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ORIGINAL PAPER

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Effect of water regime and harvest stage on essential oil accumulation in basil plant growing in sandy soil

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Abstract

Basil (*Ocimum basilicum*.L) is an aromatic herb with economic importance due to its essential oils useful for the production of foods, perfumes, and medicines. Its chemical composition may vary by genetic factors, harvesting stage, and water availability. This work evaluated the content, yield, and the composition of sweet basil essential oil irrigated at different levels of soil water tension and harvested at different flowering stages. Plants were grown in 14-L pots inside a greenhouse located at the Sao Paulo State University (UNESP), Brazil. The 15 treatments were the combination of 5 levels of soil water tension that define when to irrigate (20, 30, 40, 50, and 60 kPa) with 3 harvest stages (beginning of flowering, full flowering, and end of flowering). Growth traits including total dry and fresh mass per plant and inflorescences, plant height, stem diameter, and inflorescences number were highest in plants grown at lower soil water tensions, 20 and 30 kPa. The harvesting at the end of flowering generated the highest values of essential oil content and yield. The 60 kPa soil water tension showed the highest percentage of essential oil content in dry mass, indicating that water stress concentrated essential oil in the plant. However, the basil profit is a function of the essential oil yield. The highest essential oil yield (g, dry weight basis) occurred when irrigation started at 20 and 30 kPa. The chemical components of the essential oil showed low variation, regardless of the treatment. For all the treatments, linalool was the components found in a more considerable amount, and its highest accumulation occurred when irrigated at soil water tension of 20 kPa and 30 kPa. A useful recommendation for basil growers is irrigation scheduling with 30 kPa and harvest at the end of flowering.

Introduction

Basil (*Ocimum basilicum* L.) is an aromatic herb with economic importance, fast growing, and easily cultivated in greenhouse (Putievsky and Galambosi 1999). The fresh or dried aerial parts of the basil are marketed as spices all over the world (Chalchat and Özcan 2008). Other relevant applications are as medicinal plant (Padalia et al. 2013; Ahmed et al. 2014) and in the industry for the production of fragrances, food products, pharmaceuticals (Agami et al. 2016; Suppakul et al. 2003), and paints (Kakaraparthi et al. 2015). The herb properties as medicinal plant are partially due to the presence of essential oils, which may vary according

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to the cultivars, climate, and growing region (Padalia et al. 2017).

Basil is a shrub with a height ranging from 30 to 100 cm, woody stems, highly branched, and many inflorescences. Leaves are simple with a wavy margin, 4–7 cm in length, green color, and strong smell (Pereira and Moreira 2011). Basil grows best in mild temperatures since it is sensitive to low temperatures and frosts (Minami et al. 2007).

Essential oil is a product of secondary basil metabolism, being produced as a defense response to several forms of environmental stresses. Its content and composition can vary according to the phenological development (Sangwan et al. 2001). Australian basil varieties showed methyl chavicol as the main component of the essential oil, with varying amounts of linalool (Lachowicz et al. 1997). In Brazil, some varieties have linalool as the main component (Blank et al. 2007; Veloso et al. 2014).

Several factors can influence crop development and, consequently, essential oil yield and quality. According to Carvalho et al. (2010); Chang et al. (2008); Lung et al. (2016), temperature, photoperiod, and solar radiation can influence the basil growth, in addition to mineral nutrition and irrigation.

Water deficit is one of the main factors responsible for changes in basil production and development. A reduction in plant size and, consequently, a decrease in basil fresh and dry weight was observed when submitted to water stress; on the contrary, increased the plant basil leaf essential oil content and altered oil composition (Simon et al. 1992; Khalid, 2006; Ekren et al. 2012; Sirousmehr et al. 2014; Caliskan et al. 2017). However, the profit is associated with the basil essential oil yield.

It is hypothesized that water stress increases the content, yield and alters the composition of the essential oil extracted from basil; also, the harvesting stage affects the content and composition of essential oil extracted from basil.

This research aimed to evaluate the basil essential oil content, yield, and composition under different soil water tensions and harvesting stages.

Materials and methods

Experiment design and treatment

The research was carried out at the Sao Paulo State University (UNESP) experimental station (Botucatu, SP, Brazil) inside a greenhouse with dimensions of 30 m in length, 7 m in width, and 6 m in height in the highest point. The geographical coordinates are latitude 22° 51′ 03" South and longitude 48° 25′ 37" West with 786 m of altitude. The experimental period ranged from September 10, 2016, to January 18, 2017. The variety Manjericão IAC Linalol is rich in linalool, and all the cuttings were originated from the same genetic material provided by the "Instituto Agronômico de Campinas (IAC)", Campinas, SP, Brazil. The cuttings were rooted for 60 days before they were used as transplants. The transplanting adopted three plants per 14-L pot, and after the establishment, one plant per pot was maintained to mimic the density in the field condition.

The experiment consisted of 15 treatments, a combination of 5 levels of soil water tension that define when to irrigate (20, 30, 40, 50 and 60 kPa) with 3 harvest stages (beginning of flowering, BF; full flowering, F; and end of flowering, EF), and 4 replications (1 pot per replication). The experimental design was completely randomized, with an independent irrigation pipeline for each treatment.

The irrigation treatments started 40 days after transplanting the seedlings (DATP). They were applied until the harvest time performed at 70, 100, and 130 DATP, corresponding to the beginning of flowering, full flowering, and end of flowering, respectively. Basil parts which are completely exposed in the air were harvested by removing one plant per pot, cutting them at the base near the ground. Stem diameter, plant height, and the number of inflorescences per plant were recorded for each plant.

The different plant parts were weight to obtain fresh biomass and then separated and transferred to paper bags, then dried in a forced circulation air oven at 40 ºC until constant weight, aiming to obtain the percentage of dry matter and for the extraction of essential oils.

Soil characteristics

The sandy soil Neosol Quartzarêncio Distrophic (EMBRAPA 2006) was used in the experiment. Soil samples from ten pots were collected in the 0–20 cm soil layer before the initiation of the experiment, then air dried and sieved to remove possible plant residues such as roots, leaves, and stones. Soil chemical properties (Table 1) were analyzed according to Raij et al. (2001) and the physical features with the methodology proposed by Claessen et al. (1997). The physical analysis indicated a typical sandy soil with sand (95.7%), clay (3.4%), and silt (0.9%).

The Soil Water Retention Curve SWRC software (Dourado-Neto et al. 2000) adjusted the soil water retention curve (Fig. 1), presenting the following parameters for Van Genuchten's equation (1980): $\alpha = 0.845$; $m = 0.2736$; $n = 1.561$; θR = 0.059 cm^3 cm^{-3}; θS = 0.434 cm^3 cm^{-3}; Y m = 0.077. It allowed the irrigation depth calculation. In this work, the field capacity (FC) was associated with soil water tension of 10 kPa, corresponding to the volumetric soil moisture of 0.20 cm^3 cm. Saad et al. (2009) observed that in the 10 kPa tension in sandy soil, the volumetric moisture was 0.17 cm^3 cm^{-3}, being consistent with the value found in this work.

Table 1 Chemical properties of the sandy soil used for growing basil plants (*Ocimium basiculum*) in pots

Soil layer	pH $CaCl_2$	OM g dm^{-3}	PR mg dm^{-3}	*H* + Al	*K*	Ca	Mg	SB	CEC	*V*%
				---------- $mmol_c$ dm^{-3} ------						
0–20 cm	4.7	9	4	17	1.1	7	3	11	28	38

OM organic matter, *PR* phosphorus in resin, *SB* sum of bases, *CEC* cation exchange capacity V%, base saturation

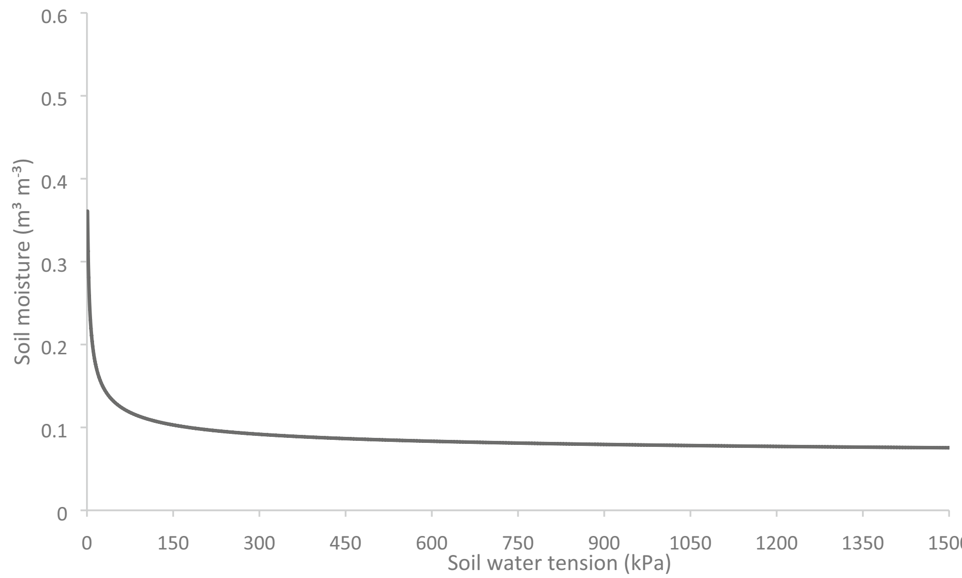

Fig. 1 Relationship between soil moisture and soil water tension of the Entisol (Quartzipsamments) Dystrophic used in the experiment

The soil water retention curve showed an expected behavior for a soil presenting a sand texture with low water retention values due to the presence of larger pores responsible for soil aeration, rapid water movement, and percolation. Urach (2007) also observed a negative effect on water retention for irrigation purposes of a higher percentage of sand in the soil.

The soil acidity amendment was based on the chemical analyzes, increasing the base saturation (BS %) to 75% using dolomitic lime. The fertilization was calculated to avoid nutritional deficiencies during the development of basil applying per soil liter, 0.07 g of nitrogen (urea–45%), 0.07 g of potassium (white potassium chloride–KCl 60% % K_2O) and 1.00 g of phosphorus (super simple–18% P_2O_5, 16% calcium and 8% sulfur).

Irrigation

Water was applied by an irrigation system composed of one pressure compensating dripper per pot with a flow rate of 2 L h^{-1}, connected to a lateral line by a microtube 4 mm thick and 40 cm long. The lateral lines had a diameter of 16 mm and 5 m in length, while the main line had a diameter of 25 mm running the entire length of the greenhouse. A motor pump with a power of 0.5 HP was used to regulate the operating pressure of the system at 0.147 MPa. The irrigation system evaluated in a test bench presented the same dimensions of the system installed in the greenhouse, giving a Christiansen uniformity coefficient (CUC) of 98.5%, considered excellent, according to Mantovani et al. (2006).

Table 2 Irrigation volume and watering time for each soil water tension

	Soil water tension for irrigation (kPa)				
	20	30	40	50	60
Irrigation volume (mL per pot)	432	626	741	821	879
Watering time (min)	13.0	18.8	22.2	24.6	26.4

The use of four tensiometers per treatment monitored the soil water tension. The monitoring carried out thrice a day released irrigation to reach the 100% FC (equivalent to 10 kPa) whenever the soil water tension reached 20 kPa, 30 kPa, 40 kPa, 50 kPa, and 60 kPa in three of the four tensiometers (Table 2). The irrigation water quality was C1S1, considered to be optimal for irrigation (Albuquerque and Durães 2008; Bernardo et al. 2008).

During the experiment, basil plants showed optimal development, presenting no visual symptoms of nutritional deficiency or attack of pests and diseases. The most frequent irrigation interval occurred in the 20 kPa soil tension with 1.5 days between irrigations, while at 60 kPa, the operation occurred every seven days (Fig. 2).

Crop measurements

Plant height, stem diameter, and the number of inflorescences were measured at three harvest stages. The plant height was measured with a ruler graduated in mm from the soil base to the plant's highest point. The diameter of the stem was measured using a digital caliper of 0.01 mm resolution of carbon fiber to avoid variations in measurements, using as reference the base of the plant approximately 1 cm above the soil surface. The number of inflorescences per plant was counted as soon as the plants were removed from the pot.

After the measurements were taken, the plants were weighed to obtain the mass of fresh matter and then placed in paper bags and dried in a forced circulation air oven to a constant weight at 40 °C to remove moisture and minimize essential oil loss. After drying, the dry matter mass and the essential oil content in the plant were determined.

Essential oil extraction and analysis

The whole plants were weighed, chopped and placed in a 2-L flask and filled with 1 L of deionized water, followed by hydrodistillation for 2 h in a Clevenger-type apparatus. The essential oil was recovered with a Pasteur pipette and weighed in a 0.0001 g scale. The oil was placed in 1.5 ml amber glass bottles and stored at −4 °C until further analyses of essential oils composition.

The chemical composition of the essential oil was determined for three independent replicates for each treatment; the fourth plant in the pot was kept to replace one of the other three eventually damaged. For gas chromatography (GC) analysis, each essential oil was diluted in T-butyl methyl ether (4 mcL of oil/mL of solvent). The analysis was performed on an Agilent 6890 Series, GC System chromatograph with DB5 fused silica capillary column (5% phenyl/95% dimethylpolysiloxane, 30 m × 0.25 mm i.d.) and equipped with a Flame ionization detector FID. Helium gas was used as the carrier gas in a pressure column of 16.2 psi (0.112 MPa) at a purity of 99.99%.

Essential oil composition were identified by a GC Agilent 6890 connected to an Agilent Mass Selective 5973 detector and 25: 1 split mass detector and 20.1 mL min^{-1}, electron impact value (EI = 70 eV). Peak identification was performed by co-injection with authentic standards wherever possible, by mass spectra and MS compound libraries (Wiley 275.L). Each component was confirmed by the Ann-alkane series (8–20) running in the GC/MS column to calculate the Retention Indices (RI) and compared with the values in the literature (Adams 2007).

The essential oil yield per plant was calculated by multiplying the total dry mass per plant by the essential oil content, which was necessary to estimate the basil grower's profit.

Meteorological data

Air temperature and relative humidity were obtained from a meteorological station of Campbell Scientific (Figs. 3, 4) located 50 m away from the greenhouse. The maximum air temperature during the period varied between 10.4 and 36.2 °C, and the relative humidity varied between 20.25 and 99.80%, agreeing with the needs of the basil culture.

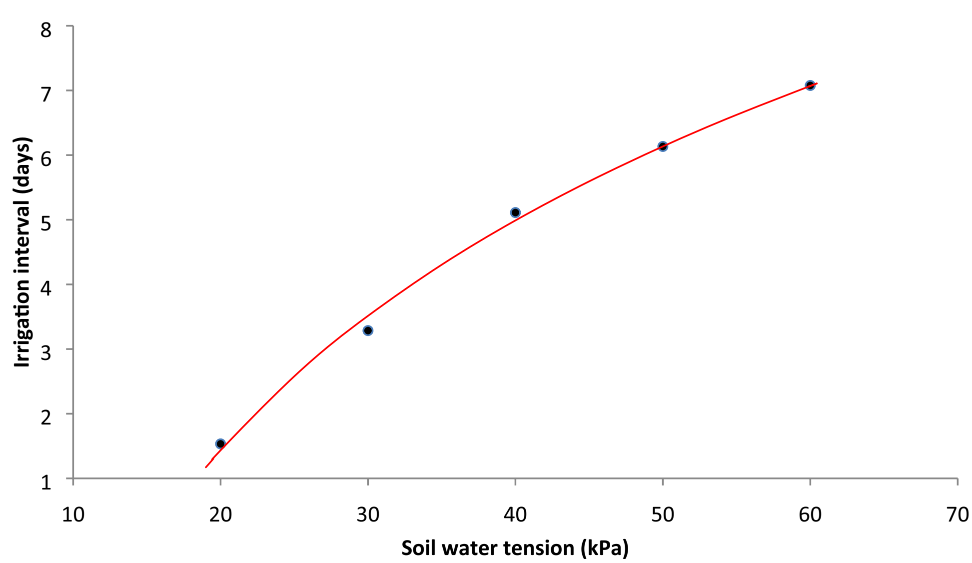

Fig. 2 The relationship between irrigation interval and soil water tension

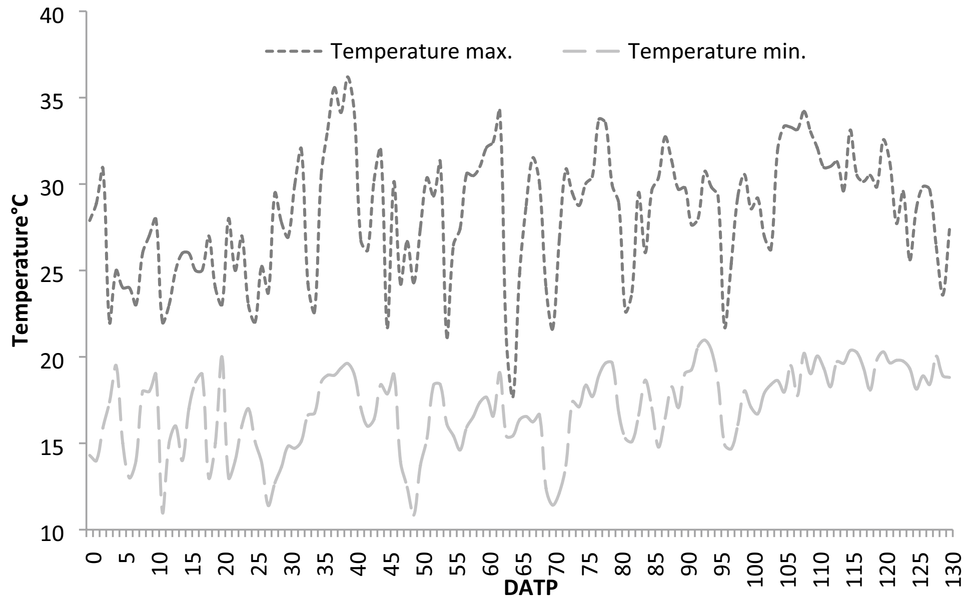

Fig. 3 Maximum and minimum atmospheric temperature during the basil experiment

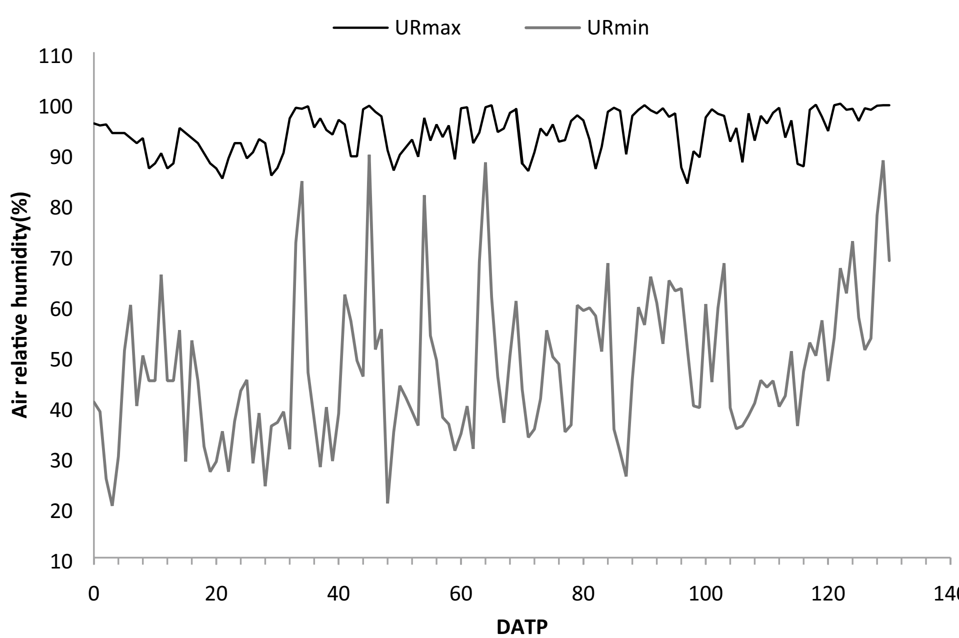

Fig. 4 Maximum and minimum relative air humidity during the basil experiment

Statistical analysis

The experimental design was completely randomized. The data were statistically analyzed and processed by software AgroEstat (Barbosa et al. 2011) and submitted to analysis of variance and the Tukey test compared the means at 5% probability.

Results and discussion

Dry and fresh biomass of basil

During the experiment, plants showed clear visual signs (Fig. 5) of wilting at higher tension (50–60 kPa). Basil plants recovered turgor shortly after the irrigation, indicating that

Fig. 5 Basil plants showing clear signs of water stress when soil water tension reached 60 kPa (left) and showing no visual signs of wilting when soil water tension reached 20 kPa (right)

the permanent wilting point did not occur. Plants irrigated with soil water tension of 20, 30, and 40 kPa did not show any visual signs of water stress.

An interaction was observed between the soil water tension and harvest stage for the total dry mass per plant (TDM) and the dry mass of the inflorescences per plant (DMI). The highest values of TDM and DMI were found in the harvest at the end of flowering (Tables 3, 4), when the plants reached their maximum size, that is, the full development of the aerial part.

When analyzing the TDM and the DMI as per the harvesting time, there was no difference in values among the soil water tension for BF and F. For the EF harvest stage, the soil water tension of 20 and 30 kPa showed higher TDM and DMI values than the soil water tension of 40, 50 and 60 kPa. However, they did not differ from each other (Tables 3, 4).

Khalid (2006), working with plants of the genus *Ocimum*, observed similar results, where plants submitted to water stress showed a decrease of the dry and fresh mass of up to 50% of field capacity. Baher et al. (2002), working with medicinal plants during the flowering phase, reported similar results with the reduction of the dry and fresh masses of the plants.

There was no interaction between soil water tension and harvesting stage for total fresh biomass (TFB) and total fresh mass of inflorescences per plant (TFI) (Table 5). The highest values of TFB and TFI were obtained with soil water tension of 20 kPa. The TFB and TFI averages for the harvesting stages showed a significant increase between the BF and EF harvests.

Stem diameter, plant height and inflorescences

For stem diameter, no interaction was observed between the harvesting stage and the soil water tension. The largest diameter was observed at the soil water tension of 20 kPa, with lower values in the tension of 50 and 60 kPa, a fact consistent with the reduction of plant size due to increase in water stress (Table 5). The stem diameter was also affected by the harvest stages, with the averages increasing gradually from BF to EF.

Table 3 Total dry mass per plant (TDM, g plant^{-1}) as affected by soil water tension and harvest stage

Harvest stage	Soil water tension (kPa)									
	20		30		40		50		60	
BF	59.00	Ca	52.76	Ba	57.86	Ba	52.10	Ba	44.36	Ba
F	99.03	Ba	76.43	Ba	70.76	ABa	74.33	ABa	71.70	ABa
EF	158.70	Aa	131.66	Aa	95.70	Ab	93.20	Ab	93.20	Ab

Values followed by the same letters are not significant different. With capital letters showing differences within flowering periods and lower case letters within a given flowering period as affected by water tension according Tukey test at 5% probability

BF beginning of flowering, *F* full flowering, *EF* end of flowering.

Table 4 Total dry mass of the plant inflorescences (DMI, g plant^{-1}) as affected by soil water tension and harvest stage

Harvest stage	Soil water tension (kPa)									
	20		30		40		50		60	
BF	14.90	Ca	13.20	Ca	13.53	Ba	11.96	Ba	8.65	Ba
F	33.93	Ba	27.50	Ba	24.73	Aa	26.13	Aa	24.00	Aa
EF	59.56	Aa	55.00	Aa	33.46	Ab	32.63	Ab	33.10	Ab

Means followed by the same lowercase letter in the line and the same capital letter in the column do not differ by the Tukey test at 5% probability

BF Beginning of flowering, *F* Full flowering, *EF* End of flowering

For plant height (Table 6), there was an interaction between harvesting stage and soil water tension. At the 20 kPa, the effect of the harvest stage was significant with increments of the plant height for each harvest stage; whereas, at the irrigation levels of 30, 50, and 60 kPa, the increase was only significant between the beginning and full flowering. At the 40 kPa soil water tension, no significant difference was observed for plant height. The plant height was affected by soil water tension in the EF harvesting with 20 kPa, resulting in higher heights than at 40, 50, and 60 kPa. At the BF, 30 kPa resulted in a higher height than 60 kPa. Baher et al. (2002), studying the effect of water stress on medicinal plants, reported similar results with a reduction in plant height of 31% with increased stress due to water restriction.

The number of inflorescences per plant showed an interaction between soil water tension and harvesting stages. For all levels of soil water tension, the number of inflorescences increased between BF and EF (Table 7). Only in the EF harvest stage, a significant reduction in the number of inflorescences was observed as a function of soil water tension, with the highest values obtained at 20 and 30 kPa.

Essential oil content and yield

The soil water tension and the harvest stage showed interaction for the essential oil content. For 20 kPa, there was no significant difference among harvest stages. The result was significant for the soil water tension of 30–60 kPa, increasing the essential oil content between the first (BF) and the last harvest, EF (Table 8).

When analyzing the effect of the soil water tension for each harvest stage, it was only significant at the end of flowering (EF), in which the water deficit caused increments of 25% in the essential oil content, from 1.04% at 20 kPa to 1.30% at 60 kPa. The water stress concentrated the essential oil, but it also generated less dry mass per plant. Khalid (2006) reported increments in the essential oil content in two water stress treatments, with oil increments up to 50% due to water stress. Baher et al. (2002)

Table 5 Stem diameter at the base (mm), total fresh mass per plant (TFB), in g, and total fresh mass of inflorescences per plant (TFI), in *g*, as a function of soil water tension and harvest stage

Variable	Soil water tension (kPa)										Harvest stage					
	20		30		40		50		60		BF		F		EF	
TFB	149.4	*a*	117.0	*b*	97.5	b	96.9	b	95.0	b	79.3	*c*	105.8	*b*	148.4	a
TFI	57.1	*a*	44.8	ab	36.0	b	34.3	b	34.5	b	21.8	*c*	42.3	*b*	59.8	a
SD	7,57	*a*	6,76	ab	6,67	ab	6,35	b	6,59	b	5,86	*c*	6,74	*b*	7,73	a

Means followed by the same lowercase letter in the line do not differ by the Tukey test at 5% probability

TFB total fresh mass per plant, *TFI* total fresh mass of inflorescences per plant, *SD* stem diameter, *BF* beginning of flowering, *F* full flowering, *EF* end of flowering

Table 6 Plant height (cm) as a function of soil water tension and harvest stage

Harvest stage	Soil water tension (kPa)									
	20		30		40		50		60	
BF	67.83	Cab	71.77	Ba	70.11	Aab	65.56	Bab	61.10	Bb
F	76.67	Ba	78.77	Aa	74.67	Aa	74.00	Aa	74.70	Aa
EF	82.78	Aa	80.44	Aab	73.89	Abc	72.67	Ac	73.20	Ac

Means followed by the same lowercase letter in the line and of the same capital letter in the column do not differ among themselves by the Tukey test at 5% probability

BF beginning of flowering, *F* full flowering, *EF* end of flowering

Table 7 Number of inflorescences per plant as a function of soil water tension and harvest stage

Harvest stage	Soil water tension to start irrigation (kPa)									
	20		30		40		50		60	
BF	39.67	Ba	22.00	Ca	22.22	Ba	21.45	Ca	20.80	Ba
F	53.11	Ba	50.44	Ba	39.28	Ba	49.11	Ba	46.00	Ba
EF	134.2	Aa	123.66	Aa	84.84	Ab	82.56	Ab	76.60	Ab

Means followed by the same lowercase letter in the line and of the same capital letter in the column do not differ among themselves by the Tukey test at 5% probability

BF beginning of flowering, *F* full flowering, *EF* end of flowering

Table 8 Essential oil content (%) in the dry mass as a function of soil water tension and harvest stage

Harvest stage	Soil water tension (kPa)									
	20		30		40		50		60	
BF	0.87	Aa	0.78	Ca	0.78	Ba	0.76	Ba	0.66	Ca
F	1.06	Aa	1.01	Ba	0.91	Ba	0.90	Ba	0.90	Ba
EF	1.04	Ab	1.23	Aab	1.25	Aab	1.27	Aab	1.30	Aa

Means followed by the same lowercase letter in the line and of the same capital letter in the column do not differ among themselves by the Tukey test at 5% probability

BF beginning of flowering, *F* full flowering, *EF* end of flowering

reported increments in the accumulation of essential oils of *Sartureja hortensis* L. as water stress increased during the flowering stage.

At the flowering stages, the essential oil yield increased between BF and EF (Table 9). In relation to the soil water tension, the harvest stages F and EF showed significant differences in the essential oil yield with the highest values occurring at 20 and 30 kPa. These results indicate that the highest essential oil yield occurred in the later harvest stage (EF) associated with soil water tension of 20 and 30 kPa.

Essential oil yield is the variable to be optimized because it is the base to estimate the basil grower's profit, which is calculated by multiplying the total dry mass per plant by the essential oil content. Irrigation scheduling using soil water tension of 60 kPa generated the highest basil essential oil content but the lowest total dry mass per plant and, consequently, the lowest essential oil yield per plant. The highest essential oil yield occurred at EF harvest stage combined with soil water tension of 20 and 30 kPa, which also generated the best performance in terms of total dry mass per plant, total dry mass of inflorescences, number of inflorescences and TFI. TFB, stem diameter, and plant height showed higher values with 20 kPa. So, a useful recommendation for basil growers to get higher essential oil yield is proceeding irrigation when the soil water tension reaches 30 kPa and harvesting at the end of flowering.

Padalia et al. (2017) reported that the highest yields of essential oils in the varieties used in the northern region of India were obtained when the harvest occurred during full flowering. Da Costa et al. (2015) observed that oil yields were less dependent on plant varieties.

Essential oil composition

For this study, 49 essential oil components were detected, with only a few showing significant changes as affected by flowering stages and soil water tension (Supplementary Material). The chemical components dominating the list of the essential oils, regardless of the treatment, were Linalool, 1,8 Cineole, camphor, and eugenol, on average. The sum of these compounds represented approximately 70% of the chemical composition of the basil essential oils.

Burducea et al. (2018) observed higher amounts of linalool in basil varieties as well as variations in their relative proportions under different levels of soil water tension for irrigation scheduling and fertilization practices. Other authors found that linalool, 1,8-cineole, and eugenol dominated the oil profile in the basil varieties (Jordán et al. 2017; Tarchoune et al. 2013).

At the different flowering stages (Table 10), some components showed opposite trends, some decreased with flowering, as was the case of Sabinene, β-Pinene, (E)-β-Ocimene, and Eugenol. In contrast, others increased as α-Terpineol and 1,8-Cineole showed. Linalool, the main component found in the basil essential oil, showed no significant variations between the flowering stages.

The components of the essential oil showed differences with the soil water tension (Table 11). The majority of components proportionally increasing when irrigation occurred at higher soil water tension, as was the case for Sabinene,

Table 9 Essential oil yield per plant (*g*, dry weight basis) as a function of the harvest stage and the soil water tension

Harvest stage	Soil water tension (kPa)									
	20		30		40		50		60	
BF	0.51	Ca	0.29	Ca	0.45	Ba	0.28	Ca	0.29	Ca
F	1.04	Ba	0.77	Bab	0.62	Bb	0.67	Bb	0.64	Bb
EF	1.65	Aa	1.62	Aa	1.16	Ab	1.18	Ab	1.21	Ab

Means followed by the same lowercase letter in the line and of the same capital letter in the column do not differ among themselves by the Tukey test at 5% probability

BF beginning of flowering, *F* full flowering, *EF* end of flowering

Table 10 Relative percentage (%) of the main components of the essential oil as affected by harvest stages

Substances	Harvest stages					
	BF		F		EF	
Sabinene	1.024	*a*	0.816	*b*	0.859	*b*
β-Pinene	1.933	*a*	1.639	*b*	1.668	*b*
1,8-Cineole	21.350	*a*	19.980	*b*	21.620	*a*
(E)-β-Ocimene	0.357	*a*	0.381	*a*	0.295	*b*
Linalool	29.350	*a*	30.880	*a*	31.180	*a*
Camphor	14.980	*a*	15.170	*a*	15.330	*a*
δ-Terpineol	0.456	*b*	0.470	*a*	0.478	*a*
Eugenol	5.760	*a*	5.139	*a*	4.145	*b*

Values within the harvest stage followed by the same letters are not significant different. Means followed by the same lowercase letter in the line

BF beginning of flowering, *F* full flowering, *EF* end of flowering

Table 11 Relative percentage (%) of the main components of the essential oil as affected by soil water tension

Substance	Soil water tension to start irrigation (kPa)									
	20		30		40		50		60	
Sabinene	0.829	*b*	0.847	ab	0.816	b	0.967	ab	1.038	*a*
β-Pinene	1.616	*c*	1.615	*c*	1.649	bc	1.857	ab	1.996	*a*
1,8–Cineole	20.110	*b*	20.080	*b*	21.340	ab	20.990	ab	22.400	*a*
(E)-*β*-Ocimene	0.286	*d*	0.299	cd	0.341	bc	0.379	ab	0.416	*a*
Linalool	33.370	*a*	33.260	*a*	29.940	b	28.550	*b*	27.230	*b*
Camphor	15.340	*a*	15.050	*a*	15.470	a	14.900	*a*	15.030	*a*
δ-Terpineol	0.421	*b*	0.429	*b*	0.484	ab	0.485	ab	0.521	*a*
Eugenol	4.950	*a*	4.668	*a*	5.372	*a*	5.021	*a*	5.061	*a*

For the substance, values followed by the same letters are not different among soil water tensions. Means followed by the same lowercase letter in the line

β-Pinene, 1,8-Cineole, (E)-*β*-Ocimene and *α*-Terpineol. Linalool had an opposite response, decreasing its relative percentages from 33% at 20 and 30 kPa, to 27% with soil water tension of 60 kPa, which showed that the water restriction affected the accumulation of this component. Jordán et al. 2017 and Radácsi et al. (2010) observed similar results once the water stress decreased the concentration of Linalool in the essential oils. Khalid (2006) and Simon et al. (1992) reported variation in the chemical composition of *Ocimum basilicum* when submitted to water stress with increments of some components such as Linalool and 1,8-Cineole, and reductions of others. The differences in these results might be explained by the genetic characteristics of plants, with variation of secondary metabolism under stress conditions, as well as differences in relative amounts of major components such as linalool (Blank et al. 2010; Soares et al. 2007; Veloso et al. 2014), Eugenol, Methylchavicol, Linalool, 1,8-Cineole (Baritaux et al. 1992).

Khakdan et al. (2017), studying genes involved in the biosynthetic routes of different essential oil components in three basil varieties, reported that water deficit during the crop cultivation produced different gene expressions. Their results also suggested that accumulating specific components seemed to be more affected by growing conditions.

Conclusions

Our results showed that the variety Manjericão IAC Linalol developed better when irrigated at lower soil water tension of 20 and 30 kPa.

The harvesting at the end of flowering (EF) generated the highest values of essential oil content and yield.

The highest percentage of essential oil content in dry mass was obtained with 60 kPa indicating that water stress concentrated essential oil, however, the profit is associated with the essential oil yield. The higher essential oil yield (g, dry weight basis) occurred when irrigation started at 20 and 30 kPa.

For all the treatments, linalool was the components found in more considerable amount, and its highest accumulation occurred when irrigation was done at soil water tension of 20 kPa and 30 kPa.

As a result, a useful recommendation for basil growers is irrigation scheduling with 30 kPa and harvest at the end of flowering.

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