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HOW DOES WATER DEFICIT AFFECT GLADIOLUS GROWTH AND DEVELOPMENT?

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KEYWORDS

Irrigation, schedule production, floral stem quality, *Gladiolus* × *grandiflorus* Hort.

ABSTRACT

The growing demand for gladiolus, especially at peaks of consumption, requires efficient scheduled production and good quality of floral stems. The objective of this study was to understand how water deficit affects the growth and development of gladiolus and, consequently, the quality of the floral stems produced. Plant development, quantitative parameters of the floral stems, and dry mass partitioning were evaluated in two field experiments with four gladiolus cultivars, with and without irrigation. The development cycle was longer in the non-irrigated treatment, whereas its duration under no water deficit was similar to that predicted by PhenoGlad, which is a gladiolus phenology model. As PhenoGlad predicts gladiolus development only for scenarios without water deficit, the inclusion of a water-stress submodel in the model would allow its application to any water supply scenario and help decision makers and farmers to plan gladiolus production more accurately. Water deficit also reduced gladiolus growth and flower stem size, but did not affect dry mass partitioning. As the development and quality of the floral stems of gladiolus were negatively affected by water stress, irrigation is essential for producing high-quality gladiolus floral stems and enabling production planning for peaks of consumption.

INTRODUCTION

Water deficit is a limiting factor for the growth and development of agricultural crops (Teixeira et al., 2019). Under conditions of reduced soil water availability, plants close their stomata, reducing carbon dioxide input and the photosynthetic process (Pinheiro et al., 2014; Souza et al., 2014). In ornamental crops, water stress causes loss of quality of the floral stems and can depreciate this marketable product (Porto et al., 2014; Pereira et al., 2016b).

Gladiolus (*Gladiolus* × *grandiflorus* Hort.) is one of the most important ornamental crops worldwide, mainly as a cut flower (Thakur et al., 2015). Because it is an easy-to-produce crop that requires low initial cost and is cultivated in open fields, gladiola has become an important cut flower for small farmers in Brazil (Uhlmann et al., 2019). Due to the ease of cultivation and the rusticity of the gladiolus plant, farmers do not pay much attention to the water needs of the crop. However, the growing demand for this flower, especially in peak consumption, requires efficient production planning and good quality of the marketed product (Schwab et al., 2015b; Becker et al., 2020; Becker et al., 2021a).

PhenoGlad is a dynamic process-based phenological model of gladiola that simulates its phenology on a daily time step (Uhlmann et al., 2017) without water limitations and considers three main phases based on the developmental scale by Schwab et al. (2015a): sprouting, vegetative, and reproductive phases. In PhenoGlad, development is driven by air temperature using the nonlinear approach of Wang & Engel (1998). With PhenoGlad, scheduling of gladiolus production can be accomplished using historical data and crop development models to simulate the best planting date of corms in scenarios without water limitations (Becker et al., 2020). However, is the developmental cycle of gladiolus insensitive to water deficit? And how accurate are the PhenoGlad predictions assuming no water limitation? Those are important questions that still need to be answered.

Under low soil water availability, plant growth of different crops can also be altered (Kelling et al., 2015; Lago et al., 2012; Pinheiro et al., 2014), and several studies

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have shown a reduction in the yield of field crops (Alberto et al., 2006; Teixeira et al., 2019). Unlike field crops, two particular aspects are crucial for determining the success of farmers in ornamental plant production. One is the efficiency in scheduling production, because the profit is lower when the product is offered outside the peak of consumption, and the other is the quality of floral stems. If water stress affects these two aspects, an extra water supply management has to be planned for gladiolus production and the PhenoGlad model needs to be improved to take water deficit into account. Therefore, the objective of this study was to understand how water deficit affects the growth and development of gladiolus and, consequently, the quality of the floral stems.

MATERIAL AND METHODS

Experiments were conducted in open field conditions in Santa Maria, Rio Grande do Sul State, Brazil, during two growing seasons (2017/18 and 2018/19) with four gladiolus cultivars: Rose Friendship (early development cycle), Rose Supreme (intermediate II development cycle), Peter Pears (intermediate I development cycle), and Jester (intermediate II cycle development). The corms were planted on 22 November 2017 (cultivars Rose Friendship, Peter Pears, and Jester) and on 1 December 2018 (cultivars Rose Supreme, Jester, and Peter Pears) in the first and second experiments, respectively. These planting times were selected to expose the plants to the conditions of high evaporative demand during summer.

The experiments were conducted in beds that were 22 m long and 1 m wide. Each experiment had three flowerbeds, one each for each cultivar (Figure 1). The flowerbeds were split into two equal areas in order to apply the irrigated and not irrigated management on each side. Using only one flowerbed for each cultivar implies the absence of random spatial replications, and the irrigation factor was not a random choice as well (Figure 1). However, this experiment had to be designed in this way to allow the installation and management of the irrigation system. Furthermore, the high homogeneity of soil in the area compensates for the lack of “true” replication and allows the use of pseudo-replicates to evaluate the treatment effects (described as follows).

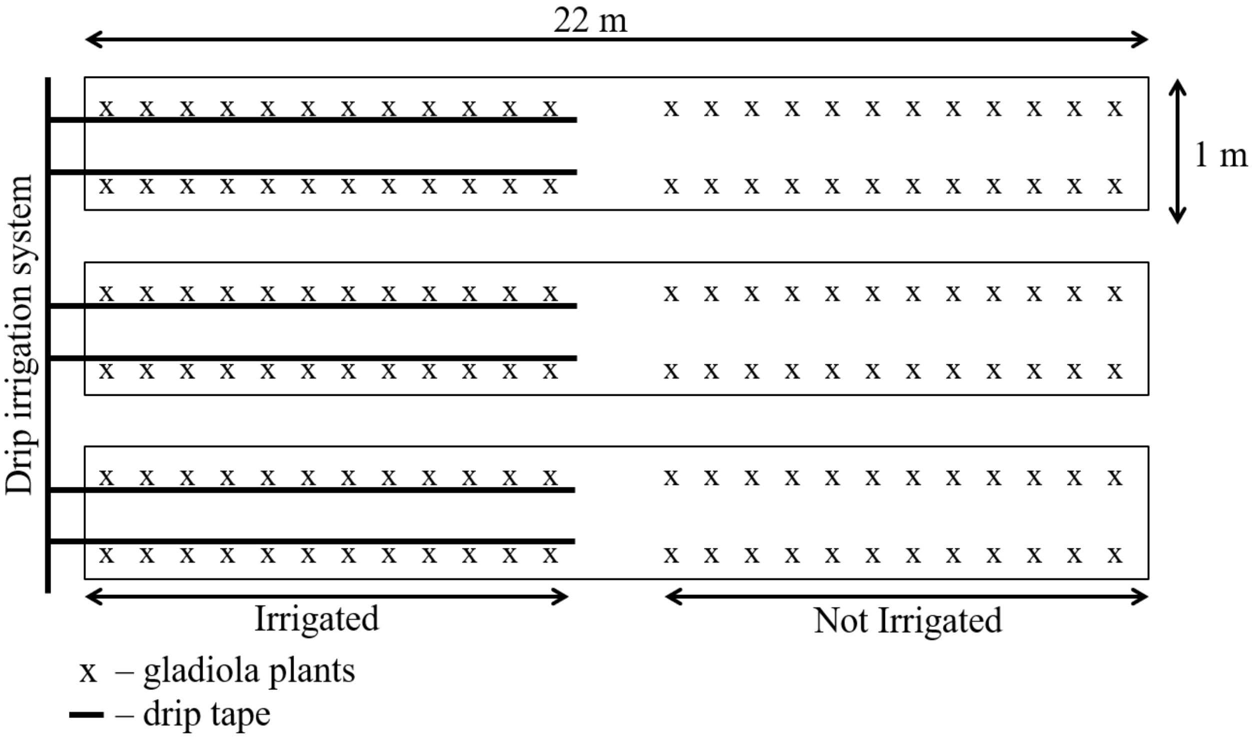

FIGURE 1. General view of the experimental design indicating the irrigation management and position of the drip tapes. Each flowerbed contained a diferent gladiola cultivar. Santa Maria, RS, Brazil.

The gladiolus corms were planted in two paired rows, 0.4 m apart in the longitudinal direction of the flowerbeds (Figure 1). The corms were spaced 0.2 m within the row, totaling 220 plants per flowerbed and 110 plants per cultivar and irrigation management. The entire flowerbeds were kept irrigated until plant emergence was completed (4 December 2017 and 12 December 2018 in the first and second experiments, respectively), following which only half of the flowerbeds received drip irrigation (Figure 1).

For irrigation management, a daily water balance was calculated, considering a root layer of 0–35 cm, based on root development observed in this soil. A fraction of 80% of the total available water (TAW = 62.5 mm) of the root layer was considered as readily available water (RAW = 50 mm). TAW was calculated as the difference between the soil water content at field capacity and the permanent wilting point. Irrigation was performed whenever the predicted water depletion reached 10 mm, which was 20% of the RAW (Allen, 1998). Water depletion was estimated as the potential crop evapotranspiration (ETc), which was calculated as ETc = ETo × Kc, where ETo is the reference evapotranspiration by the Penman-Monteith method and Kc is the crop coefficient. The Kc was 0.7 for the sprouting phase and 1.0 for the reproductive phase. During the vegetative phase, the Kc values were calculated using linear interpolation. As the flowerbed had a high drainage rate, irrigation was stopped at the onset of the outflow from the flowerbed, which was an indicator that the field capacity was reached.

The PhenoGlad model (Uhlmann et al., 2017) was used to simulate the date of harvest of the floral stems of each cultivar in the potential condition (without water limitation) from the planting date. Meteorological data for the ETc calculation and for PhenoGlad model runs were taken from an automatic weather station of Instituto Nacional de Meteorologia (INMET), Santa Maria, RS, located approximately 100 m from the experiments.

Soil moisture sensors were installed to measure the volumetric soil water content in irrigated and non-irrigated treatments in the flowerbeds. The moisture measurements were made at a soil depth of 15–25 cm in the Rose Friendship (Experiment 1) and Rose Supreme cultivars (Experiment 2).

The emergence of plants was monitored, and subsequently the phenological development stages were evaluated on a daily basis in 20 tagged plants (20 pseudo-replicates, as mentioned before), according to the scale of Schwab et al. (2015a). When these plants reached the harvest point (R2 stage), quantitative parameters of the floral stem (Schwab et al., 2015b) were also measured: total plant length, floral stem length, and diameter of the floral stem just below the first floret of the spike. Furthermore, at the R2 stage, 10 plants (10 pseudo-replicates) were collected to determine the dry mass of the plant parts (new-corms, leaves, and floral stems). The collected material was separated and dried in an oven at 60°C until a constant weight was achieved. Statistical analyses were performed separately for each experiment. The average total dry mass, floral stem dry mass, floral stem length, spike length, floral stem diameter, number of florets, and dry mass percentage were subjected to two-way analysis of variance (ANOVA) ($p<0.05$) to evaluate the effect of cultivars and water regime, considering a completely randomized design, with the number of replicates varying depending on variables: 10 plants for dry mass and 20 plants for other variables. In cases where the cultivars × water regime interaction was significant, the Tukey test analysis ($p<0.05$) for mean differences was unfolded within each factor. When the cultivar × water regime was not significant, the averages of each factor were compared using Tukey test ($p<0.05$).

RESULTS AND DISCUSSION

During crop development in Experiment 1, the maximum air temperature ranged from 18.2°C to 38.6°C, and the minimum temperature ranged from 9.2°C to 22.8°C (Figure 2A). Precipitation distribution was characterized by rain showers of 20 mm interspersed with periods of 10 days without precipitation, which led to water deficiency in non-irrigated plots. From 52 to 66 days after planting, there was an accumulated precipitation of 123.2 mm, but during that period the plants were already at the end of the cycle (very close to the harvest point). In Experiment 2 (Figure 2B), the maximum air temperature ranged from 22.0°C to 38.6°C and the minimum temperature ranged from 10.0°C to 24.8°C. Immediately after the emergence of the crop, sufficient rainfall occurred, totaling 155 mm, after which there were dry periods interspersed with rainy periods.

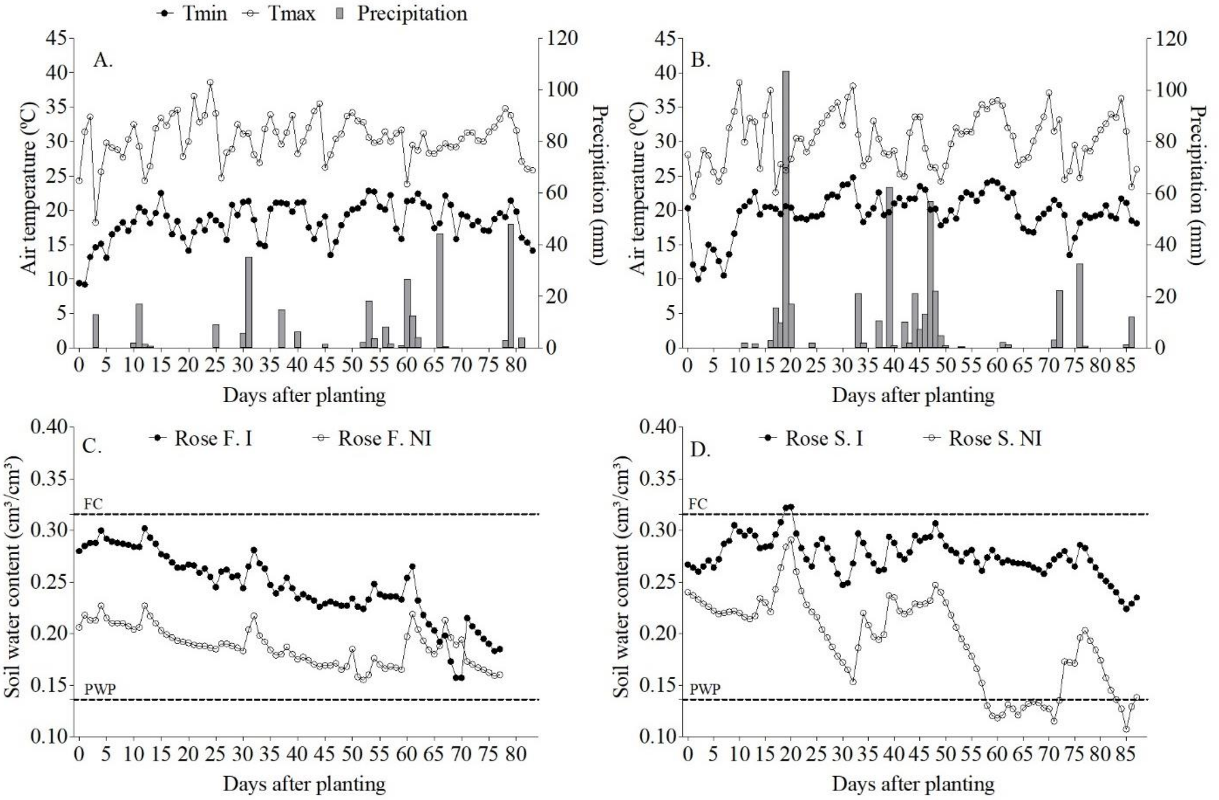

FIGURE 2. Minimum (Tmin) and maximum air temperature (Tmax), precipitation (mm) and soil water content during experiment 1 (PL = 22/11/2017) (A, C) and experiment 2 (PL = 01/12/2018) (B, D) in Santa Maria, RS, Brazil.

In both experiments, there was a large difference in soil water content between irrigated and non-irrigated treatments over the crop development cycle (Figures 2C, 2D). In the non-irrigated treatment, soil water content remained near the wilting point for many days in the Experiment 1 (Figure 2D) and was lower than the wilting point in the Experiment 2 (Figure 2D). Consequently, the gladiolus plants in the non-irrigated treatment experienced water deficit for many days in both experiments.

Water deficit affected the duration of the developmental cycle in all cultivars that were not irrigated (Figure 3). In Experiment 1, the duration of the vegetative phase was 45, 56, and 57 days for the irrigated treatment and 52, 60, and 64 days in the non-irrigated treatment for Rose Friendship, Peter Pears, and Jester, respectively. Consequently, the duration from planting to harvest point (R2) was 62, 72, and 73 days for irrigated treatment and 68, 77, and 83 days for non-irrigated treatment. In Experiment 2, the vegetative phase was 59 and 61 days for irrigated treatment and 63 and 66 days for non-irrigated treatment for Rose Supreme and Jester, respectively. The cycle duration up to stage R2 was 77 and 80 days in the irrigated treatment, and 83 and 87 days in the non-irrigated treatment, respectively.

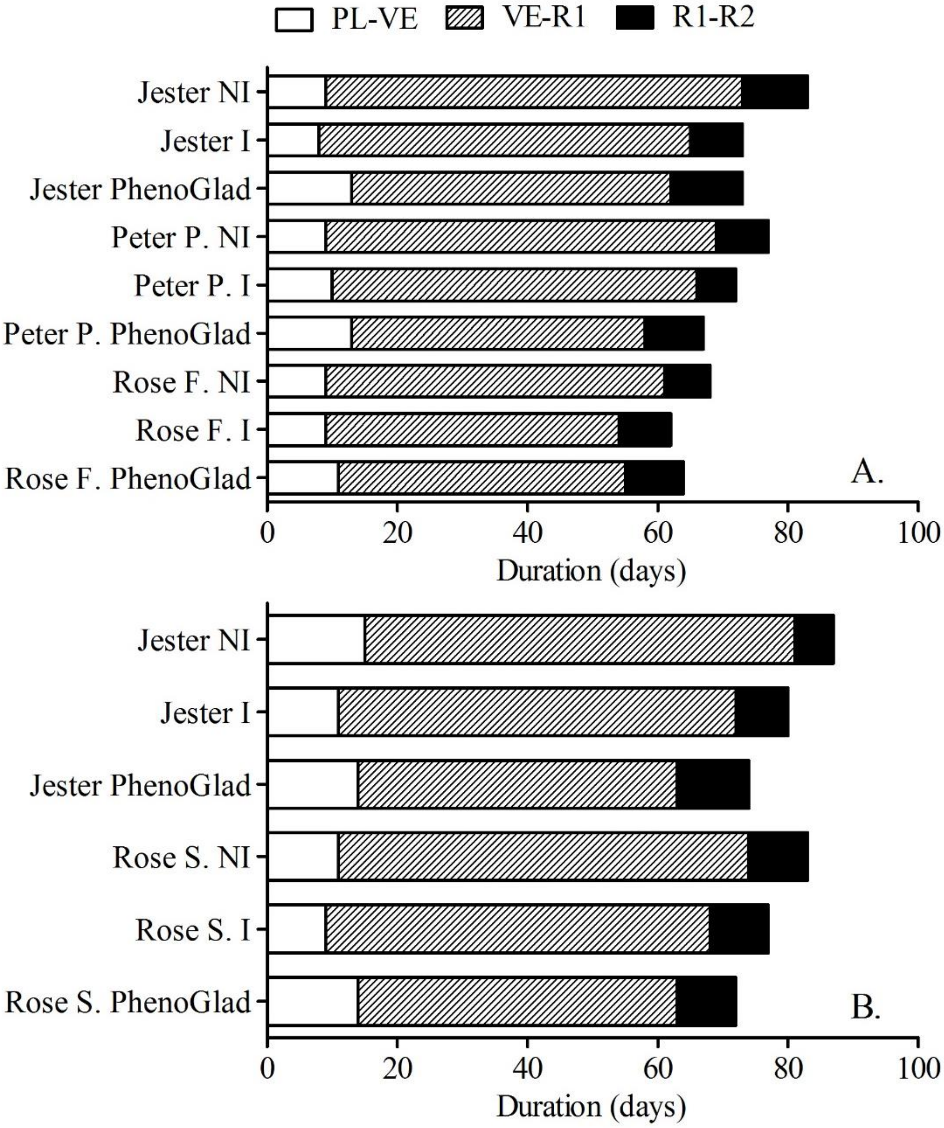

FIGURE 3. Duration (days) of sprouting (PL-VE), vegetative (VE-R1) and reproductive (R1-R2) phases of gladiolus cultivars Jester, Peter Pears and Rose Friendship in Experiment 1 (PL = 22/11/2017) and, of the cultivars Jester and Rose Supreme in Experiment 2 (PL = 01/12/2018) for the irrigated (I) and non-irrigated (NI) treatments, and simulated by the PhenoGlad model in Santa Maria, RS, Brazil.

This lengthening of the crop development cycle by water deficit was a consequence of its effect on the extension of the duration of the vegetative phase (Figure 3), which is the developmental phase that drives the overall cycle length (Streck et al., 2012). This result is in agreement with those of Pereira et al. (2016a) and Becker et al. (2021b), who found that lower water content delays gladiolus flowering due to the reduction in leaf emission rate. The effect of water deficit is likely similar to the effect of the combination of hot and humid air, as reported by Shillo & Halevy (1976), who found that plants in V2-V3 stage under hot and dry air for 15 days had 3–4 leaves, while those under hot and humid air had 4–5 leaves. Stomatal closure, reduction of transpiration, and increase in plant temperature are all negative effects of water deficit because they slow down the plant development rate (Shillo &

Halevy, 1976). Gladiolus development has a daily maximum rate at 25°C in the sprouting and reproductive phases, and at 27°C in the vegetative phase; above or below these limits, the daily rate of development is reduced (Uhlmann et al., 2017).

Such information is important to assist farmers in planning their gladiolus crops. According to the PhenoGlad model (Uhlmann et al., 2017), simulations for conditions without water limitation indicate that flower stems of cultivar Jester, in Experiment 1 (planting on 22 November 2017) would be harvested on 3 February 2018 (Figure 3). If the farmer had used irrigation, he could actually harvest on 3 February 2018. However, due to water deficit, the flower stems of this cultivar during Experiment 1 were ready for harvest only on 13 February 2018. A 10-day delay in harvesting makes it impossible for farmers to supply customers on the days of highest demand and also reduces the farm profits, because they would sell their product after the date of highest prices (Becker et al., 2020; Uhlmann et al., 2019). For the Peter Pears cultivar, this difference was also 10 days, and for Rose Friendship cultivar, it was 4 days. In Experiment 2, the Jester flower stems were ready for harvest only 13 days after what was informed by the Phenoglad and, for Rose Supreme, only 11 days later. These results indicate that the PhenoGlad model, which is increasingly being used to schedule gladiolus production under conditions without water limitation (Becker et al., 2020; Becker et al., 2021a), must be updated to consider water deficit. When simulating the growth of the crop, PhenoGlad needs to consider the effect of water deficit in reducing the dry mass of the plants, and consequently, in the quality of flower stems. All of these adjustments will expand the practical application of the PhenoGlad model for decision making by farmers to ensure higher quality and efficient production planning to meet peak consumption.

In addition to changing the development rate of gladiolus, water deficit also affects the quality of the flower, due to reduced plant growth. Because there was no interaction between cultivars and water regimes, Figure 4 shows the mean of total dry mass of the plant (without considering the mass of old corms), the dry mass of the floral stem, floral stem length, floral stem diameter, number of florets, and spike length observed in Experiment 1 and Experiment 2 for irrigated and non-irrigated treatments. In Figure 5, these variables are compared among cultivars. In Experiment 1 (Figures 4A-4E), there was a reduction in the quality of all variables analyzed when plants did not receive supplementary irrigation. In Experiment 2 (Figures 4F-4J), there was a difference between irrigated and non-irrigated treatments only in terms of floral stem length. These results demonstrate that the water deficit in Experiment 2 was less severe. In terms of floral stem length (Figure 5C) and number of florets (Figure 5E), there were no differences between cultivars in Experiment 1. The comparisons of cultivars indicated the best floral stem quality for cultivars Jester and Rose Supreme. The Jester cultivar produced a higher total dry mass (Figure 5A) and floral stem dry mass (Figure 5B). In Experiment 2 (Figures 5F-5J), the Rose Supreme cultivar had higher total dry mass (Figure 5F), floral stem diameter (Figure 5I), and spike length (Figure 5J).

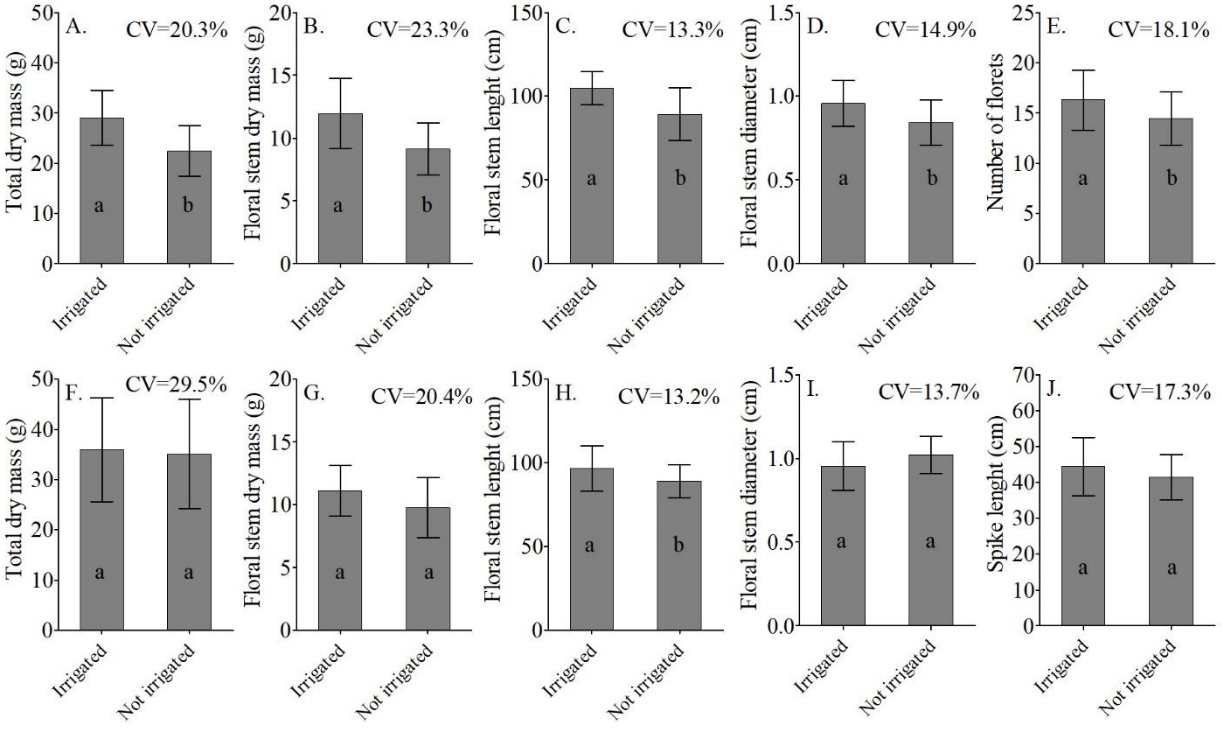

FIGURE 4. Total dry mass (A, F), floral stem dry mass (B,G), floral stem length (cm) (C, H), floral stem diameter (D, I), number of florets (E) and spike lenght (J) of gladiolus for irrigated and non-irrigated treatments during Experiment 1 (PL = 22/11/2017) (panels from A to E) and Experiment 2 (PL = 01/12/2018) (panels from F to J) in Santa Maria, RS, Brazil. n=10 plants (A,F, B, G). n=20 plants (C, H, D, I, E). *Bars not followed by the same letter differ by Tukey's test at 5% significance level.

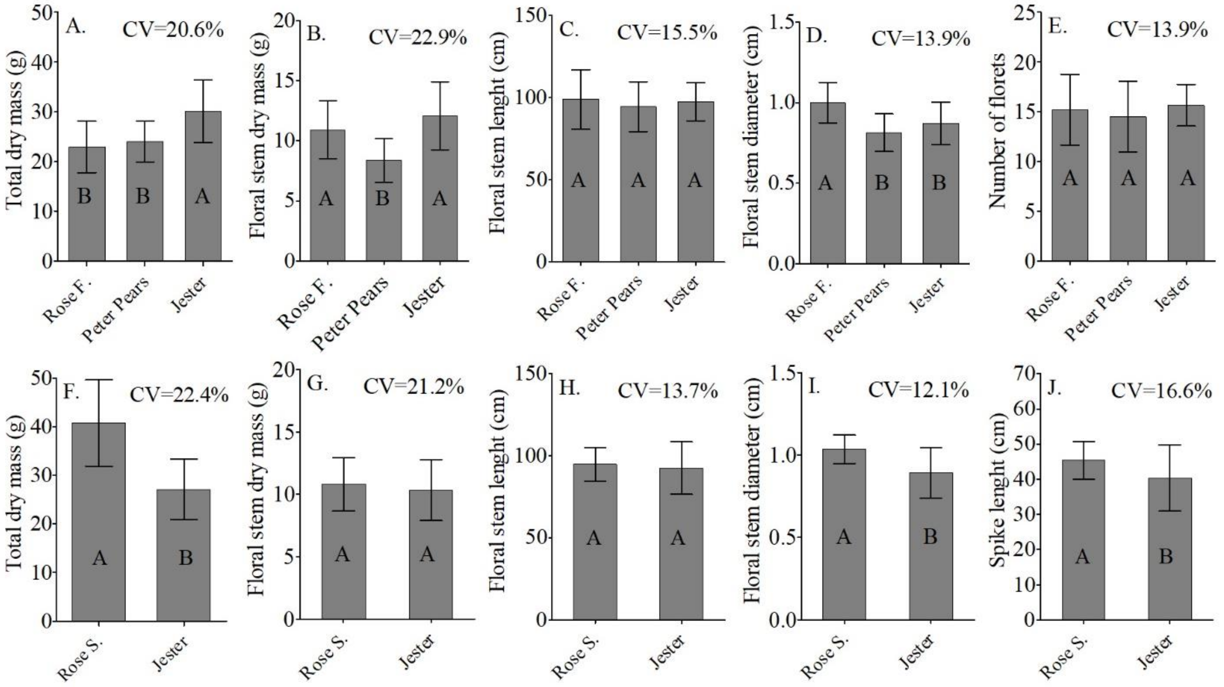

FIGURE 5. Total dry mass (A, F), floral stem dry mass (B,G), floral stem length (cm) (C, H), floral stem diameter (D, I), number of florets (E) and spike lenght (J) for gladiolus cultivars Rose Friendship, Peter Pears and Jester during Experiment 1 (PL = 22/11/2017) (panels from A to E) and for Rose Supreme and Jester during Experiment 2 (PL = 01/12/2018) (panels from F to J) in Santa Maria, RS, Brazil. n=10 plants (A,F, B, G). n=20 plants (C, H, D, I, E).*Bars not followed by the same letter differ by Tukey's test at 5% significance level.

The interaction between cultivar and water regime was significant for spike length in Experiment 1 (Figure 6A) and for number of florets in Experiment 2 (Figure 6B). The spike length in all cultivars was higher in the irrigated treatments (Figure 6A). The cultivar Rose Friendship presented the larger spike length in the irrigated treatment, and Jester and Rose Friendship presented the best results in the non-irrigated treatment. The number of florets was the only variable not affected by water deficit and cultivars.

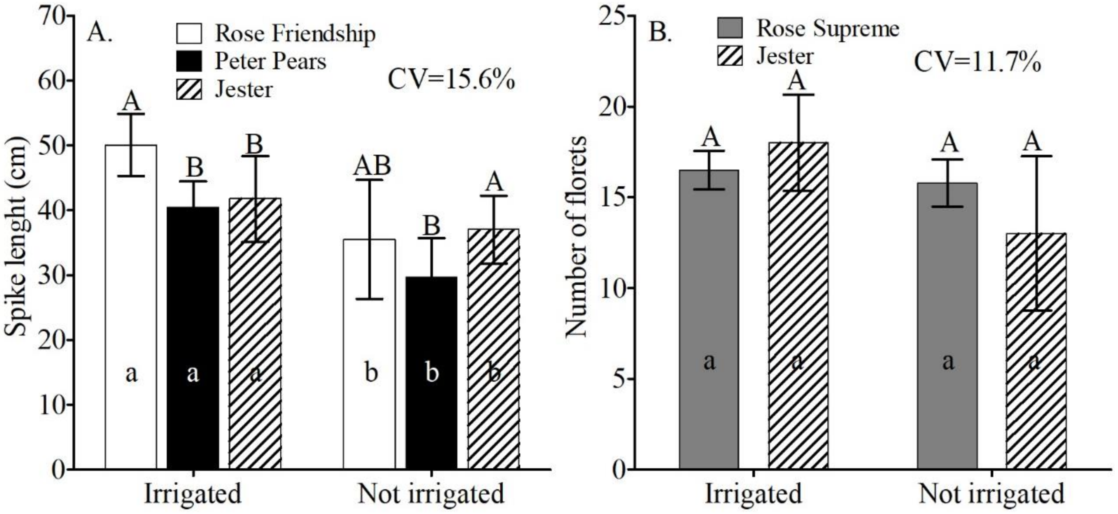

FIGURE 6. Spike lenght (A) for gladiolus cultivars Rose Friendship, Peter Pears and Jester during experiment 1 (PL = 22/11/2017) and number of florets for Rose Supreme and Jester during experiment 2 (PL = 01/12/2018) in the irrigated and non-irrigated treatments in Santa Maria, RS, Brazil. n=20 plants. * Capital letters compare the cultivars within the treatment and lowercase letters compare the effect of the treatment within the same cultivar. Bars not followed by the same letter differ by Tukey's test at 5% significance level.

These results demonstrate the importance of irrigation in gladiolus plants to obtain floral stems of high quality (larger in full size and spike and, with a greater number of florets), which will ensure the longest vase life of the floral stem (Schwab et al., 2014; Uhlmann et al., 2019). These findings are similar to those of several studies that have evaluated the effect of irrigation management on gladiolus crop growth. For example, there was a reduction in the dry mass of the floral stem when produced with less soil water replacement (Porto et al., 2014; Mazzini-Guedes et al., 2017), and lower levels of irrigation resulted in reduced floral stems with fewer florets and smaller flower diameters (Bastug et al., 2006; Porto et al., 2014).

Similar to gladiolus, irrigation management is also important for the productivity and final product quality of chrysanthemum (Farias et al., 2012; Kelling et al., 2015). This is because under conditions of reduced soil water availability, plants close the stomata, decrease carbon dioxide input, and reduce the photosynthetic process (Pinheiro et al., 2014; Souza et al., 2014). In addition, leaf expansion is reduced, and as a result, there is a reduction in flower quality (Bastug et al., 2016; Porto et al., 2014), or in the case of field crops, the crop yields decrease (Alberto et al., 2006).

Understanding the dynamics of dry mass partitioning between plant organs is also important, as crop models that simulate mass production in the crop consider partitioning at each stage of the plant to grow mass (Tironi et al., 2017). The three main organs of the gladiolus plant (leaves, new-corm, and floral stem) were considered to determine the percentage of dry mass for the respective organ at stage R2 (Table 1). Note that the difference exists only when comparing cultivars. However, when considering irrigated and non-irrigated treatments, there was no favored organ during partitioning, indicating that water deficit reduces the dry mass of plants (reduces the size of the plant), but does not affect dry mass partition in gladiolus. When the PhenoGlad model is able to simulate the growth of gladiolus, it is important to introduce a penalty for water deficit so that it faithfully represents the reduction in the quality of flower stems under this condition. To simulate the development of the gladiolus and also assist farmers when water deficit occurs, the model needs to be adjusted to simulate development in the non-irrigated condition as well, indicating that the farmer will harvest the flower stems later when water deficit occurs.

TABLE 1. Dry mass of leaves, new-corms and floral stems of gladiolus cultivars Rose Friendship, Peter Pears and Jester cultivars during Experiment 1 (PL=22/11/2017) and Rose Supreme and Jester cultivars during Experiment 2 (PL = 01/12/2018), in the irrigated and non-irrigated water regimes in Santa Maria, RS, Brazil.

Cultivar	Water regime		Mean	Cultivar	Water regime		Mean
	Irrigated	Non-Irrigated			Irrigated	Non-Irrigated	
	Experiment 1				Experiment 2		
			Dry mass of leaves (%)				
Rose F.	47.1	46.8	46.9B	Rose S.	57.2	57.2	57.2A
Peter P.	53.3	53.7	53.5A	Jester	52.5	49.5	52.0B
Jester	52.8	53.9	53.2A	Mean	54.9a	55.8a	
Mean	51.3a	51.0a					
CV (%)			4.8	CV (%)			7.8
			Dry mass of new-corm (%)				
Rose F.	4.0	3.8	3.9C	Rose S.	16.2A	14.2A	15.3
Peter P.	10.1	10.1	10.1A	Jester	8.6B	18.3A	10.2
Jester	5.2	6.0	5.6B	Mean	12.6	14.9	
Mean	6.3a	6.4a					
CV (%)			23.0	CV (%)			31.0
			Dry mass of floral stem (%)				
Rose F.	47.6	47.9	47.8A	Rose S.	26.0	28.1	26.9B
Peter P.	35.1	34.3	34.7C	Jester	37.8	31.2	36.7A
Jester	40.6	39.0	40.0B	Mean	31.6a	28.7a	
Mean	41.0a	41.1a					
CV (%)			6.8	CV (%)			16.1

* Capital letters compare the cultivars within the treatment and lowercase letters compare the effect of the treatment within the same cultivar. Bars not followed by the same letter differ by Tukey's test at 5% significance level. n=10 plants.

CONCLUSIONS

Water deficit increases the duration of the vegetative phase of gladiolus and, consequently, the duration of the overall cycle (gladiolus development is affected), making it difficult to schedule production using the PhenoGlad model. The total dry mass and floral stem dry mass are reduced under water deficit (gladiolus growth is affected), resulting in floral stems of reduced size and lower market value. The dry mass partition between the plant organs is not altered. The quality of the floral stems in the gladiolus is reduced under water deficit conditions, therefore irrigation is essential to guarantee a high value of the marketed product.

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