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Essential oil content of basil under controlled water deficit during pre-harvesting

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Abstract: The intensity of water deficit influences directly the essential oil content for medicinal and aromatics plants, such as basil. In this context, the objective of this study was to quantify the effect of different levels of controlled water deficit before harvest on basil plants. The experiment was performed during 347 days, using the fully randomized factorial design (5x3) with five treatments defined by the irrigation suppression and three harvests, with five replications each treatment. The pre harvest irrigation suppression promoted an increase of essential oil content for basil plants.

Keywords: *Ocimum basilicum*, leaf water potential, medicinal plant.

Teor de óleo essencial de manjericão sob déficit de água controlado durante a pré-colheita

Resumo: Diferentes níveis de déficit hídrico influenciam diretamente o teor de óleo essencial de plantas aromáticas e medicinais, como é o caso do manjericão. Diante disso, o objetivo deste trabalho foi quantificar o efeito de diferentes níveis de déficit hídrico antes da colheita do manjericão. O experimento foi realizado durante 347 dias, em esquema fatorial (5x3) com cinco níveis de déficit hídrico e três épocas de colheita, com cinco repetições. A supressão da irrigação pré-colheita promoveu um aumento do teor de óleo essencial das plantas de manjericão.

Palavras-chave: *Ocimum basilicum*, potencial hídrico na folha, plantas medicinais.

Introduction

Basil (*Ocimum basilicum* L.) is an herbaceous and annual aromatic plant that belongs to the Lamiaceae family. It is widely cultivated in tropical and temperate regions, including Asia, Africa, Central and South America (Özcan, Arslan and Ünver, 2005; Sajjadi, 2006). The economic importance of basil is due to the presence of essential oil that is stored within the glandular trichomes on leaves (Sangwan et al., 2001), in which has high active biological substances content that provides health benefits (Bufalo et al., 2015). In addition, the essential oil from basil has a range of biological properties that can be used for pest control (Chang, Cho & Li, 2009) and disease control (Zhang, Li & Wu, 2009), as well as for the anti-microbiological (Hussain et al., 2008; Liber et al., 2011) and antioxidant activities (Hussain et al., 2008; Kwee & Niemeyer, 2011).

The water deficit stress, as well as the salinity and temperature stresses, are considered the main abiotic stress that can influence on crop yield due to its influence on the adequate plant development and growth (Lisar et al., 2012). According to (Jaleel et al., 2008), water deficit stress on crops affects many physiological and biochemical plant processes, such as photosynthesis, respiration, nutrient translocation, ion absorption, carbohydrate synthesis, nutrient metabolism and growth promoters, influencing on the adequate plant development. However, for medicinal and aromatic plants, the water deficit stress level and duration may contribute to a positive effect on some plant components. Studies have been indicating that plant oil quality and quantity can be increased in systems with reduced water availability for plants (Alvarenga et al., 2011).

In medicinal plants, studies showed that plants under water deficit increased the nitrogen, phosphorous and potassium contents, as well as carbohydrate and essential oil (Khalid, 2006; Alvarenga et al., 2011), and water availability is considered the factor that most influences the oil quality and quantity (Baghalian et al., 2008; Bahreininejad, Razmjoo and Mirza, 2013). For basil, authors described that its yield is directly associated with the water and nutrient availability, genotype, and moderately influenced by the environmental conditions (Arabaci & Bayram, 2004).

Even though studies indicate that low soil water availability may contribute to the oil content increment on medicinal and aromatic plants, others important aspects from plants can be reduced, such as plant vegetative growth (total green mass or yield). However, most of the studies were performed using full season water deficit stress technic. It is important, then, to create strategies for controlled water deficit stress that can improve oil content on basil at the same time that plant growth parameters are not affected. One alternative is to perform pre-harvesting controlled water deficit stress, which could contribute to the improvement oil content quality and quantity.

Studies that used the automated irrigation system can be satisfactorily used to manage irrigation for plants cultivated under greenhouse (Batista et al., 2013; Cardoso et al., 2013; Boaretto et al., 2014; Gomes et al., 2014; Medici et al., 2014), however, the system must be properly installed so it is possible to guarantee the adequate pressure levels. The main reason for using the above-mentioned system is due to the high-frequency irrigation requirement from plants, which would be time and cost consumptive if irrigation was managed manually.

Even though there are a number of studies with the effect of full irrigation and different water deficit stress levels on basil plant development and essential oil content, there are not studies with pre-harvesting water deficit stress on basil plants. In this context, the objective of this study was to evaluate the effect of different levels of pre-harvesting water deficit on basil cultivation.

Material and Methods

Experiment site and characteristics

The experiment was conducted under greenhouse condition at Biosystems Engineering Department of ESALQ/USP (University of Sao Paulo), at Piracicaba city, Brazil. The study was located at 22º 42’ 40” S latitude and 47º 37’ 45” longitude, at 547 m altitude. The experiment was performed from January 28th, 2012 to January 9th, 2013, totalizing 347 days.

The greenhouse had 12.8 m width and 22.5 m length, with 6 m height and with frontal windows. It was covered by a low-density transparent polyethylene film with 0.15 mm. The agrometeorological parameters were monitored using the CM3 equipment by Kipp & Zonen® for solar radiation and a thermo-hygrometer sensor HMP45C by Vaissala® for air temperature and relative humidity. These parameters were used to estimate reference evapotranspiration into the greenhouse by the Penman-Monteith method (Allen et al., 1998). Due to the low wind speed inside the greenhouse, this parameter was fixed in 0.5 m s^{-1}. Reference evapotranspiration was, then, used to identify the irrigation requirement from basil plants.

The basil cultivation was divided into two main parts, one with vegetative propagation and other where the experiment with controlled water deficit stress was performed. For the vegetative propagation, it was used cutting cultivated for 135 days, period from January 28th to July 11th, 2012 (Figure 1). The cuttings were obtained by the main basil plant with an essential oil content of 40% linalool, 13% camphor, and 26% 1-8 cineol and cultivated in small plastic pots. After vegetative propagation, the plants were transplanted to plastic pots so it was initiated the controlled water deficit stress experiment. The second part was performed from July 11th 2012 to January 9th, 2013, totalizing 212 days. At 66 days after seedling transplant (DAT, in August 16th, 2012), all the basil plants were pruned at 20 cm from the soil level to guarantee that all plants at the same canopy structure.

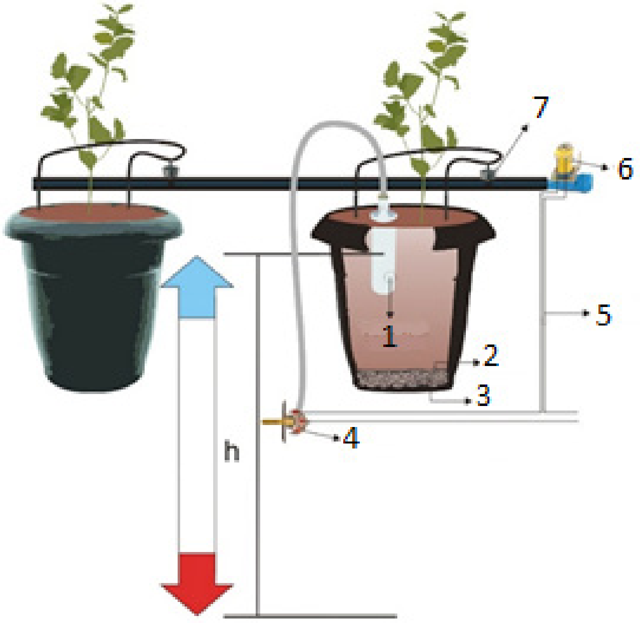

Figure 2. Illustration of the “Irrigation trigger simplified” equipment used to manage irrigation and its use: 1 – ceramic capsule filter (tension sensor); 2 – geotextile Bidim; 3 – rubble; 4 – pressure switch from a washing machine (switcher); 5 – electric wires; 6 – electromagnetic valve or water pump; 7 – dripper; h – vertical distance between the sensor and the switcher

Irrigation was performed in two steps, one that plants were fully irrigated until 12 days after each harvest (Figure 1) and other that irrigation was performed using five water deficit stress levels. For both case, it was used a micro irrigation system by drippers with a nominal flow of 2 L h^{-1}. The irrigation was automated by the “irrigation trigger simplified” equipment (patent register number MU 8700270-1 U). The automated system was composed of multiples equipment, including a ceramic capsule filter that was installed in the soil of each plastic pot, a flexible tube that one side was connected to the ceramic cap and the other a pressure switch, and an electromagnetic valve (Figure 2). Using a calibration equation, it was determined the relationship between the soil water tension and vertical distance (h) between the pressure switch and ceramic capsule filter. So, if the pressure switch is placed with low “h” (closer to the ceramic capsule) the starting point to open the valve is lower, indicating that irrigation will be performed with higher frequency if the pressure switch is placed at higher “h”. This technique allows performing different irrigation levels, in which higher vertical distance is associated with the higher water deficit time. The detailed equipment description,

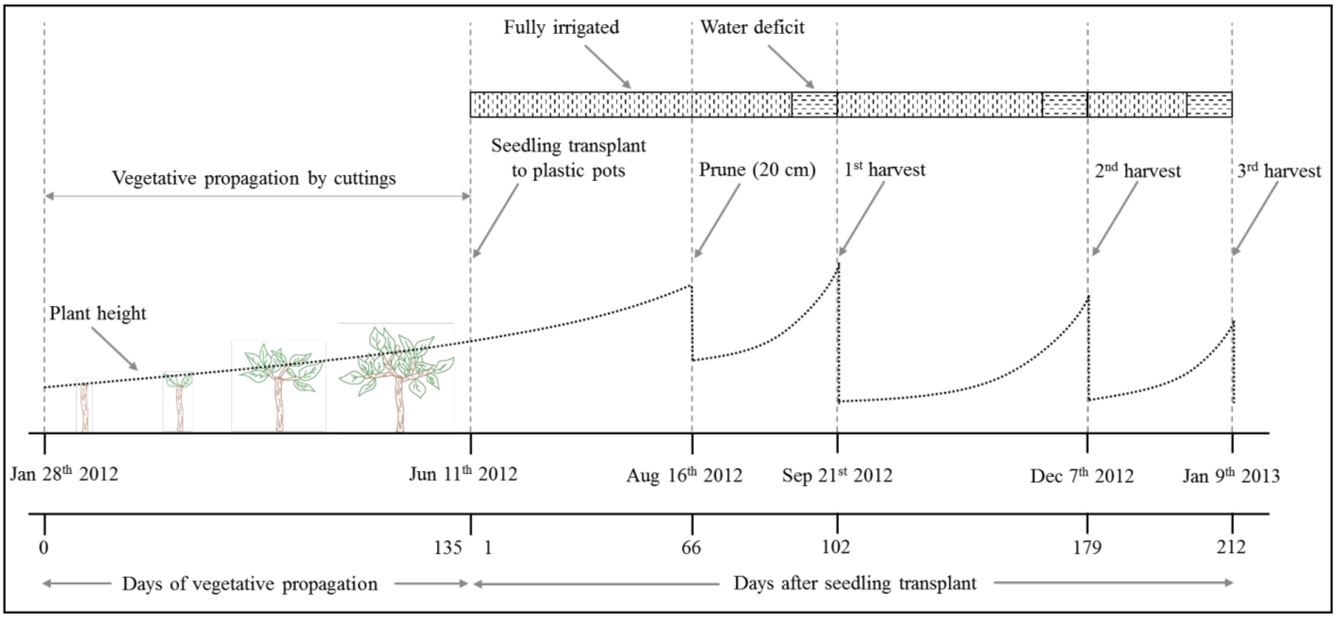

Figure 1. Experiment characteristics illustrating the vegetative propagation, seedling transplant, prune and harvests.

building, and installation are described in detail by (Medici et al., 2010).

The irrigation system was previously evaluated to determine the uniformity coefficient, resulting in values of 89.4, 82.4, and 97.5% of Christiansen Uniformity Coefficient, distribution uniformity coefficient, and static uniformity coefficient (or Wilcox-Swailes coefficient), respectively.

The soil of the plastic pot was a Red Eutrophic Nitosol with clay texture, with 35, 14, and 21% of sand, silt, and clay, respectively. The soil pH was 5.0 and the total organic matter of 1.5%. The phosphorous and potassium levels were 4 $mmol_c$ dm^{-3} and 183 mg kg^{-1}, respectively. To adjust the nutrient requirement to the plants, it was used the Osmocote® fertilizer after each harvest using 4 g per pot. The regular fertilization was performed every 20 days using the Yogen 2® with 6 g L^{-1} concentration.

Experimental design and variable analyzed

The experimental design used was the fully randomized in a factorial design. It was considered five water deficit stress treatments with five replications each, totalizing 25 plastic pots. For each treatment, all plants from the five replications were harvest in three different periods, considered the second variable of the experiment. The harvests were performed at 102 (1st, harvest), 179 (2nd, harvest), and 212 DAT (3rd, harvest), at September 21st, 2012, December 7th, 2012, and January 9th, 2013, respectively. It is important to note that it was used the same plant to perform all three harvests. The water deficit was performed 12 days after each harvest, by positioning the pressure switch at 0, 0.25, 0.50, 0.75, and 1 m vertical distance from the ceramic capsule (h-0, h-25, h-50, h-75, and h-100, respectively).

After each harvest, it was evaluated the plant height and stem diameter using a measuring tape and digital calipers, respectively. The plant stem, leaves, and inflorescence were dried at forced ventilated oven at 60 °C until constant mass, so there were individually weighed using a digital scale. The essential oil from leaves and inflorescence were extracted by hydrodistillation using the Clevenger equipment for two hours. The essential oil content was estimated using the corresponding leaves and inflorescence dry weight difference (mL g^{-1}).

The leaves water potential (LWP) were measured using a pressure chamber model 3000 (Soil Moisture Co.), before sunrise with two measurements in each evaluation. The first reading was performed two days before the irrigation suppression (water deficit stress) and the second reading after three days from the irrigation suppression. So it was possible to observe if plants were under water stress after irrigation suppression.

Data analysis

The data were analyzed using the Shapiro-Wilk ($P>0.01$) and Levene tests ($P>0.01$) to identify the normal and homoscedasticity residuals, respectively. According to the results, it was performed the variance analysis and then compared using the Scott-Knott criteria ($P<0.05$). The tests were performed using the R software (version 2.2.1).

Results and Discussion

Climate variables

The daily maximum air temperature (T_{max}) ranged from 10.98 to 25.6 °C and minimum air temperature (T_{min}) from 5.26 and 21.15 °C, and daily mean relative humidity varied from 13.5 to 30.15%. The highest difference between T_{max} and T_{min} observed into the greenhouse was 8.25 °C at 82 DAT (Figure 3A). According to Almeida (2006), the optimum temperature for adequate basil development are within 15 and 25 °C. During the period before pruning (from 0 to 66 DAT), it was observed that air temperature was considered not adequate, with average of 15.4 °C and with short periods with daily T_{max} below 15 °C. It was previously expected since this period was within the coldest months of the year (during winter time). After 66 DAT, it was observed an increase of daily air temperature, with an average of daily air temperature of 18.4, 20.9, and 23.8 °C during 1st, 2nd, and 3rd harvest periods, respectively (Figure 3A), indicating that the air temperature was adequate for the adequate plant development.

Relative humidity and global solar radiation varied from 34 to 100% and from 0.1 to 19.1 MJ m^{-2} d^{-1}, respectively (Figure 3B). In average, it was observed that relative humidity was decreasing daily from 0 to 100 DAT and, then, started to increase until the end of the experiment (212 DAT). The average of daily relative humidity during 1st, 2nd, and 3rd harvest was 59, 69, and 81%, respectively. For global solar radiation, it was observed an increase pattern of daily values from 0 to 212 DAT, with values within 1st, 2nd, and 3rd harvest period of 12.0, 13.0, and 13.1, respectively.

The cumulative thermal unit during 1st, 2nd, and 3rd harvest periods was 411.01, 978.36, and 489.28 °C, respectively, totalizing 1878.65 °C (Figure 3C). While in 2nd harvest period plants had 77 days for development, in the 1st and 3rd harvests plants had 36 and 25 days,

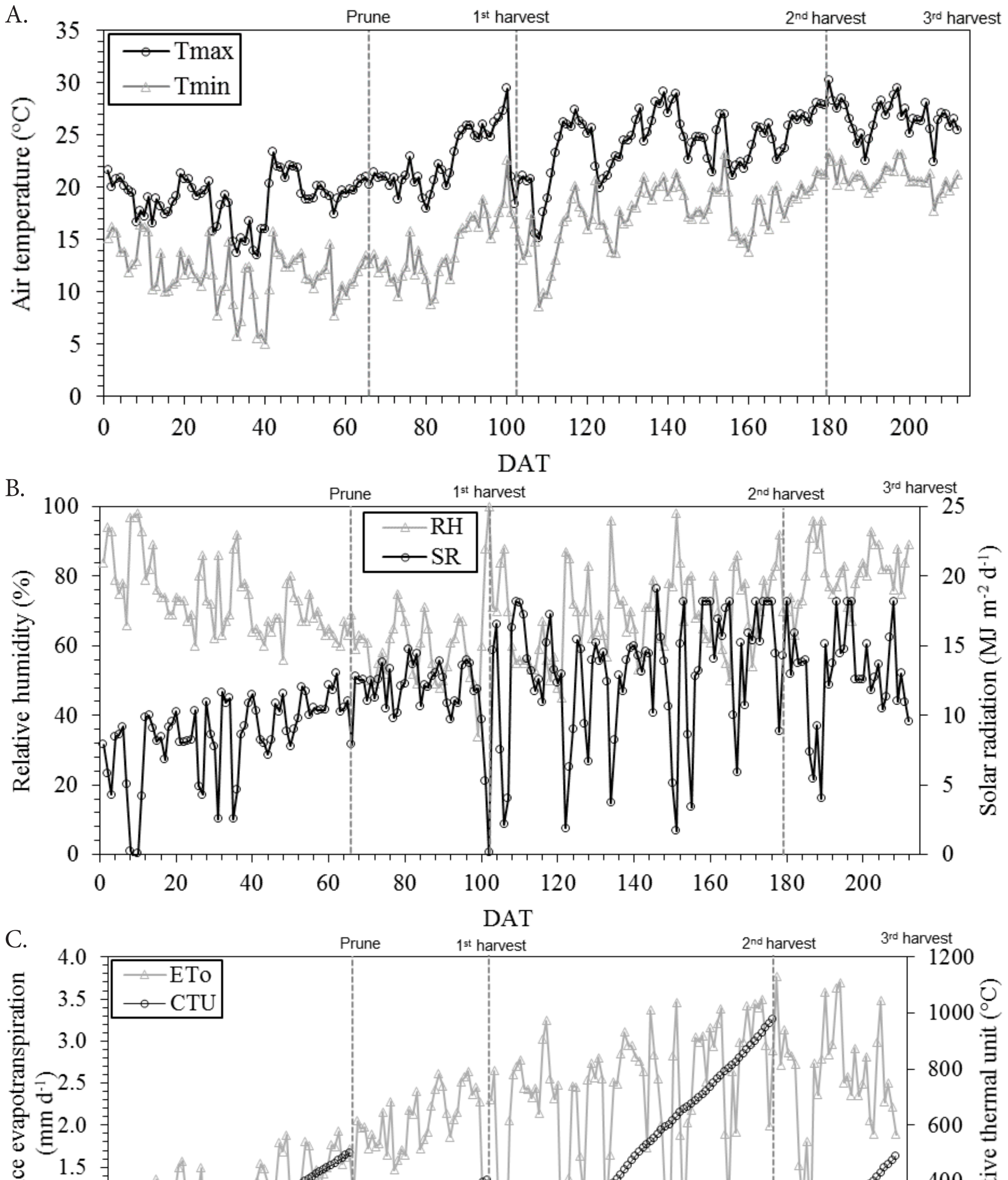

Figure 3. Maximum (T_{max}) and minimum (T_{min}) air temperature (A), relative humidity (RU) and solar radiation (SR) (B), and reference evapotranspiration (ETo) and cumulative thermal unit (CTU) (C) during the experiment period.

respectively. The daily average of the thermal unit for 1st, 2nd, and 3rd harvest period was 11.3, 12.7, and 14.8 °C, respectively. For reference evapotranspiration, it was observed maximum and minimum values of 3.78 and 0.1 mm d^{-1}, respectively. During 0 and 66 DAT, the combined effect of low air temperature and low global solar radiation, it was observed that reference evapotranspiration presented values below 2 mm d^{-1} (average of 1.15 mm d^{-1}). As the air temperature and global solar radiation increased, it was observed a fast increase of reference evapotranspiration values, in which the daily average during 1st, 2nd, and 3rd harvest period it was observed values of 2.04, 2.36, 2.58 mm d^{-1}, respectively.

Leaf water potential

The leaf water potential was used to identify if water deficit stress performance and, according to the results presented in Table 1, it was observed that the increase of irrigation suppression (or vertical difference between

Table 1. Leaf water potential of basil leaves with and without irrigation suppression under different gaps during the harvests periods.

Irrigation suppression (vertical distance - h)	Leaf water potencial - LWP (MPa)					
	1st Harvest		2nd Harvest		3rd Harvest	
	Without* suppression	With** suppression	Without* suppression	With** suppression	Without* suppression	With** suppression
h-0	- 1.1 a	-0.73 a	- 1.0 a	- 1.05 a	- 1.0 a	- 1.2 a
h-25	- 0.8 a	-1.53 b	- 1.1 a	- 1.22 a	- 0.8 a	- 1.2 a
h-50	- 0.8 a	-1.94 b	- 0.9 a	- 2.00 b	- 0.7 a	- 2.0 b
h-75	- 0.9 a	-1.94 b	- 0.9 a	- 1.84 b	- 0.9 a	- 2.2 c
h-100	- 1.1 a	-2.50 c	- 1.1 a	- 2.20 c	- 1.1 a	- 2.2 c

* Two days before irrigation suppression; ** Three days after irrigation suppression

the pressure switch and ceramic capsule) reduced LWP, where the lowest values were observed for the h-100 treatment (-2.5 MPa). In the other hand, the treatment with no irrigation suppression (h-0) it was observed highest values of LWP of -0,73 MPa, showing that the different irrigation suppression influenced on the LWP of basil plants.

According to (Deloire et al., 2004) the LWP can be used to identify if plants are under water stress in basil, in which values below -0.2 MPa is considered the limit when plants start to reduce their development due to the water deficit. In addition, the authors describe different levels of water deficit according to the LWP, with light stress ($-1.4 < \text{LWP} < -0.2$ MPa), moderate stress ($-2.5 < \text{LWP} \leq -1.4$ MPa), and severe stress ($\text{LWP} \leq -2.5$ MPa). Before water suppression, it was observed that plants were under light stress since LWP of all treatments were between -1.1 and -0.7 MPa, however, after irrigation suppression, it was observed a reduction of LWP in all treatments and harvest period (Table 1). During the 1st harvest, it was observed that only h-0 treatment was under light water stress after irrigation suppression, while others h-25, h-50, and h-75 treatments presented LWP values varying from -1.94 to -1.53 MPa, resulting in moderate water stress. The h-100 treatment was the only treatment that was under severe water stress with all treatments and harvest period, with values of -2.5 MPa after irrigation suppression. For the 2nd and 3rd harvests, it was observed light water stress for h-0 and h-25 treatments with values varying from -1.22 to -1.05 MPa, and moderate stress to others treatments, with values varying from -2.20 to -1.84 MPa (Table 1).

The effect of water stress on plants starts when the plant evapotranspiration rates are higher than the ability of the roots extract water, contributing to the lower transferring of water for the leaves. The water stress is associated, therefore, with the progressive reduction of soil water level, and dependent on the root depth. As higher the soil water reduction, higher is the water deficit (Silveira & Stone, 2001).

It can be observed in Table 2 that plant height decreased from the first to third harvest, which is explained due the stress caused by the harvest on the plants. In all irrigation suppression treatments, the average of plant height was 74.07 cm in the 1st harvest, and during the 2nd and 3rd harvests the plants were with 65.5 and 55.07 cm, respectively. For plant stem, it was observed an increase of diameter for all irrigation suppressions from 1st to 3rd harvest, increasing from 10.5 cm to 14.3 mm, respectively.

Plant height was affected by the irrigation suppression only for the 3rd harvest, indication that the amount of water by irrigation affected significantly the plant height at 1% level of significance (Table 2). The h-0 treatment resulted in the minimum value of 50.8 cm for plant height, with maximum value of 57.5 cm for the h-100 treatment. Similar results of plant height reduction with the decrease of water availability, as well as for the harvest periods, were observed by Yassen et al. (2003); Alishah et al. (2006); Pravuschi et al. (2010) and Ekren et al. (2012).

The dry leaf and inflorescence mass (DM) was higher in the 2nd harvest (31.28 g), intermediate in the 3rd harvest (25.46 g) and lower in the 1st harvest (21.76 g) (Table 2) for all irrigation suppression treatment. It was not observed any pattern with the result of DM within treatments, with the highest value of 60.83 g for h-0.75 in the 3rd harvest and lowest of 12.96 g for h-0.5 in the 3rd harvest as well. However, it was observed that DM was affected significantly by irrigation suppression in each harvest at 5% level of significance.

Alishah et al. (2006) studied the effect of different water deficit levels on basil and observed that, with the increase of water deficit, plant height and total dry mass decreased. In the other hand, the treatment with 100% irrigation replacement resulted in the maximum plant height and DM, with values of 56.4 cm and 4.573 g plant^{-1}, respectively.

The irrigation suppression also influenced the essential oil content (EO) at 1% level of significance

Table 2. Water stress effect on basil plant height, stem diameter, leaves and inflorescences dry mass and essential oil content.

Irrigation suppression (I)	PH – Plant height (cm)				SD – Stem diameter (mm)			
	1st Harvest	2nd Harvest	3rd Harvest	Average	1st Harvest	2nd Harvest	3rd Harvest	Average
h-0	74.17 aA	65.17 aA	50.80 aA	66.22 a	11.84 bA	12.33 bA	16.27 aA	13.49 a
h-25	73.17 aA	66.83 aA	53.67 bA	64.55 a	10.76 aA	12.91 bA	13.10 aB	12.26 a
h-50	78.83 aA	65.33 aA	54.00 bA	66.05 a	9.55 aA	12.77 bA	13.11 aA	11.81 a
h-75	72.83 aA	67.50 aA	53.83 bA	63.72 a	10.32 aA	12.57 bA	15.24 aA	12.71 a
h-100	71.33 aA	62.67 aA	57.50 cA	63.83 a	10.04 aA	11.75 aA	13.77 aB	11.86 a
Average	74.07 A	65.50 B	55.07 C		10.50 C	12.47 B	14.30 A	

Irrigation suppression (I)	DM – Leaves and inflorescences dry mass (g)					EO – Essential oil content (%)			
	1st Harvest	2nd Harvest	3rd Harvest	Average	Sum	1st Harvest	2nd Harvest	3rd Harvest	Average
h-0	25.35 bA	31.51 aA	24.01 aA	26.96 a	80.87 b	2.11 aB	2.40 aA	1.73 aB	2.08 a
h-25	17.94 aA	30.53 aB	14.32 aA	20.93 a	62.79 a	1.91 aB	2.30 aA	2.27bB	1.85 a
h-50	23.61 bA	32.08 aB	12.96 aA	22.88 a	68.65 a	2.63 aA	2.27 aA	2.27 bA	2.39 b
h-75	24.29 bA	34.65 aA	60.83 bB	39.93 b	82.59 b	2.75 aA	2.33 aA	2.30 bA	2.42 b
h-100	17.59 aA	27.65 aA	15.20 aA	20.15 a	60.43 a	2.57 aA	2.29 aA	2.43 bA	2.43 b
Average	21.76 A	31.28 C	25.46 B			2.39 B	2.31 B	2.20 A	

Columns (lowercase) and lines (uppercase) followed by the same letters do not differ statistically. ** Statistically different at 1% level of probability ($p < 0.01$); * Statistically different at 5% level of probability ($0.01 \leq p < 0.05$); ^{ns} Not statistically different ($p \geq 0.05$); Lambda (λ) is the transformation factor from Box-Cox family; C.V. is the coefficient of variation.

(Table 2). The highest value of EO was observed for the highest water stress treatments (h-50, h-75, and h-100), with values close to 2.40%. The lowest EO content observed was for the h-0 and h-25 treatments, with 2.08 and 1.85%, respectively. According to the irrigation suppression treatments, it was not observed statistically difference of EO within 1st and 2nd harvest, however, it was observed statistically difference for the 3rd harvest at 1% level of significance. The increase of EO content due the increase of water deficit was also observed by (Khalid, 2006).

The EO content presented in our study were similar to those described in the literature. Taylor et al. (2008) studied 270 basil genotypes in Germany and found mean EO content of 2.65%. Vieira & Simon (2000), evaluating different species in Brazil found values varying from 0.3 to 3.6% of oil content. Blank et al. (2004), found values of EO content varying from 0.19 to 2.5% of 53 different *Ocimum basilicum* genotypes.

Ekren et al. (2012) describe that the EO content for purple basil was affected by the irrigation treatments. The highest oil proportion was observed for the treatment that irrigation was performed until 50% of field capacity and the lowest values were observed for those treatments that irrigation provided 100% water plant requirement. The EO increment with the water deficit was also observed by Omidbaigi, Hassani, and Sefidkon (2003) and Khalid (2006). According to Khalid (2006), the highest EO content for basil was observed for the treatment with soil availability of 75% of field capacity. As observed in many studies, the oil content of basil and other medicinal species are increased with reduction of soil water availability (Alvarenga et al., 2011; Baghalian et al., 2011; Bahreininejad, Razmjoo & Mirza, 2013)

It is known that the EO content in basil plants can be influenced by different factors, in which environmental condition can affect moderately in this parameter (Khalid, 2006; Ekren et al., 2012). According to Omidbaigi, Hassani & Sefidkon (2003) basil cultivated under pots with irrigation of 55, 70, 85, and 100% from field capacity increased from 1.12 to 1.26% the EO content, considering 100 and 55% irrigation replacement, respectively.

The effect of different water management on the basil essential oil content cab be related to the water deficit stress, in which promoted the development interruption, affecting on the biomass accumulation and increasing the secondary metabolic processes. The water deficit stress has been presenting positive correlation with the secondary metabolic concentration, inducing the increasing of some terpenoids yield (Lopes et al., 2001), and affirming that water deficit stress may improve the essential oil concentration (Khalid, 2006). This increasing can also be associated with the fact that plants produce high terpenes concentration due the carbon allocation for plant growth, indicating the relationship between plant growth and defense (Turtola et al., 2003;

Silva et al. (2002) mentioned that the water deficit stress contributed to the increase in the glandular trichomes density with the reduction of leaf area. In this context, the results presented in our study indicate that the increase of basil essential oil biosynthesis can be a plant adaptation effect when plants are under water deficit stress. Therefore, higher essential oil content can be obtained in long periods between irrigations, since this effect may contribute to the basil essential oil increasing.

Conclusions

The results here presented showed that basil is sensitive to water stress when it is performed only before harvest. The essential oil content and plant height were significantly affected due to the irrigation suppression 12 days before harvest. Since essential oil content increased with the increase of water stress, it can be affirmed that irrigation suppression before harvest has a positive effect on the basil plant.

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Literature Cited

Alishah, H. M., Heidari, R., Hassani, A. and Dizaji, A. A. (2006) "Effect of Water Stress on Some Morphological and Biochemical Characteristics of Purple Basil (*Ocimum basilicum*)," *Journal of Biological Sciences*, 6(4), pp. 763–767. doi: 10.3923/jbs.2006.763.767.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998) "Crop by Evapotranspiration Guidelines for computing crop water requirements," *Irrigation and Drainage*. Edited by FAO. Rome, 300(56), p. 300. doi: 10.1016/j.eja.2010.12.001.

Alvarenga, I. C. A., Valadares, R. V., Martins, E. R., Oliveira, F. G., de Figueiredo, L. S. and Kobayashi, M. K. (2011) "Water stress before harvest of pepper-rosmarin," *Pesquisa Agropecuaria Brasileira*, 46(7), pp. 706–711. doi: 10.1590/S0100-204X2011000700005.

Arabaci, O. and Bayram, E. (2004) "The Effect of Nitrogen Fertilization and Different Plant Densities on Some Agronomic and Technologic Characteristic of *Ocimum basilicum* L. (Basil)," *Jornal of agronomy*, 3(4), pp. 255–262.

Baghalian, K., Abdoshah, S., Khalighi-Sigaroodi, F. and Paknejad, F. (2011) "Physiological and phytochemical response to drought stress of German chamomile (*Matricaria recutita* L.)," *Plant Physiology and Biochemistry*. Elsevier Masson SAS, 49(2), pp. 201–207. doi: 10.1016/j.plaphy.2010.11.010.

Baghalian, K., Haghiry, A., Naghavi, M. R. and Mohammadi, A. (2008) "Effect of saline irrigation water on agronomical and phytochemical characters of chamomile (*Matricaria recutita* L.)," *Scientia Horticulturae*, 116(4), pp. 437–441. doi: 10.1016/j.scienta.2008.02.014.

Bahreininejad, B., Razmjoo, J. and Mirza, M. (2013) "Influence of water stress on morpho-physiological and phytochemical traits in Thymus daenensis," *International Journal of Plant Production*, 7(1), pp. 151–166.

Batista, S. C. O., Carvalho, D. F., Rocha, H. S., Santos, H. T. and Medici, L. O. (2013) "Production of automatically watered lettuce with a low cost controller," pp. 485–489.

Blank, A. F., Carvalho Filho, J. L. S. De, Santos Neto, A. L. Dos, Alves, P. B., Arrigoni-Blank, M. D. F., Silva-Mann, R. and Mendonça, M. D. C. (2004) "Caracterização morfológica e agronômica de acessos de manjericão e alfavaca," *Horticultura Brasileira*, 22(1), pp. 113–116. doi: 10.1590/S0102-05362004000100024.

Boaretto, L. F., Carvalho, G., Borgo, L., Creste, S., Landell, M. G. A., Mazzafera, P. and Azevedo, R. A. (2014) "Plant Physiology and Biochemistry Water stress reveals differential antioxidant responses of tolerant and non-tolerant sugarcane genotypes," *Plant Physiology et Biochemistry*. Elsevier Masson SAS, 74, pp. 165–175. doi: 10.1016/j.plaphy.2013.11.016.

Bufalo, J., Cantrell, C. L., Astatkie, T., Zheljazkov, V. D., Gawde, A. and Boaro, C. S. F. (2015) "Organic versus conventional fertilization effects on sweet basil (*Ocimum basilicum* L.) growth in a greenhouse system," *Industrial Crops and Products*. Elsevier B.V., 74, pp. 249–254. doi: 10.1016/j.indcrop.2015.04.032.

Cardoso, G., Dias, D. E. O., Medici, L. O., Antonio, M., Silva, D. A., Carvalho, D. F. D. E., Pimentel, C., Com, A. and Baixo, C. D. E. (2013) "Papaya seedlings growth using a low-cost, automatic watering controller 1," pp. 527–535.

Chang, C. L., Cho, I. K. and Li, Q. X. (2009) "Insecticidal activity of basil oil, trans-anethole, estragole, and linalool to adult fruit flies of Ceratitis capitata, Bactrocera dorsalis, and Bactrocera cucurbitae.," *Journal of economic entomology*, 102, pp. 203–209. doi: 10.1603/029.102.0129.

Deloire, A., Carbonneau, A., Wang, Z. and Ojeda, H. (2004) "Vine and water a short review," *Journal International des Sciences de la Vigne et du Vin*, 38(1), pp. 1–13.

Ekren, S., Sönmez, Ç., Özçakal, E., Kurttaş, Y. S. K., Bayram, E. and Gürgülü, H. (2012) “The effect of different irrigation water levels on yield and quality characteristics of purple basil (*Ocimum basilicum* L.),” *Agricultural Water Management*, 109, pp. 155–161. doi: 10.1016/j.agwat.2012.03.004.

Gomes, D. P., Carvalho, D. F. De, Almeida, W. S. De, Oliveira, L., Guiherme, J. and Guerra, M. (2014) “Organic carrot-lettuce intercropping using mulch and different irrigation levels,” pp. 323–328.

Hussain, A. I., Anwar, F., Hussain Sherazi, S. T. and Przybylski, R. (2008) “Chemical composition, antioxidant and antimicrobial activities of basil (*Ocimum basilicum*) essential oils depends on seasonal variations,” *Food Chemistry*, 108(3), pp. 986–995. doi: 10.1016/j.foodchem.2007.12.010.

Jaleel, C. A., Gopi, R., Sankar, B., Gomathinayagam, M. and Panneerselvam, R. (2008) “Differential responses in water use efficiency in two varieties of *Catharanthus roseus* under drought stress,” *Comptes Rendus - Biologies*, 331(1), pp. 42–47. doi: 10.1016/j.crvi.2007.11.003.

Khalid, K. A. (2006) “Influence of water stress on growth , essential oil , and chemical composition of herbs (Ocimum sp .),” pp. 289–296.

Kwee, E. M. and Niemeyer, E. D. (2011) “Variations in phenolic composition and antioxidant properties among 15 basil (*Ocimum basilicum* L.) cultivars,” *Food Chemistry*. Elsevier Ltd, 128(4), pp. 1044–1050. doi: 10.1016/j.foodchem.2011.04.011.

Liber, Z., Carović-Stanko, K., Politeo, O., Strikić, F., Kolak, I., Milos, M. and Satovic, Z. (2011) “Chemical characterization and genetic relationships among *Ocimum basilicum* L. cultivars,” *Chemistry & Biodiversity…*, 8, pp. 1978–1989. doi: 10.1002/cbdv.201100039.

Lisar, S. Y. S., Motafakkerazad, R., M., M. and M. Rahm, I. M. (2012) “Water Stress in Plants: Causes, Effects and Responses,” in *Water Stress*. InTech, pp. 1–15. doi: 10.5772/39363.

Lopes, R. C., Casali, V. W. D., Barbosa, L. C. A. and Cecon, P. R. (2001) “Influência de três regimes hídricos na produção de óleo essencial em sete acessos de Polygnom punctatum Ell,” *Revista Brasileira de Plantas Medicinais*. Botucatu, 3(2), pp. 7–10.

Medici, L. O., Reinert, F., Carvalho, D. F., Kozak, M. and Azevedo, R. A. (2014) “What about keeping plants well watered ?,” *Environmental and Experimental Botany*. Elsevier B.V., 99, pp. 38–42. doi: 10.1016/j.envexpbot.2013.10.019.

Medici, L. O., Soares, H., Carvalho, D. F. De and Azevedo, R. A. (2010) “Automatic controller to water plants,” (December), pp. 727–730.

Omidbaigi, R., Hassani, A. and Sefidkon, F. (2003) “Essential oil content and composition of sweet basil (*Ocimum basilicum*) at different irrigation regimes,” *Journal of Essential Oil Bearing Plants*, 6(2), pp. 104–108. doi: 10.1080/0972-060X.2003.10643335.

Özcan, M., Arslan, D. and Ünver, A. (2005) “Effect of drying methods on the mineral content of basil (*Ocimum basilicum* L.),” *Journal of Food Engineering*, 69(3), pp. 375–379. doi: 10.1016/j.jfoodeng.2004.08.030.

Pravuschi, P. R., Angélica, P., Marques, A. and Marega, B. H. (2010) “Efeito de diferentes lâminas de irrigação na produção de óleo essencial do manjericão (*Ocimum basilicum* L .),” (2004), pp. 687–693. doi: 10.4025/actasciagron.v32i4.3160.

Sajjadi, S. E. (2006) “Analysis of the essential oils of two cultivated basil (*Ocimum basilicum* L.) from Iran” *Daru*, 14(3), pp. 128–130.

Sangwan, N. S., Farooqi, A. H. A., Shabih, F. and Sangwan, R. S. (2001) “Regulation of essential oil production in plants,” *Plant Growth Regulation*, 34(1), pp. 3–21. doi: 10.1023/A:1013386921596.

Silva, S. R. S., Demuner, A. J., Claudio, L., Barbosa, D. A., Wagner, V., Casali, D., Nascimento, E. a and Pinheiro, L. (2002) “Efeito do estresse hídrico sobre características de crescimento e a produção de óleo essencial de *Melaleuca alternifolia* Cheel,” *Acta Scientiarum*, 24, pp. 1363–1368.

Silveira, P. M. . and Stone, L. F. (2001) *Irrigação do Feijoeiro*. Edited by Embrapa: Arroz e Feijão. Santo Antônio de Goiás.

Taylor, P., Krüger, H., Wetzel, S. B. and Zeiger, B. (2008) “The Chemical Variability of Ocimum Species The Chemical Variability of Ocimum Species,” 6475(July 2013), pp. 37–41. doi: 10.1300/J044v09n04_11.

Turtola, S., Manninen, A. M., Rikala, R. and Kainulainen, P. (2003) “Drought stress alters the concentration of wood terpenoids in Scots pine and Norway spruce seedlings,” *Journal of Chemical Ecology*, 29(9), pp. 1981–1995. doi: 10.1023/A:1025674116183.

Vieira, R. F. & and Simon, J. E. (2000) “Chemical characterization of basil *Ocimum* spp.) found in the markets and use in traditional medicine in Brazil,” *Economic Botany*, 54(2), pp. 207–216. doi: 10.1007/BF02907824.

Yassen, M., Ram, P., Yadav, A. and Singh, K. (2003) “Response of Indian basil (*Ocimum basilicum* L.) to irrigation and nitrogen schedule in Central Uttar Pradesh,” *Annual Review of Plant Biology*, 17(2), pp. 177–181.

Zhang, J. W., Li, S. K. and Wu, W. J. (2009) “The main chemical composition and in vitro antifungal activity of the essential oils of *Ocimum basilicum* Linn. var. pilosum (Willd.) Benth,” *Molecules*, 14(1), pp. 273–278. doi: 10.3390/molecules14010273.