. Physical, hydraulic and chemical characterization of the soil used to fill the pots. Viçosa, MG, Brazil, DEA-UFV, 2022.

Coarse Sand	Fine Sand	Silt	Clay	FC	PWP	Bd	Ko	Textural Classification	
		kg kg ⁻¹				g cm ⁻³	m d ⁻¹		
0.307	0.137	0.128	0.428	0.247	0.137	1.06	5.56	Clay	
pH H ₂ O	pH KCl	P	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	Al ³⁺	H + Al	
			mg dm ⁻³				cmol _c dm ⁻³		
6.30	5.69	117.3	46.0	6.60	5.68	0.55	0.00	1.90	
SB	t	T	V	m	SSI	OM	N-total	P-rem	
	cmol _c dm ⁻³			%		dag kg ⁻¹		mg L ⁻¹	
6.38	6.38	8.28	77.1	0.00	0.35	2.96	0.115	37.0	
S	B	Cu	Mn	Fe	Zn	Cr	Ni	Cd	Pb
				mg dm ⁻³					
1.90	0.26	2.54	40.5	54.1	12.93	0.00	0.78	0.42	1.26

FC = field capacity; PWP = permanent wilting point; Bd = soil bulk density; Ko = saturated hydraulic conductivity; P, Na, K, Fe, Zn, Mn, Cu, Cd, Pb, Ni, and Cr—Mehlich-1 extractant; Ca²⁺, Mg²⁺, and Al³⁺—1 mol L⁻¹ KCl extractant; H + Al—0.5 mol L⁻¹ calcium acetate extractant at pH 7.0; SB = sum of exchangeable bases; t = effective cation exchange capacity; T = cation exchange capacity at pH 7.0; V = base saturation index; m = aluminum saturation index; SSI = sodium saturation index; OM (organic matter) = C. Org × 1.724—Walkley–Black; P-rem = remaining phosphorus; N-total—sulfuric digestion and Kjeldahl distillation; S—extracted with monocalcium phosphate in acetic acid; B—hot-water extractant.

The experiment was conducted using a completely randomized design (CRD) with four replicates. The experimental setup featured split plots over time, where the main plots represented the three cultivation cycles and the subplots varied in dripper installation depths. The drip tapes were installed at depths of 0, 5, 10, 15, 20, 25, and 30 cm, resulting in 28 experimental units.

Only one dripper-type emitter was installed in each pot, inserted at the central point considering the horizontal direction. The drippers used were the NaanDanJain Amnondrip (NaanDanJain, Dandenong, Australia). They operated with service pressure of 10 mwc and flow rate of 1.6 L h⁻¹.

To minimize significant fluctuations in soil water storage and maintain moisture levels near field capacity, Sabia grass was irrigated every two days. Irrigation management was conducted by means of two pots with soil designated as drainage lysimeters, installed in the same experimental area. These lysimeters were used to measure crop evapotranspiration (ETc). Equation (1) was used to calculate ETc and determine the amount of water applied to the pots with soil.

$$ETc = P + I - D \quad (1)$$

where ETc—crop evapotranspiration, L; P—precipitation, L; I—volume of irrigation applied, L; and D—drained water, L.

The average volume, calculated from the data of the two drainage lysimeters, was used to irrigate the pots with imposition of the treatments. In the lysimeters, in addition to the evapotranspired volume, an additional 20% was added to induce drainage. It is important to note that all the volume drained from each lysimeter was reintegrated with the irrigation water in the same lysimeter, maintaining the balance of salts and nutrients in the soil. Before applying the water to the lysimeters, its electrical conductivity and pH were measured to ensure it would not harm the crop.

To assess seed germination and vigor, the pots were inspected daily, with the initial count on the first day and the final count on the twentieth day after starting the experiments. The following parameters were evaluated: final germination (FG), germination speed index (GSI), time to reach 10% germination (T10), time to reach 50% germination (T50), time to reach 90% germination (T90), germination uniformity (GUnif), mean germination time (MGT), and mean germination rate (MGR). The equations for calculating these traits, as outlined by Silva et al. [32], are detailed in Table 2. Calculations were performed using R software version 4.0.5 [33] and the SeedCalc package [32] following the procedures described by Freitas et al. [34].

Table 2. Functions in the SeedCalc package for calculating indices based on daily seed count data from germination and emergence tests.

Function	Function Description	Formula	Reference
FG	Final germination percentage	$FG = \left(\frac{n}{N}\right) \times 100$ n—number of germinated seeds; N—total number of seeds.	ISTA [35]
GSI	Germination speed index	$GSI = \sum_{i=1}^K (n_i/t_i)$ ni—number of seeds germinated on each day of daily count until the last count; ti—number of days after starting the test in each count.	Maguire [36]
T10	Time required for germination of 10% of seeds	$T_{10} = t_i + \left\{ \left[\frac{\frac{N}{100}}{(n_f - n_i)} \right] - n_i \right\} (t_f - t_i)$ N—final number of germinated seeds; ni and nf—total number of germinated seeds at adjacent counts at times ti and tf, respectively, when $n_i < \frac{N+1}{2} < n_f$	Farooq et al. [37]
T50	Time required for germination of 50% of seeds	$T_{50} = t_i + \left\{ \left[\frac{\frac{N}{100}}{(n_f - n_i)} \right] - n_i \right\} (t_f - t_i)$ Same code as T10.	Farooq et al. [37]
T90	Time required for germination of 90% of seeds	$T_{90} = t_i + \left\{ \left[\frac{\frac{N}{100}}{(n_f - n_i)} \right] - n_i \right\} (t_f - t_i)$ Same code as T10.	Farooq et al. [37]
MGT	Mean germination time	$MGT = \frac{\sum_{ni} ni ti}{\sum_{ni} ni}$ ni—number of seeds germinated each day (not cumulative, but specific to the i-th observation); ti—time elapsed from the beginning of the germination test to the i-th observation.	Labouriau [38]
MGR	Mean germination rate	$\bar{v} = \frac{GSCo}{100} = 100/\bar{t}$ t—mean germination time; GSCo—germination speed coefficient.	Labouriau [38]
GUnif	Germination uniformity	$GUnif = (T_{90} - T_{10})$ T90—time required for germination of 90% of the seeds; T10—time required for germination of 10% of the seeds.	Demilly et al. [39]

After seedling emergence, the following characteristics were determined:

- Root length (RL): the distance from the soil surface to the deepest root of the Sabia grass seedling in centimeters was measured using a ruler.
- Shoot length (SL): the height in centimeters of the Sabia grass seedling was measured using a ruler.

- Seedling fresh mass (SFM): all seedlings were collected and weighed on a precision scale (0.1 mg), and SFM in mg pl^{-1} was obtained by dividing the total mass by the number of seedlings evaluated.
- Seedling dry mass (SDM): Seedlings were dried in a forced air circulation oven at 65 °C for 72 h and then weighed using a precision scale (0.1 mg). SDM, expressed in milligrams per plant, was calculated by dividing the total mass by the number of seedlings assessed.

The data were analyzed using analysis of variance (ANOVA) with a significance level of 0.05 in the F tests. Regardless of the significance of the interaction between the factors, it was decided to decompose it, considering the interest in the study. The assumptions of homogeneity of variance and normality were assessed using the Bartlett and Shapiro–Wilk tests, respectively, with a significance level of 0.05 for both. For qualitative factors, means were compared using the Tukey test at a 0.05 significance level. For quantitative factors, both linear and quadratic models were evaluated. The appropriate model was chosen based on the significance of the regression coefficients (determined by the *t*-test at a 0.05 significance level), the coefficient of determination (R^2), and the biological relevance. Statistical analyses were conducted using the Experimental Designs package in R software version 4.0.5 [33].

3. Results and Discussion

In the following subsections, the results and analysis of water consumption, seed germination, seed vigor, and seedling emergence of Sabia grass will be presented, considering different emitter installation depths and various sowing times.

3.1. Water Consumption

Figure 2 shows the water consumption of Sabia grass seeds and seedlings throughout the evaluated cultivation cycles. The total water consumption of Sabia grass during the evaluations was 16.2, 16.1, and 13.2 L of water per pot in cycles 1, 2, and 3, respectively. In addition to irrigation, Figure 2 shows the reference evapotranspiration (ET_o) rates, with cumulative values of 38.3, 35.5, and 28.5 mm d^{-1} in cycles 1, 2, and 3, respectively. The curves showed similar patterns, and the ratios between total irrigation and accumulated ET_o were 0.42, 0.45, and 0.46 for cycles 1, 2, and 3, respectively. Crop evapotranspiration (ET_c) is directly related to crop coefficient (K_c), so similar curves patterns were expected, since K_c is obtained by the ratio between ET_c and ET_o, correlating them with the development stage and climatic conditions of the study site.

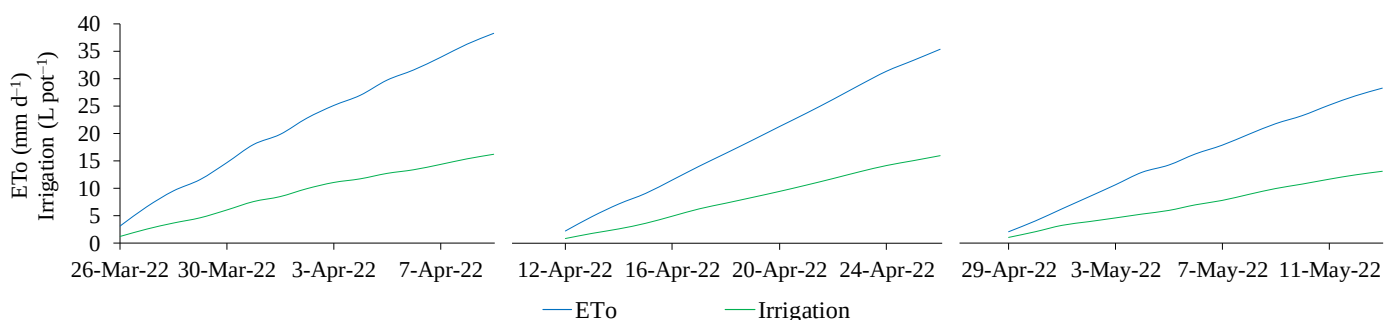


Figure 2. Cumulative values of reference evapotranspiration (ET_o) and irrigations carried out in three cycles of germination and emergence of Sabia grass. Viçosa, MG, Brazil, DEA-UFV, 2022.

Variations in ET_o directly influence the irrigation requirement and water consumption of crops. High ET_o values, as observed in the three cycles, indicate a greater water flux from the soil to the atmosphere, affecting water availability for seeds during germination and the initial development of seedlings [34,40]. Moreover, an increase in ET_o can reduce soil moisture, negatively impacting the process of water imbibition by seeds and consequently germination [41,42].

3.2. Seed Germination

Table 3 presents summaries of the analysis of variance (ANOVA) for the variables final germination (FG) and the times required to achieve 10%, 50%, and 90% germination (T10, T50, and T90) of Sabia grass seeds. The interaction between cycles and dripper installation depth had significant effects on all characteristics evaluated. In general, higher values were observed in the first cultivation cycle, i.e., the germination of Sabia grass in the first cycle was slower than in the other cycles. This difference may be attributed to air temperature, since the maximum temperature exceeded 25 °C on all days during cycle 1, which may have hampered germination. Chiodini and Silva [43], when evaluating the impact of air temperature on the germination of Marandu grass, which is the same species as Sabia grass, found better performances when air temperature was below 25 °C. Other studies also show the influence of temperature on germination [44–46].

Table 3. Mean squares, significance of F tests (ANOVA), and mean values for final germination (FG) and times required for 10%, 50%, and 90% germination (T10, T50, and T90) of Sabia grass seeds across different germination cycles and irrigation depths of drippers. Viçosa, MG, Brazil, DEA-UFV, 2022.

Variable	Mean Squares			CV (%)	Depth (cm)	Cycles					
	Cycle	Depth	C × D			1	2	3	4	5	6
T10 (days)	1.42×10^1 **	1.26×10^0 **	1.22×10^0 **	5.89	0	5.979	b	6.634	a	5.760	b
					5	6.119	ab	6.321	a	5.639	b
					10	6.841	a	6.515	a	5.835	b
					15	7.280	a	6.788	a	5.675	b
					20	8.435	a	6.617	b	5.987	b
					25	7.813	a	6.383	b	5.429	c
					30	7.606	a	5.873	b	5.777	b
T50 (days)	6.38×10^0 **	1.50×10^0 **	1.70×10^0 **	5.03	0	7.58	b	8.84	a	8.18	ab
					5	8.62	a	8.47	ab	7.85	b
					10	8.70	a	8.73	a	7.86	b
					15	9.11	a	8.71	ab	8.12	b
					20	10.19	a	8.72	b	8.66	b
					25	10.02	a	8.05	b	8.48	b
					30	10.06	a	7.81	c	8.76	b
T90 (days)	1.41×10^1 **	3.40×10^0 **	3.10×10^0 **	4.95	0	10.32	b	11.78	a	10.65	b
					5	11.13	b	10.03	c	12.70	a
					10	12.56	a	9.80	b	12.02	a
					15	12.69	a	11.59	b	12.40	ab
					20	13.48	a	11.54	b	12.22	b
					25	12.43	a	10.40	b	11.50	a
					30	13.13	a	10.97	b	11.45	b
FG (%)	3.04×10^3 **	7.90×10^2 **	1.23×10^2 **	9.64	0	68.47	a	58.06	b	69.48	a
					5	71.34	a	48.56	c	60.02	b
					10	53.59	a	40.97	b	54.38	a
					15	61.58	a	45.00	b	55.32	a
					20	49.37	a	27.68	b	47.84	a
					25	58.07	a	34.09	b	64.25	a
					30	45.88	b	29.92	c	61.35	a

Depth: dripper installation depths; C × D: interaction between Sabia grass cycles and dripper depths; **: significance at the 1% probability level, by F test; means followed by the same letter in a row are not significantly different from each other according to the Tukey test ($p < 0.01$).

The slower germination in cycle 1 may also have been influenced by evaporation from the soil surface, as indicated by the ETo values, which were higher in this cycle compared to the others, as shown in Figure 2. High ETo values indicate a greater flow of water from the soil to the atmosphere [47], resulting in reduced soil water availability. On the other hand, low ETo values indicate higher soil moisture, lower water deficit, and consequently a higher probability of germination [48,49]. It is also worth highlighting that in a situation of lower

water availability in the soil, evaporation is lower and the conversion of sensible heat into latent heat is lower, resulting in an increase in soil temperature [50], which is detrimental to germination. In summary, ETo exerted an indirect influence on the germination of Sabia grass, impacting soil moisture availability and water stress conditions.

Also in Table 3, despite the longer germination times, the final germination rate was higher in the first cycle. This can be attributed to better soil water availability during this period, which promoted more complete germination despite the slower rate. The longer germination times in the first cycle may have been influenced by higher air temperatures and increased evaporation, which could initially have delayed germination. However, the adequate water availability ultimately supported a higher final germination rate. This underscores the complexity of how environmental factors, such as temperature and soil moisture, interact and affect seed germination dynamics.

Figure 3 shows the variables FG, T10, T50, and T90 as a function of the dripper installation depths. In general, the increase in dripper installation depth impaired the germination of Sabia grass. In cycle 1, the final germination was reduced and the times for germination of 10%, 50%, and 90% of the seeds were increased with the increase in dripper installation depth. This suggests that there was less water availability due to the lower rise of irrigation water in the clayey soil. A decrease in water availability reduces seed water imbibition, potentially disrupting the germination process and lowering germination percentages. Plants under water stress may exhibit varied responses to this stress, influenced by their species-specific tolerance to water deficit [51]. Cellular responses to water scarcity include alterations in cell division and cycle, modifications in the endomembrane system, and changes in cell wall structure [52,53].

Superficially installed drippers can provide a more uniform moisture supply in the first layers of the soil, where seeds are sown [54,55]. This arrangement favors a more homogeneous germination when compared to deeper installations. Thus, by positioning the drippers closer to the surface, the water source becomes more easily accessible to the seeds, ensuring that they germinate and have access to moisture during the early stages of seedling development [19,56].

Figure 3 also shows that FG was also reduced with dripper installation depth in cycle 2. In addition to the reduction of water, it must be considered that the environment loses less latent heat of vaporization and accumulates a greater amount of sensible heat. High temperatures can cause protein denaturation and disrupt membranes, leading to the gradual deterioration of seeds. This is primarily due to the effects on enzyme activity and restricted oxygen availability [57]. This fact can also be confirmed by the germination results in the treatments with greater dripper depths (Table 3). Note that cycle 2 had the worst results and was the period with greater solar radiation (Figure 2), causing higher temperatures in the soil.

It was also observed in cycle 2 that the dripper depths caused a quadratic effect on the variables T10 and T50 (Figure 3). Based on the regression analysis, the optimal dripper depth for maximizing T10 was 11.2 cm, which resulted in a value of 6.7 days. For T50, the ideal depth was 7.5 cm, yielding a value of 8.8 days. These results are in line with those reported in the literature [55]. Those authors reported that drippers installed on the surface promote water accumulation in the initial layer of the soil, leading to an uneven distribution of moisture and problems in germination. On the other hand, if drippers are installed deeper, water does not reach the seed zone, resulting in insufficient moisture for germination. Thus, the ideal depth for drippers is the one that will ensure an even distribution of soil moisture [4], promoting consistent and timely germination throughout the sown area.

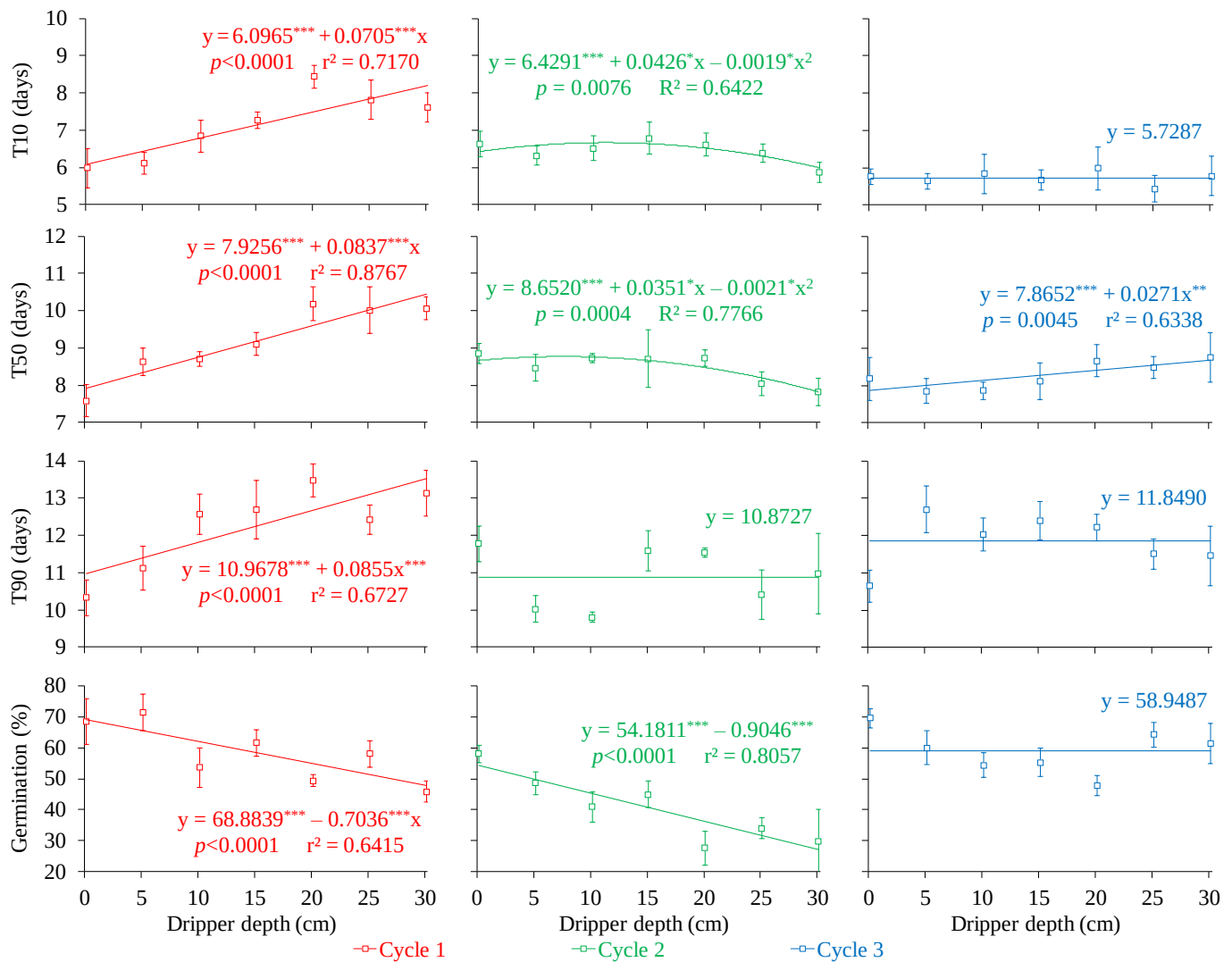


Figure 3. Final germination (FG) and times required for germination of 10%, 50%, and 90% of seeds (T10, T50 and T90) of Sabia grass as a function of irrigation with drippers installed at different depths and in different germination cycles. Viçosa, MG, Brazil, DEA-UFV, 2022. *, **, *** = significant at 5%, 1%, and 0.1% probability levels, respectively.

Dripper depth influences soil moisture distribution and consequently seed germination [13,40]. Variations in moisture can create uneven water availability zones, affecting both germination rates and seedling growth. This study highlights the need to adjust drifter depth and irrigation frequency to optimize germination and ensure uniform plant development, maximizing productivity and efficiency.

3.3. Seed Vigor

Table 4 presents the summaries of the analysis of variance (ANOVA) for the variables germination speed index (GSI), mean germination time (MGT), mean germination rate (MGR), and germination uniformity (GUNif) of Sabia grass seeds. The interaction between cycles and drifter installation depth had significant effects on all characteristics evaluated. Overall, the values of GSI, MGR, and GUNif were higher in cycle 3, while MGT was higher in cycle 1.

Table 4. Mean squares, F values (ANOVA), mean values of germination speed index (GSI), mean germination time (MGT), mean germination rate (MGR), and germination uniformity (GUnif) of seeds in different germination cycles of Sabia grass irrigated by drippers installed at different depths. Viçosa, MG, Brazil, DEA-UFV, 2022.

Variable	Mean Squares			CV (%)	Depth (cm)	Cycles					
	Cycle	Depth	C × D			1	2	3			
GSI	3.68×10^2 **	9.04×10^1 **	4.53×10^1 **	8.76	0	8.35	c	16.58	b	23.59	a
					5	23.62	a	17.85	c	20.46	b
					10	15.89	b	15.17	b	18.89	a
					15	18.07	a	12.92	b	18.73	a
					20	9.74	b	8.60	b	16.29	a
					25	13.46	b	11.06	c	21.76	a
					30	10.78	b	11.57	b	20.74	a
MGT (days)	6.51×10^0 *	1.48×10^0 **	1.31×10^0 *	4.90	0	8.29	b	9.52	a	8.74	b
					5	9.07	a	8.43	a	8.95	a
					10	9.54	a	8.41	b	8.54	b
					15	9.87	a	9.65	a	8.85	b
					20	10.45	a	9.42	b	9.11	b
					25	10.41	a	8.79	b	8.89	b
					30	10.58	a	8.65	b	8.92	b
MGR (%)	8.58×10^0 **	2.55×10^0 **	2.04×10^0 **	5.44	0	12.19	a	10.53	b	11.49	a
					5	11.06	a	11.88	a	11.23	a
					10	10.64	b	11.89	a	11.71	a
					15	10.24	b	10.41	b	11.37	a
					20	8.97	b	10.63	a	11.07	a
					25	9.66	b	11.42	a	11.26	a
					30	9.47	b	11.60	a	11.27	a
GUnif	2.03×10^1 *	1.01×10^0 **	2.02×10^0 **	7.32	0	4.343	b	5.149	a	4.887	ab
					5	5.006	b	3.704	c	7.065	a
					10	5.783	a	3.288	b	6.189	a
					15	5.415	b	4.801	b	6.721	a
					20	5.172	b	4.921	b	6.228	a
					25	4.871	b	4.018	c	6.074	a
					30	5.327	a	5.097	a	5.678	a

Depth: dripper installation depths; C × D: interaction between Sabia grass cycles and dripper depths; * and **: significance at 5% and 1% probability levels, respectively, by F test; means followed by the same letter in a row are not significantly different from each other according to the Tukey test ($p < 0.01$).

Similarly to the final germination results, it was also found that cycle 2 showed the worst seed vigor, coinciding with the period of highest solar radiation (Figure 2). High temperatures can denature proteins and alter cell membranes, leading to the progressive deterioration of seeds [41]. In cycle 1, the longer duration of MGT may have been influenced by less ideal temperature or humidity conditions, which delayed the germination process. In contrast, cycle 3's better GSI, MGR, and GUnif indices suggests that the environmental or management conditions were more favorable for seed germination. Thus, cycle 3 provided an environment that enabled faster and more uniform germination, highlighting the importance of considering climatic and management conditions when planning cultivation cycles to optimize seed germination.

Figure 4 shows that GSI was affected by dripper installation depth only in cycle 2, showing a negative linear effect, i.e., the increase in dripper depth caused a reduction in GSI. In cycle 1, the increment in dripper depth increased MGT and reduced MGR. These results corroborate those of Felix et al. [58], who studied *Leucaena leucocephala* seeds under water deficit conditions and observed that both germination speed and percentage decreased with lower water potentials. Additionally, in cycle 1, an increase in dripper depth exhibited a quadratic effect on GUnif (Figure 4). According to the regression analysis, the optimal dripper depth for maximizing GUnif was 17.5 cm, achieving a value of 5.4.

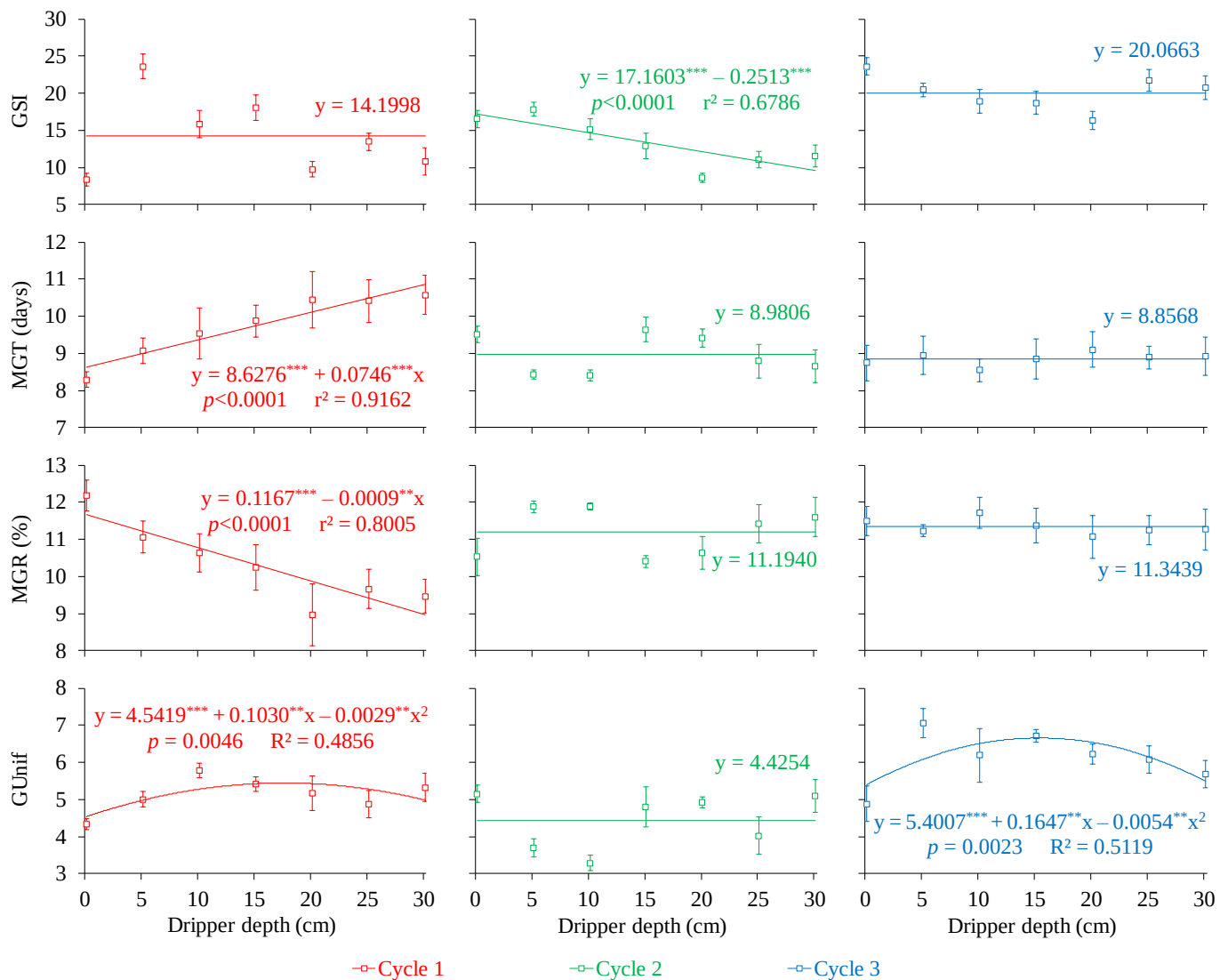


Figure 4. Germination speed index (GSI), mean germination time (MGT), mean germination rate (MGR), and germination uniformity (GUnif) of Sabia grass as a function of irrigation with drippers installed at different depths and in different germination cycles. Viçosa, MG, Brazil, DEA-UFV, 2022. **, *** = significant at 1%, and 0.1% probability levels, respectively.

In cycle 3, dripper installation depth influenced only GUnif, causing a quadratic effect. According to the regression equation, the dripper depth that maximized GUnif was 15.3 cm, resulting in a value of 6.7. This suggests that dripper installation depths of up to 15–20 cm can be used for Sabia grass pasture formation for the clayey soil used in this study. Rapid stabilization of germinated seeds and higher speed of germination are beneficial traits. These characteristics contribute to reducing the exposure of seeds to biotic and abiotic factors that may compromise their development. Thus, dripper installation depths ranging from 15 to 20 cm in clayey soil were those that stood out and were considered optimal for the germination of Sabia grass in the present study.

3.4. Seedling Emergence

Table 5 shows the analysis of variance (ANOVA) results for the variables root length (RL), shoot length (SL), and fresh (SFM) and dry (SDM) mass of Sabia grass seedlings. The interaction between cycles and dripper installation depth had significant effects on all characteristics evaluated. Overall, RL values were higher in cycle 1, while SL, SFM, and SDM were higher in cycle 2.

Table 5. Mean squares, F values (ANOVA) and mean values of root length (RL), shoot length (SL) and fresh (SFM) and dry (SDM) mass of Sabia grass seedlings irrigated by drippers installed at different depths during three cultivation cycles. Viçosa, MG, Brazil, DEA-UFV, 2022.

Variable	Mean Squares			CV (%)	Depth (cm)	Cycles					
	Cycle	Depth	C × D			1	2	3			
RL (cm)	1.67×10^0 **	1.62×10^0 **	8.87×10^{-1} **	13.38	0	3.699	a	3.215	ab	2.630	b
					5	4.208	a	3.443	b	2.960	b
					10	3.313	a	3.055	a	3.225	a
					15	3.421	a	2.174	b	2.738	b
					20	2.887	a	2.488	ab	2.168	b
					25	2.828	a	2.777	a	2.849	a
					30	2.209	b	2.172	b	3.446	a
SL (cm)	8.96×10^{-2} ns	4.66×10^0 **	5.90×10^0 **	12.95	0	8.458	a	4.962	b	5.670	b
					5	6.203	a	6.442	a	5.775	a
					10	7.807	a	5.663	b	5.863	b
					15	5.846	a	5.944	a	5.525	a
					20	3.708	b	5.387	a	5.429	a
					25	4.776	b	6.267	a	5.772	ab
					30	3.293	b	6.012	a	5.887	a
SFM (mg pl ⁻¹)	1.43×10^4 **	1.51×10^3 *	1.16×10^3 **	11.82	0	129.7	a	143.9	a	130.2	a
					5	96.3	c	156.4	a	126.0	b
					10	96.0	b	122.7	ab	141.6	a
					15	121.1	a	143.6	a	137.1	a
					20	91.2	a	113.5	a	111.4	a
					25	56.4	b	135.5	a	137.6	a
					30	79.3	c	153.2	a	124.0	b
SDM (mg pl ⁻¹)	1.72×10^2 *	9.39×10^1 **	2.51×10^1 **	11.23	0	23.21	b	28.48	a	26.75	ab
					5	20.08	b	30.35	a	21.42	b
					10	18.22	a	21.31	a	21.14	a
					15	21.36	a	22.47	a	22.34	a
					20	20.97	a	20.76	a	17.34	a
					25	13.73	b	21.65	a	21.95	a
					30	14.95	b	22.16	a	18.65	ab

Prof.: Dripper installation depths; C × D: interaction between Sabia grass cycles and dripper depths; * and **: significance at 5% and 1% probability levels, respectively, by F test; ns: not significant; means followed by the same letter in a row are not significantly different from each other according to the Tukey test ($p < 0.01$).

Although air temperature affected the germination of Sabia grass, it did not affect the subsequent stage, because the best performance of the seedlings was observed in the initial cycles. The ideal air temperature for the growth of tropical grasses after emergence is between 30 and 35 °C [59]. While temperatures above 35 °C inhibit growth [60], temperatures below 30 °C reduce the growth rates of forage grasses [61].

The better performance of Sabia grass seedlings in the two initial cycles can also be attributed to higher solar radiation in this period (Figure 1). Solar radiation directly influences the biomass production rate of *Urochloa* seedlings [62]. Higher levels of solar radiation provide a greater amount of energy for photosynthesis [63], resulting in an increase in organic matter production and biomass accumulation [62]. The intensification of solar radiation also favors the development of larger and more expansive leaf canopies [64], contributing to higher rates of biomass accumulation [65]. Adequate presence of sunlight also facilitates an efficient regulation of water loss through transpiration, thanks to ideal stomatal opening and closing [66]. This allows plants to adjust their water needs effectively while simultaneously maximizing photosynthetic rates, hence optimizing water use efficiency [67].

In cycle 1 (Figure 5), the increase in dripper installation depth caused linear reductions in all characteristics evaluated. In cycle 2, only RL and SDM were reduced with increasing dripper depth. In cycle 3, only SDM was reduced with the increase in dripper depth. The

results suggest that the rise of water in the soil was compromised as the dripper installation depth increased, as previously reported.

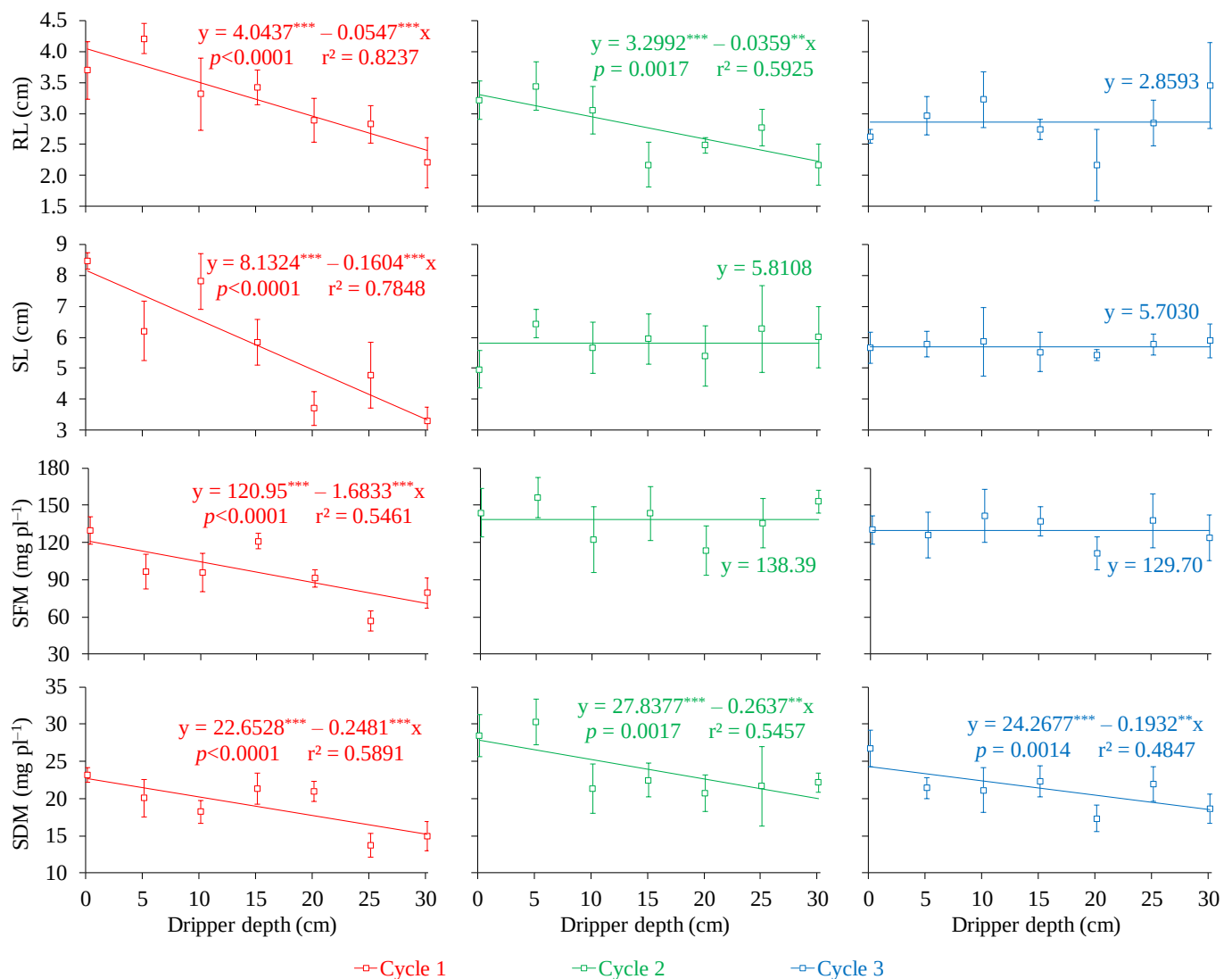


Figure 5. Root length (RL), shoot length (SL), and fresh (SFM) and dry (SDM) mass of *Sabia* grass seedlings as a function of irrigation with drippers installed at different depths and in different cultivation cycles. Viçosa, MG, Brazil, DEA-UFV, 2022. **, *** = significant at 1%, and 0.1% probability levels, respectively.

Drippers installed at a shallower depth can also stimulate the growth of roots closer to the surface [68], where water and nutrients are more readily available. This can result in rapid root development and seedling establishment, promoting faster germination and early growth. When installed deeper in the soil, drippers stimulate deepening of the roots [68], which can benefit already established plants, but can delay initial growth. Therefore, the choice of dripper installation depth should consider both the soil characteristics and the specific needs of seedlings at different development stages to maximize irrigation system efficiency and promote healthy growth.

Considering that for some variables, the best dripper installation depth was 15–20 cm, and considering that this depth contributes to reducing soil water evaporation and improving operability compared to the emitter installed on the surface, drippers should be installed between 15 and 20 cm deep in subsurface drip irrigation systems in areas with clayey soil.

4. Conclusions

Through the results obtained in this study, it is possible to identify better germination of Sabia grass based on the responses related to the germination and vigor characteristics of the species exposed to water and thermal stress conditions. This provides the best performance and growing conditions in environments where abiotic factors affect crop development.

Sabia grass seed germination, as well as parameters related to germination speed, were negatively affected by the increase in dripper installation depth in clayey soil areas. With the decrease in water potential and consequently the increase in temperature, there was a reduction in the performance of Sabia grass seeds.

Drippers should be installed at 15–20 cm depth in subsurface drip irrigation systems in areas with clayey soil, considering benefits such as reduced soil water evaporation and increased operability compared to surface systems. This practice optimizes the use of water, contributing to more efficient and sustainable irrigation.

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