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Water productivity of *Melissa officinalis L.* irrigated with magnetically treated water*

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ABSTRACT

The water consumption, leaf dry mass (LDM), essential oil yield (Y), essential oil production (Prod), and water productivity as a function of the LDM and the essential oil production of lemon balm were evaluated. The treatments included 25%, 75%, 100%, and 125% crop evapotranspiration (ETc) replacement by irrigation with untreated water (CW) and magnetically treated water (MTW). Through analysis of variance (F-test), means tests (Scott-Knott), and regression analysis, it was observed significant differences among the water replacement level but not between the water treatment. The contribution of magnetically treated water was not clear from the results obtained. The water productivities as a function of leaf dry mass and essential oil production shows the 75% of ETc quite promising for achieving satisfactory leaf production and efficient oil production relative to the amount of water applied.

Keywords: medicinal plants; magnetizer, drip irrigation, agricultural water, lemon balm.

Produtividade da água no cultivo de *Melissa Officinalis L.* irrigada com água tratada magneticamente

RESUMO

Avaliou-se o consumo de água, a massa seca de folhas, rendimento de óleo essencial, produção de óleo essencial, e a produtividade da água em relação a massa seca de folhas e em relação a produção de óleo essencial da melissa produzida em vaso em ambiente protegido. Utilizando-se como tratamento a variação na reposição da água evapotranspirada nas proporções de 25%, 75%, 100% e 125% da evapotranspiração da cultura (Etc), aplicada por gotejamento com água sem tratamento (AC) e tratada magneticamente (ATM). Através da análise da variância (Teste F), teste de médias (Scott-Knott) e regressão, observou-se que os tratamentos que receberam 25% da ETc tanto para ATM quanto para AC, apresentaram diferenças significativas, com valores inferiores, em relação aos demais para massa seca de folhas e produção de óleo essencial, e superior, para rendimento do óleo essencial e produtividade da água em relação a produção de óleo essencial. Não foi observado efeito significativo da magnetização da água, e levando em consideração os parâmetros avaliados, o tratamento de 75% da ETc foi o que apresentou melhores resultados, concluindo que as variáveis produtividade da água em relação a produção de massa seca de folhas e em relação a produção de óleo essencial foram influenciadas em função do tipo de água utilizada.

Palavras-chave: Plantas medicinais, Magnetizador, Gotejamento, Ambiente protegido, Melissa.

Introduction

In recent decades, interest in medicinal plants and their related products has increased, resulting in the establishment of national and global markets for herbal medicines and bioactive plants due to increasingly strong public demand (Ethur et al., 2011; Krupek e Nedopetalski, 2020; Silva et al., 2020; Soares et al., 2020; Ramos and Damascena, 2018). Lemon balm (*Melissa* *officinalis L.*) is a medicinal plant belonging to the family Lamiaceae that is commonly used in folk medicine. Its medicinal principles include calming and diuretic properties (Heshmati et al., 2020; Lameira et al., 2008; Mohasseli et al., 2020).

The increased demand for water by different users and the inadequate use of water make it essential to seek more efficient irrigation methods that minimize waste and maintain crop productivity (Lima et al., 2017). According to Luz et al. (2014), the cultivation of lemon balm in a protected environment results in higher biomass production, essential oil yield, and content of citral, a compound of interest to the industry.

To obtain better production, the agricultural sector is seeking new techniques, and the use of magnetically treated water (MTW) has shown promising results due to its unique physical/chemical characteristics in order that treatments have shown to have beneficial effects on seeds' germination, plant growth and development, the ripening and crops yield (Alavi et al., 2021; Ali et al., 2014; Liu et al., 2020). MTW is a type of water prepared by exposure to a constant magnetic field, causing changes to the physical and chemical properties of the water and resulting in an increase in water quality. This type of water has been studied in several areas beyond the agricultural sector, such as civil construction, mining, poultry farming, and other industrial applications (Almeida et al., 2020; Lemos et al., 2021; Samadyar et al., 2014; Ghorbani et al., 2019; Zhou et al., 2018; Hassan et al, 2018). Almeida et al. (2020) observed that using MTW combined with coconut fiber substrate in the cultivation of *Sweet Heaven* tomato has developed expressively superior stems than cultures without MTW. However, Lemos et al. (2021) evaluating the influence of different soil water tensions at the initiation of irrigation with magnetically treated water on ‘iceberg’ lettuce Lucy Brown (*Lactuca Sativa L.*) observed that the use of MTW may have hindered water absorption by the culture. On the other hand, Verssiani et al. (2021) observed MTW influence on the Capsicum pepper cv., as a result, caused a significant increase in allometric variables.

Water productivity is a concept that plays a crucial role in the modern agricultural sector; it is used to evaluate the production per unit of water used, both under rainfed and irrigated conditions. Amaral et al. (2019) analyzed the 'Water Productivity' for soybean crops under irrigated and rainfed conditions, also, Frizzone and Melo (2022) conceptualize in a theoretical way the term 'Water Productivity' in the context of irrigated agriculture, its main impacts, and the importance for the environment. This concept assigns a specific value to the productivity obtained per unit of water used and can be used as an indicator at times and in locations with relative water scarcity (Halsema and Vicent, 2012).

Thus, the objective of the present study was to evaluate the influence of the applied water volume on water productivity as a function of the leaf dry mass (LDM) and essential oil production of lemon balm grown in pots in a protected environment using drip irrigation with MTW, which studies in other types of cultivation have been showing efficiency improvement of production when compared to applying untreated water.

Methods

The present study was conducted at the experimental site of the Department of Engineering of Federal University of Lavras (Universidade Federal de Lavras – UFLA), located at 21°14'00" S latitude, 45°00' W longitude and 918 m mean altitude. The climate is classified as Cwa, rainy temperate, according to the Köppen classification system. According to Dantas et al. (2007), in a study conducted with data from 1990 to 2014, the highest mean monthly temperature was 22.8°C (February), with 1460 mm mean annual cumulative rainfall and 956 mm mean annual potential evapotranspiration.

The study was conducted in a protected environment under a metal structure with an arched roof, measuring 15 m in length and 7.5 m in width (area of 112.5 m^2) with a ceiling height of 3.5 m. The structure is covered with 150-μm thick anti-UV treated clear polyethylene film. The sides of the structure, which is seated on a 0.30-m high concrete base, are enclosed with polypropylene mesh. Over the years, the place has already served as an experimental area for several other surveys, such as Gontijo et al. (2020) who evaluated the water productivity and agronomic performance of strawberries with different leaching fractions application, Caldas et al. (2016) evaluated the effect of different soil water tensions applied in two phenological phases of the Cayenne pepper grown in the same environment, and Almeida et al. (2020) who evaluated the use of MTW in *Sweet Heaven* tomato. Experimental areas such as that it has been used by the most diverse studies because it allows control of climatic processes such as precipitation, evapotranspiration, and air temperature.

The lemon balm seedlings were obtained by micropropagation from mother plants grown in the tissue culture laboratory of the Department of Agriculture of UFLA. The seedlings were acclimatized, and when they reached 10 cm in height, they were transplanted into 13 L round plastic pots filled with two-thirds medium-textured red latosol soil and one-third sand. A total of 440 g per pot of cured cattle manure was also added to improve the soil organic matter content. The pots were placed on a bench, and a completely randomized experimental design was used to assign the treatments inside a protected environment, the experiment was conducted for 90 days.

The water depths used by the irrigation system corresponded to four water volumes defined as 25%, 75%, 100%, and 125% of the water volume evapotranspirated by the crop. The crop evapotranspiration (ETc) was determined using a weighing lysimeter, with daily monitoring. Four replicates were used per treatment, with each replicate consisting of a set of six pots with one plant per pot, totaling 192 pots (Figure 1). Six control pots were measured by the weighing lysimeter: 3 irrigated with MTW and 3 irrigated with untreated water (CW). The irrigation interval adopted was two days, according to a study by Caldas et al. (2017), which analyzed the effect of different irrigation intervals on the vegetative growth rate of lemon balm and found that the best results were obtained with a two-day irrigation interval.

Figure 1. Arrangement of pots on the benches, with the experimental plants and the irrigation system respectively.

The irrigation system used was a self-compensating drip system with one emitter per pot, with a flow rate of 4 L. h^{-1}. To perform irrigation with MTW, a 250 L reservoir was used, to which a Sylocimol® magnetizer model Residence 1000 L was applied.

The variables evaluated were the water consumption, LDM, essential oil yield, essential oil production, water productivity as a function of LDM and water productivity as a function of essential oil production per plant.

The volume of water consumed during the 90 experiment days was determined using the control pots used in the weighing lysimeter, daily the control pots were weighed and the water volume was determined for each treatment.

To determine the LDM, the leaves of each plant were detached from the stem, placed in paper bags and dried in a forced air oven at 39°C to a constant weight, so that it was used to ensure that there was no loss by volatilization of the essential oil components. The extraction of essential oil from lemon balm leaves was performed by hydrodistillation in a modified Clevenger apparatus (Wasicky, 1963) using 60 g LDM in 1 L of distilled water for a period of 90 min, the methodology has been used in several studies such as Azevedo et al. (2022), Medeiros (2020) e Oliveira et al. (2020). The essential oil was purified by liquid-liquid partitioning with dichloromethane (3 × 15 mL). The organic phase was combined and treated with approximately 5 g of anhydrous magnesium sulfate for 30 min. After this period, the solution was filtered, and the solvent was evaporated in a rotary evaporator under controlled temperature and pressure. The extracted essential oil yield was determined by equation 1.

$$Y = \frac{TOW}{Ma} \times 100 \qquad (1)$$

Where:
Y: essential oil yield (%);
TOW: total weight of oil extracted from the sample (g);
Ma: leaf dry mass used in the sample (equal to 60 g in the present study).

Using the essential oil yield (Y) data, the essential oil production per plant was determined using equation 2.

$$Prod = LDM_{mean} \times Y \times 10 \qquad (2)$$

Where:
Prod: essential oil production (mg $plant^{-1}$);
LDM: leaf dry mass per plant (g $plant^{-1}$);
Y: essential oil yield (%).

Equations 3 and 4 were used to determine the water productivity as a function of LDM (PWm) and of essential oil yield (PWo), respectively.

$$PWm = \frac{LDM}{TW} \quad (3)$$

Where:
PWm: water productivity as a function of leaf dry mass (g L^{-1});
LDM: leaf dry mass (g $plant^{-1}$);
TW: total water applied during the experiment (L $plant^{-1}$).

$$PWo = \frac{Prod}{TW} \quad (4)$$

Where:
PWo: water productivity as a function of essential oil production (mg L^{-1});
Prod: essential oil production of (mg $plant^{-1}$)
TW: total water applied during the experiment (L $plant^{-1}$).

Statistical analysis was performed by analysis of variance of the data (F-test) at 5% significance. When there was a significant difference between treatments, the data were subjected to regression analysis and the Scott-Knott means test, it was calculated by the statistical software SISVAR (FERREIRA, 2008).

Results and Discussion

Figure 2 shows the water volumes applied throughout the crop season in each treatment. The amount of water applied varied significantly, which was to be expected for the wide replacement range adopted, of 25% to 125% evapotranspiration. Considering each replacement level separately, the water consumption was very close when untreated or MTW was used.

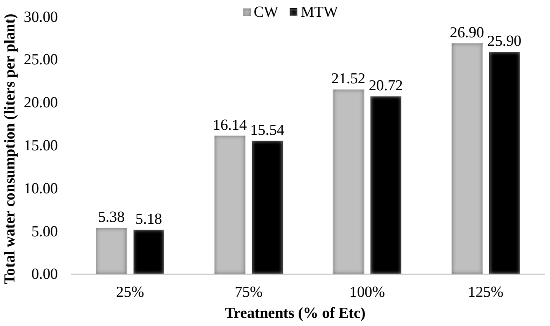
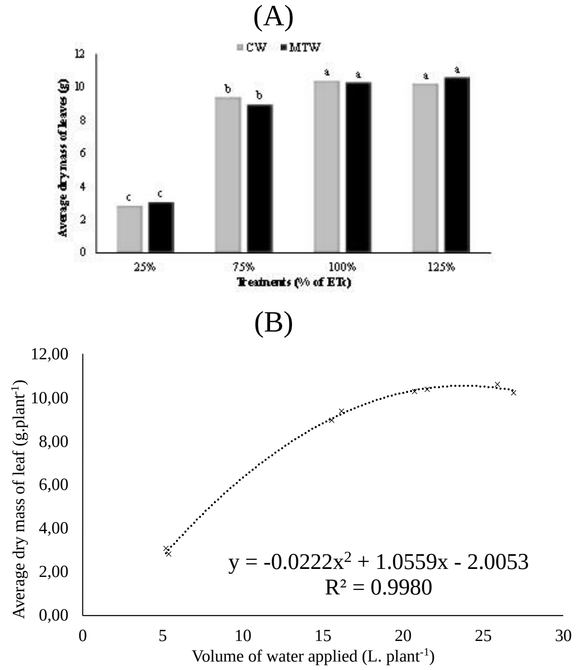


Figure 2. Water volume applied throughout the crop season in the conventional and MTW treatments.

The results of the mean LDM per treatment are shown in Figure 3. The analysis of variance (F-test, Figure 3A) and the means test (Scott-Knott) showed that the water treatment applied had no significant affect but that the amount of water applied did. The LDM values shown in Figure 3A evidence the positive response of lemon balm to the water availability, with higher LDM production observed at the highest water volumes applied. Other studies, such as Medeiros (2020), Meira et al. (2013) and Farahani et al. (2009), observed higher dry biomass values in lemon balm in treatments that received greater water volumes, corroborating the results of this study.



Averages followed by the same letter do not differ by the Scott-Knott test, at α = 0.05

Figure 3. LDM (A) and second-order polynomial regression (B) as a function of the applied water volume.

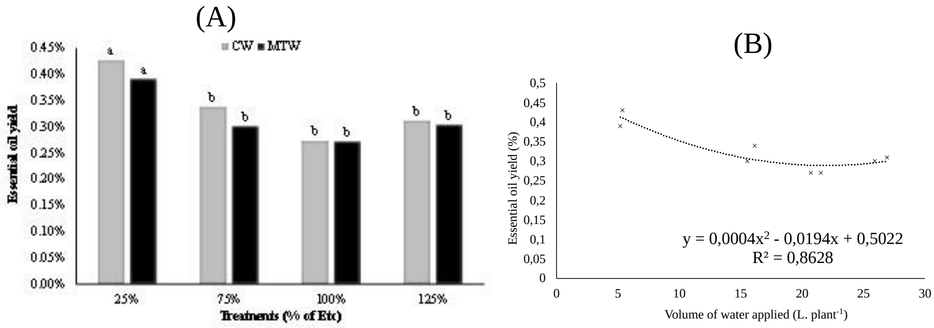
To determine the relationship between LDM and the amount of water applied, a regression analysis was performed with all results, regardless of the water treatment (Figure 3B). It was observed that the water volume applied affected the LDM production, which is one of the main production components. There was an increase in biomass production up to the treatment that received 100% ETc. There were no significant differences between the treatments that received 100% and 125% ETc.

The regression analysis showed that the water volume applied had a strong correlation with LDM, presenting an R² of 0.9980 in the second-degree polynomial regression (Figure 3B). Meira et al. (2013) observed dry mass values between 2.39 and 7.16 g, where the lowest values were obtained in the plants that received the lowest water volumes (50% of the reference evapotranspiration) and the highest values in the plants that received the highest water volumes (175% of the reference evapotranspiration). Through regression analysis, the authors obtained an R² of 0.931 in the linear regression. Compared with the present study, the values obtained by Meira et al. (2013) were lower, evidencing the good results obtained in the present study regarding leaf biomass production, which is one of the commercial products of the lemon balm crop. On other hand, Medeiros (2020) presented behavior similar to the present study, when dealing with the relationship between the water volume applied and the LDM.

Lopes et al. (2011) report that although crop development under different irrigation volumes showed the same pattern obtained in this study, in which the highest dry mass production was obtained with the highest water volumes applied, attention should be paid to the irrigation of crops of the family Lamiaceae so as to not increase the production cost, since water is costly and its excess application, in addition to not being a limiting factor for the species such as high temperature, causes greater losses both by evaporation and percolation and reduces essential oil production.

Essential oil extraction was performed by hydrodistillation, and the essential oil yield was obtained through the ratio between the total extracted mass of the oil and the dry mass of leaves. The results are shown in Figure 4.

Higher essential oil yields were obtained in the treatments irrigated with the lowest water volumes (Figure 4A). The highest essential oil yield was obtained in the treatment irrigated with 25% ETc, with a mean yield of 0.41%. Analysis of the results by the F-test and Scott-Knott test showed that the type of water applied had no significant effect on essential oil yield; only the water availability influenced the oil yield, where the treatments irrigated with 25% ETc showed higher yield values at 5% significance. To determine the relationship between water availability and oil yield, regression analysis was performed using all data regardless of the water treatment (Figure 4B). The variable essential oil yield had a strong correlation the applied water volume, with an R² of 0.8628 in the second-degree polynomial regression. Meira et al. (2013) and Medeiros (2020) evaluated the relationship between the applied water volume and essential oil yield and obtained similar results, where the highest oil yields were observed in the treatments maintained at the lowest water availability.



Averages followed by the same letter do not differ by the Scott-Knott test, at α = 0.05

Figure 4. Essential oil yield (A) and second-order polynomial regression (B) as a function of the applied water volume.

Higher essential oil yields in treatments that received the lowest applied water volumes (20% of field capacity) were also observed by Farahani et al. (2009), presenting a mean yield of 0.3013%. Essential oil yield values ranging from 0.125 to 0.16% were found by Ozturk et al. (2004), where the highest values were also observed in the irrigated treatment with the lowest water availability, in this case 50% ETc.

The essential oil content is a variable of great importance for the industry since the possibility of extracting a larger amount of oil using less plant material may be economically beneficial. The essential oil content obtained was relatively high, ranging from 0.27% to 0.42%, demonstrating the importance of water management for this variable.

It is evident from the results of LDM production and essential oil content that these variables are antagonistic in their response to water availability. Thus, equation 2 was used to obtain the essential oil production per plant for the analyzed treatments (Figure 5). This variable may be more interesting for the management of crop irrigation. The essential oil production data presented in Figure 5A showed that treatment with MTW did not have a significant effect on essential oil production according to the F-test and the Scott-Knott test at the 5% significance level. Only the treatments irrigated with 25% ETc showed significantly lower values than the others. The regression analysis performed with all the data (Figure 5B) showed that essential oil production had a strong correlation the water volume applied, with an R² of 0.9436 for the second-order polynomial regression. As observed in Figure 4, the treatments that received lower water volumes had a higher oil yield; however, essential oil production showed inverse behavior, where the highest essential oil production was observed for the 75%, 100%, and 125% ETc treatments. This pattern was also observed by Farahani et al. (2009), who obtained the highest lemon balm essential oil production values in the treatments irrigated at 60% and 40% field capacity and the lowest values in the treatment with the highest essential oil yield (20% field capacity).


(A)
(B)

Averages followed by the same letter do not differ by the Scott-Knott test, at α = 0.05

Figure 5. Essential oil production (A) and second-order polynomial regression (B) as a function of the applied water volume.

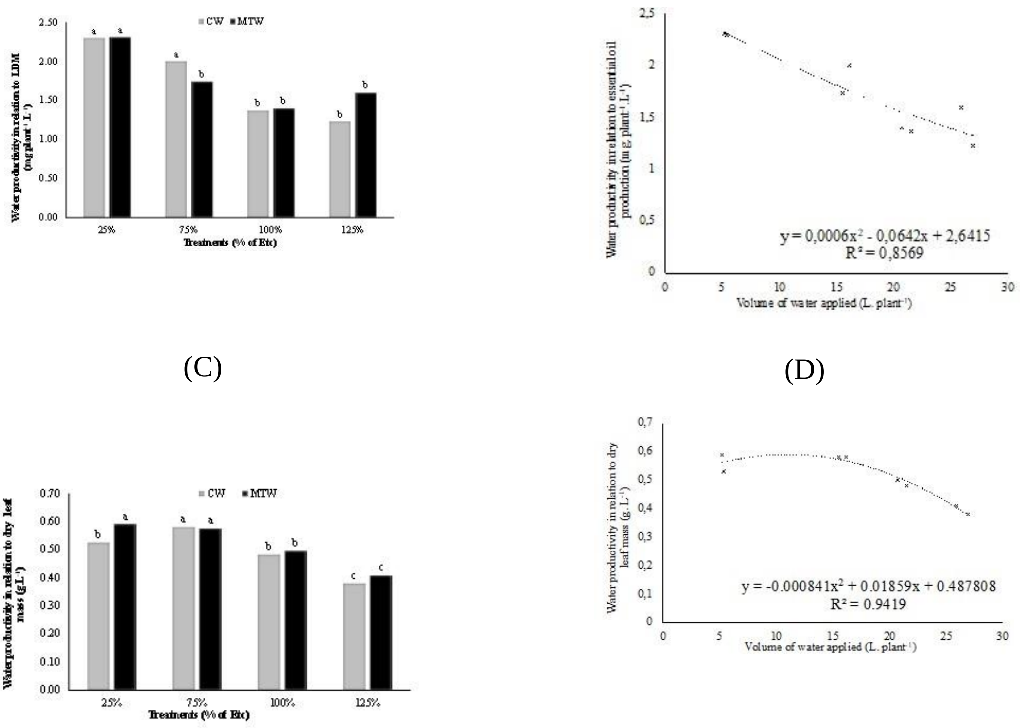
With the LDM production and essential oil production values, it was possible to determine the water productivity for each treatment by equations 3 and 4 (Figure 6).

The results presented in Figure 6A showed that MTW positively affected water productivity as a function of LDM production only in the pots that received 25% ETc, evidencing a possible contribution of MTW under low water availability conditions. This contribution may be linked to structural changes in the water molecules caused by magnetization, such as reduced surface tension and increased viscosity (Cai et al., 2009; Toledo, Ramalho and Magriotis, 2008, (Cai et al., 2009; Toledo, Ramalho e Magriotis, 2008, Pradela et al., 2020). As the effect was significant only in the treatment that received 25% ETc, it was decided to perform a regression analysis between water productivity as a function of LDM and water volume applied, with all the data points (Figure 6B). It was found that the correlation is practically constant until the application of 75% ETc, decreasing considerably with increasing water availability from this point on. Soares et al. (2022) obtained significant positive gains in accumulated productivity for coffee yield when using MTW.

Considering the essential oil production per plant and not just the LDM production, water productivity could be calculated as a function of essential oil production (Figure 6C). For this variable, a significant negative effect of MTW was observed only for the pots that received 75% ETc. For the other treatments, there were no significant effects from the type of water used, only of the water volume applied. Thus, all data were used for the correlation between water productivity as a function of total essential oil production and the water volumes applied (Figure 6D). An inverse correlation was observed between water availability and water productivity as a function of essential oil production, a finding that should be considered in the adoption of irrigation practices in regions with high water scarcity. Mendes et al. (2020) used MTW in the irrigation of leguminous *Dipteryx alata Vogel*, as a result, it caused a reduction in plant height with this type of treatment, however, it increased the number of leaves per plant.

These values are explained by the fact that the essential oil yield of lemon balm is relatively very low, as shown by Paviani (2004), and that with an increase in the applied water volume, the water productivity values as a function of essential oil yield tend to decrease, resulting in higher values at lower application volumes. Caldas (2019) found the same result, in which the water replacement volume affected water productivity, both in terms of dry biomass production and essential oil production.

It is of great interest to conduct studies such as the present one to find ways to obtain greater crop productivity as a function of the amount of water applied, i.e., “more crop per drop” (Giordano et al., 2006), thus maximizing the applied water volume relative to the final product.


(A)

(B)

(C)

(D)

Averages followed by the same letter do not differ by the Scott-Knott test, at α = 0.05

Figure 6. Water productivity as a function of LDM (A) and essential oil production (C), and second-order polynomial regression as a function of the applied water volume for water productivity as a function of LDM (B) and essential oil production (D).

Conclusion

According to the results from the present study, it can be concluded that:

I. Regarding crop water availability, the water productivities as a function of leaf dry mass and essential oil production did not show the same behavior.

II. However, for both cases, 75% crop evapotranspiration replacement was quite promising for achieving satisfactory leaf production and efficient oil production relative to the amount of water applied.

III. Regarding the use of MTW in the lemon balm culture, the results did not show significant improvements when compared with CW.

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