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Methods of soil moisture maintenance for production of sunflower under controlled conditions

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Abstract

Soil water content is one of the most significant restriction factors for plant growth and development. This study focused on evaluating the methods of soil moisture maintenance during trials under controlled conditions by observing the morphological and structural characteristics of sunflower (*Helianthus annuus* L.). The experiments were performed in a greenhouse using an Oxisol. Four types of soil moisture maintenance treatments were tested (tensiometer, Irrigas, gravimetric method and self-irrigation system) with eight repetitions, employing a completely randomized experimental design. The variables analyzed included plant height, leaf number, stem diameter, and dry mass of shoot. The self-irrigation system was found to be technically fitting to manage the irrigation throughout the growth and development period of sunflower. The gravimetric method enabled a higher accumulation of dry mass of shoot.

Keywords. *Helianthus annuus* L.; irrigation; matric potential.
Abbreviations: DAE_Days After Emergency; B_Boron; Cu_Copper; CV_ Coefficient of Variation coefficient; FC_Field Capacity; Mn_Manganese; Mo_Molybdenum; Zn_Zinc; PRNT_ Relative Total Power of Neutralization.

Introduction

Many studies on crop production under protected cultivation have considered as controllable variables the following aspects: weather characteristics and atmospheric composition (Oliveira et al., 2014). However, when the main focus of the agricultural experimentation is appropriate irrigation water management then maintaining the soil water content assumes great significance for each crop.

The maintenance of soil moisture in agricultural experiments,
especially those carried out in greenhouse, has been carried out in general, without the adoption of criteria to standardize the volume of restored water to the experimental units. This is because the study of soil water content variation requires the use of appropriate methodologies to monitor the water availability to the plants, in order to avoid excess or water deficit conditions (Silva, 2014). According to several researches, the sunflower crop positively responds to soil water availability. Farahvash et al., (2011) and Canavar et al., (2014) reported a strong relationship between productivity and irrigation. Moreover, Nezami et al., (2008) indicated that excessive or drought conditions resulted in a reduction in the structural and productive traits of sunflower. Therefore, if the aim of the experiment is to identify the effect of proper soil moisture management in agricultural experiments, the critical water limits recommended for each crop must be considered, as well as the methodology employed to monitor the water available for the plants. This will minimize the experimental errors and variability among the treatments (Beltrão et al., 2002). Considering the possible alterations in soil water content that can occur, several irrigation management methods have been proposed for the experimental, the four most significant ones being the gravimetric method (Dutra et al., 2012), Irrigas sensor (Marouelli et al., 2010), tensiometer (Libardi, 2012) and self-irrigation system (Bonfim-Silva et al., 2007). The gravimetric method is one of the most used, pherhaps due to its simplicity and low cost. In this method, is characterized the “pot capacity” and then the soil water content is maintained through the difference in weighing of the experimental units in a given time interval (Bonfim-Silva et al., 2011).

The Irrigas system consists of a porous capsule, connected through a flexible tube to a small transparent tank, which is immersed in a bottle with water at the moment of the measurement of soil water tension. Among the advantages in using this method are the reduced cost, the low maintenance and the facility of use. On the other hand, the disadvantage is that the sensor does not indicate quantitatively the soil water tension, but only if it is below or above the reference values (Marouelli et al., 2005). The tensiometers in turn, is widely diffused in irrigation studies. This equipment directly measures the soil water potential and the determination of soil moisture is done indirectly from the determination of the soil water retention curve. Lastly, an autoirrigating system is defined as a controlled suction irrigation system, using porous capsules connected to a pendant water column (Aboukhaled et al., 1982). One of the advantages of this system in relation to other methods is the possibility of automatic irrigation of the experimental plots, guaranteeing the continuous replacement of water.

In light of these facts, it becomes crucial to establish methods that are effective in maintaining the soil water content to such a level that the plant productivity in the experiments under field conditions is unaffected, thus ensuring a high degree of reliability of the results thus achieved. This study focused on evaluating the methods of soil moisture maintenance during trials under controlled conditions by observing the morphological and structural characteristics of sunflower (*Helianthus annuus* L.).

Results and discussion

The soil moisture maintenance methods and plant growth

The methods of maintaining the soil water interfere in the sunflower development, revealing a similar behavior among the variables, with the highest average of the morphological and structural features being recorded in the self-irrigating system, except for the dry matter of the shoot, which revealed greater production in the gravimetric method.

In all the treatments an exponential increase was observed in the number of leaves in the vegetative phase until the early reproductive stage, after which stabilization was noted in the formation of new leaves, with the potential to highlight the self-irrigation system, which displayed the highest values among all the evaluations (Table 1). At the end of the experiment, at harvest time (69 DAE) the self-irrigation system (55.63) and gravimetric method (51.13) recorded the highest yields.

From this result it is evident that the constant maintenance of soil water (self-irrigation system) caused the stomata to stay open, enabling the entry of more quantities of CO_2, which most likely promoted greater leaf production in the plants under this treatment (Nazarli et al., 2010).

Silva et al., (2012) in their evaluation of the vegetative and reproductive development of sunflower cultured under water deficit conditions also reported a larger number of leaves in the treatment of well-watered culture throughout its growth period. These results further validate the findings of Nezami et al., (2008), who assessed the number of sunflower leaves soon after the vegetative growth period, and reported a drop in the number of leaves during conditions of less soil water availability. The sunflower plant heights were significantly affected by the soil moisture maintenance methods during the vegetative stage although no observable significance was evident in the reproductive stage. The self-irrigation system was the most effective method of soil moisture maintenance, as it achieved the highest values of 44.69 cm at 29 DAE; this result was significantly different from the results observed in the other methods, except for the tensiometer, which showed similarity to the Irrigas method (Table 2).

The variation in the soil water availability provided by the gravimetric method and Irrigas® sensor, probably resulted in the drop in the water potential of the stem cells, inducing a smaller cells and internodal elongation, climaxing in the growth of these plants (Nezami et al., 2008).

Silva et al. (2007), in their study on the growth and productivity of the sunflower cultivar using a variety of water depths, reported that the increased water supply induced greater plant height, with values of 151 cm on average in the cultivar *Helio* 251. These authors evaluated the sunflower development under field conditions, which could justify the difference in the results of the two studies. In the reproductive stage the absence of significant differences in plant height may be due to the inflorescence that is formed and developed, as the plant reduces the mobilization of the stem-elongation assimilate produced during chapter formation. Saensee et al., (2012) reported findings quite contrary to the above. They observed that the significant differences in plant height depended upon the soil water availability. They further stated that the parameter of plant height is a suitable index to assess the response of the sunflower plants to drought stress during the developmental period.

The stem diameter response to soil moisture maintenance methods

Regarding the stem diameter, the continuous water supplied via the self-irrigation system induced the best results throughout the evaluation periods. At 43 DAE the highest value of 10.93 mm in response to the self-irrigation system was noted, which did not significantly differ from those reported for the gravimetric method and tensiometer. The less soil water content indicates that the Irrigas method encourages reduced stem development (Table 4).

The results showing an increase in the stem diameter evident in the self-irrigation system is linked to ethylene production. This hormone has been observed to be produced in greater amounts when there is abundant soil water, which in turn results in the increased stem development (Dutra et al., 2012). Farahvash et al., (2011) reported that the drop in the soil water levels produced a decrease in the stem diameter in the sunflower plants, likely because of the lesser degree of cell division.

Iqbal et al., (2009) and Gomes et al., (2012) reported similar results obtained by utilizing irrigation blades during the development of sunflower. They observed an increase in the stem diameter in response to an increase in the soil water levels. Thus this parameter has been identified as an efficient criterion for the selection of sunflower plants.

Effect of soil moisture maintenance methods on the sunflower dry mass accumulation

With respect to the dry mass of shoot in the sunflower plants, the highest yields were recorded by the gravimetric method, a rise of 19.65% when compared with the irrigator system (Figure 1).

According to Farahvash et al., (2011) the reduction in the dry weight of the sunflower plants is due to the drought experienced during the growth and development period of the plants. This had resulted in a reduced leaf area, and thus of photosynthesis, which in turn induced a lowered production of assimilates and less development of the leaf, stem and chapters.

These reports concur with the findings of Castro et al., (2006), who found that soil moisture control hastened the development of the sunflower crop, under controlled conditions; they also identified a decrease in the plant total dry weight in all the stages of drought implemented. Nobre et al. (2010) also confirmed that the soil water content exerted a positive effect on the dry mass of shoot of the sunflower plants. They reported a fit of the linear regression model and 140% increase in the dry mass of the plant parts when 80% of the water requirement of the crop was replaced, as against the values during hypoxia. The results of this work showed

Table 1. Number of sunflower plant leaves subjected to soil moisture maintenance methods.

Stage	------------- Vegetative ------------			------------ Reproductive ----------		
Methods	15 DAE	22 DAE	29 DAE	43 DAE	57 DAE	69 DAE
Gravimetric	13.38b	25.25a	29.50b	38.13b	49.50ab	51.13ab
Tensiometer	17.88b	25.00a	29.38b	38.75b	45.38bc	47.38b
Irrigas	17.50b	20.38b	26.88c	39.88ab	44.00c	46.88b
Self-irrigation	19.63a	25.63a	32.13a	42.13a	53.25a	55.63a
CV (%)	4.97	7.58	4.70	6.21	6.70	8.64
Mean	18.09	24.06	29.47	39.72	48.78	50.25*

*Means followed by the same letter in the columns do not differ by Tukey test at 0.05 probability.

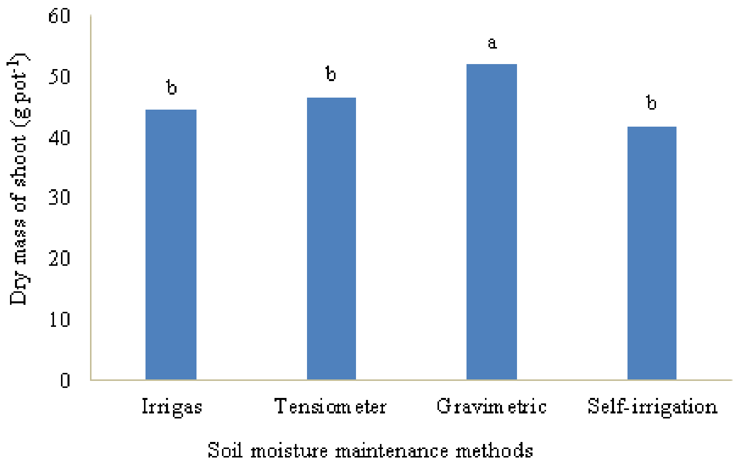

Fig 1. The dry mass of shoot of the cultivated sunflower in response to the different soil moisture maintenance methods at 69 DAE.

Table 2. Sunflower plant height (cm) in response to the methods of soil moisture maintenance.*

Stage	----------- Vegetative -----------			---------------- Reproductive ---------------			
Methods	15 DAE	22 DAE	29 DAE	43 DAE	50 DAE	57 DAE	69 DAE
Gravimetric	12.94c	26.08b	39.36b	83.25a	92.59a	96.90a	96.97a
Tensiometer	14.62b	27.58ab	41.24ab	79.06a	87.97a	90.59a	90.91a
Irrigas	13.56bc	25.53b	39.14b	82.44a	89.56a	92.81a	92.78a
Self-irrigation	16.19a	30.23a	44.69a	79.56a	87.63a	91.66a	91.65a
CV (%)	7.65	8.56	8.47	9.66	6.31	5.65	5.75
Mean	14.33*	27.35*	41.10*	81.08^{ns}	89.44^{ns}	92.99^{ns}	93.08^{ns}

*Means followed by the same letter in the columns do not differ by Tukey test at 0.05 probability, ^{ns} non-significant.

Table 4. Stem diameter (mm) of the sunflower plants in response to the soil moisture maintenance methods.

Stage	------ Vegetative -----		------------------ Reproductive ------------------			
Methods	22 DAE	29 DAE	43 DAE	50 DAE	57 DAE	69 DAE
Gravimetric	8.21b	9.28ab	10.50a	10.27a	10.21a	9.87ab
Tensiometer	8.01bc	9.02bc	10.25a	10.00a	10.00a	9.78ab
Irrigas	7.20c	8.32c	9.36b	9.16b	9.16b	9.09b
Self-irrigation	9.19a	9.86a	10.93a	10.73a	10.62a	10.51a
CV (%)	7.82	6.46	5.56	5.55	5.61	6.95
Mean	8.15	9.12	10.26	10.01	9.99	9.81

*Means followed by the same letter in the columns do not differ by Tukey test at 0.05 probability.

Table 5. Characterization chemical and of the particle size of the soil in the 0-0.20 m.

pH	P	K	Ca	Mg	H	Al	SB	CEC	V	O.M.	Sand	Silt	Clay
$CaCl_2$	(mg dm^{-3})		------------------- cmol$_c$ dm^{-3} ----------------------						%	g dm^{-3}	----------g kg^{-1} ---------		
4.1	2.4	28	0.3	0.2	4.2	1.1	0.6	5.9	10.2	22.7	549	84	367

that the highest dry matter yields corroborated with the gravimetric method, which maintained the soil moisture at 80% of field capacity.

Materials and Methods

General information

The plant species used was sunflower (*Helianthus annuus* L.), cultivar Helium 250. All the experimental trials were done in a greenhouse through the Graduate Program in Agricultural Engineering of the Federal University of Mato Grosso, Brazil. The completely randomized design was employed involving four methods of maintaining soil moisture (gravimetric method, Irrigas sensor, tensiometer, and self-irrigation system) with eight repetitions.

The soil was collected from a depth of 0-0.2 m from the Oxisol under Cerrado vegetation and passed through a 4 mm sieve prior to the experiment. The chemical composition and texture of the soil are listed in Table 5, determined based on the EMBRAPA (2011) standards.

Each experimental unit included a plastic pot of 3.18 dm^3 capacity. The saturation by bases was raised to 60% by adding dolomitic limestone (PRNT = 80.3%), for 30 days until the soil acidity decreased.

Incubation with lime was done next, followed by fertilization up to 0.1 m of the surface soil layer using phosphorus and potassium in 150 and 100 mg dm^{-3} doses, respectively, with superphosphate and potassium chloride being the source materials.

Three nitrogen fertilizer doses (200 mg dm^{-3}) were applied at 10, 20 and 40 days after emergence (DAE). Micronutrient fertilizer was added in solution form, using 1 mg dm^{-3} of B and Cu, 3 mg dm^{-3} of Zn and Mn and 0.2 mg dm^{-3} of Mo, from the following sources: boric acid chloride copper, manganese chloride, zinc sulfate and sodium molybdate, respectively.

The seeds were treated with systemic fungicide and contact. Ten seeds per pot were planted and germination was observed four days post sowing. The first thinning process was done at 11 DAE leaving only three plants per pot and a second thinning was done at 18 DAE, leaving the two most vigorous plants.

The average temperature recorded during this period inside the greenhouse was 36.7 ° C maximum, higher than the 34 °C maximum, which is the highest temperature for the growth of the sunflower culture, according to EMBRAPA (2001). The mean relative moisture values recorded were 87.7% maximum and 30.58% minimum.

Soil moisture maintenance

For the management methods of irrigation water maintenance in the soil the van Genuchten (1980) equation was used by determining the water retention curve in the soil (Dourado Neto et al., 2000) from the undisturbed soil samples drawn from the experimental units (Equation 1).

$$\theta = \frac{0,468}{\left[1+(0,0573\left|\Psi_m\right|^{0,3545}\right]^{0,5724}} \quad (1)$$

In which;
θ = volume-based moisture
Ψm = matric potential

In all the treatments the irrigations were done at 7 and 14 h every day. An analog scale was used to maintain the soil water content for water replacement in the gravimetric method and a digital tensiometer was employed to record the soil water tension.

In the gravimetric method the maximum soil water retention or field capacity (FC) was determined in the laboratory pots of 3.18 dm^3 capacity containing the equivalent of 3.620 kg soil to 3% moisture of the base mass. Ten replications were done. The pots were placed in plastic trays and mounted on a support. Up to two-thirds of the pot height was filled with water until the soil was saturated by capillary action, and all the air present in the pores was removed. Once the soil was saturated the pots were taken off the tray and kept on a support to drain the unretained soil water (Bonfim-Silva et al., 2011). To stop the drainage pot deformed moisture content of the soil samples was assessed to determine the mass base. Once the samples were drawn they were weighed and the wet weight recorded. They were then dried in a forced air circulation oven at 105 °C for a 24-hour period. The samples were reweighed and the difference in weights indicated the moisture with reference to the field capacity.

From the perspective of irrigation management during the crop cycle, the volume of water required to maintain the soil moisture at 80% FC was calculated. Thus, the volume of water and dry soil mass were added to the weight of the pot, to calculate the full value of the weight when the pots needed irrigation.

Irrigation management tensiometry was performed depending on the assessment of the water supply into the soil, using a digital tensiometer. The volume of water to be supplied via irrigation was calculated based on the soil water retention curve. The soil water pressure needed for moisture maintenance was set at 5 kPa. Using the tensions observed the corresponding moisture was calculated by employing the equation of van Genuchten (1980). With the value of the current soil moisture content known for 80% of the FC the volume of water replacement was calculated (Equation 2). Water was then manually poured by measuring the volume of water in a semi-analytical balance.

$$V = \left(\theta_{fc} - \theta_{actual}\right)3180 \quad (2)$$

in which;
V - Volume of water, cm^3;
θ_{fc} - moisture to 80% of field capacity;
θ_{actual} - moisture in the voltage of each treatment cm^3 cm^{-3};
3180 - Volume of soil in the pot, cm^3.

A signaling system to control irrigation was also utilized to maintain the soil moisture in the experimental units, the Irrigas system (Calbo & Silva, 2001). The sensors were designed for a large range of critical stress, to complete the bubbling pressure test and facilitate grouping together of the porous capsules having same critical stress, as well as to identify any bubbling or air leakage at the seams of the Irrigas system (Libardi, 2012). Porous capsules were placed in the pot up to a depth of 0.15 m, in the wide extended portion of the root system. The irrigation time was assessed from the stress of 20 kPa by adding 250 ml of water to each pot.

The Irrigas system included a sensor (porous capsule) connected to a transparent syringe (3 ml) via a flexible microcube, which acted as an indicator of the water supply in the soil.

In the case of the subsurface self-irrigation treatment system the soil moisture was maintained with continuous water replacement according to the plant requirements. This system included a porous ceramic cap (filter candle of 0.05 m diameter and 0.07 m height), pushed into the soil in the upper part of the pot. A flexible micro tube (0.005 m in internal diameter and 0.001 m in wall thickness) connected the ceramic capsule at a constant reservoir level (Mariotte bottle) placed below the pot.

The soil water potential was estimated by the water column height between the pot and tank (0.3 m) corresponding to a controlled voltage of 3 kPa. Thus, an uninterrupted flow of evapotranspiration ensured automatic soil water replenishment, making it a self-irrigation system (Bonfim-Silva et al., 2007). A scale fixed to the reservoir enabled the water consumption to be quantified in each experimental unit.

Plant growth analysis

The growth and development of the sunflower plants were reviewed at 15, 22, 29, 43, 50, 57 and 69 days after emergence (DAE), and the following aspects were evaluated: plant height, leaf number, and stem diameter. At 69 DAE the dry matter of the shoot was assessed. The plant height was measured with a graduated measuring tape.

The stem diameter was measured with digital calipers, just above the cotyledon leaves. The dry mass was assessed by storing the samples in paper bags and drying them in a forced air circulation stove for 72 h at 65 ° C, till they attained constant weight.

Data analyses were submitted to the analysis of variance and the Tukey test was significant at 5% probability by the Sisvar statistical program (Ferreira, 2011).

Conclusion

Soil moisture maintenance methods were observed to influence the morphological characteristics and sunflower productivity under controlled conditions. This reinforces the importance and necessity of choice the correct soil moisture maintenance method in research, because inappropriate management of soil moisture can create a new source of variation influence the results of experiments. The self-irrigation system was technically suitable to manage the irrigation during the growth and development period of sunflower. The gravimetric method of irrigation management in sunflower cultivation was adequate to enable a higher accumulation of the dry mass of shoot.

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