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Harvest interval for phytomass production of peppermint transplanted in summer and winter

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Abstract

The objective of this study was to determine the appropriate harvest interval for the phytomass production of peppermint (*Mentha* x *piperita* L.) transplanted in summer and winter. Two experiments were carried out in soilless cultivation, one with transplantation in summer and the other with transplantation in winter, in a completely randomized design, with five harvest intervals (30, 45, 60, 72, and 90 days) and four replicates. Fresh and dry matter weights of leaves, branches and shoots were determined. The fresh matter weight of peppermint leaves and the daily growth rate of this trait were similar between the harvest intervals for the transplantation performed in the summer. The dry matter weight of leaves was higher for the intervals of 72 days (90.80 g plant^{-1}) and 90 days (90.24 g plant^{-1}). For the transplantation performed in winter, the fresh matter and dry matter weights of leaves were higher for the intervals of 60 days (660.54 g plant^{-1}, 107.14 g plant^{-1}) and 90 days (630.40 g plant^{-1}, 105.95 g plant^{-1}). The same was observed for the daily growth rates of these traits. Peppermint harvests at 60-day intervals in winter transplantation are more appropriate for phytomass production. In summer transplantation, one can opt for the 45-day interval.

Keywords: soilless cultivation, *Mentha* x *piperita* L., accumulated production, daily growth rate

Introduction

The consumption of condiment, medicinal, and aromatic plants by the Brazilian population is increasing (Trento Filho et al., 2011). Peppermint (*Mentha* x *piperita* L.) is one of the most important species, being used fresh for food preparation, in addition to the use in folk medicine and by the pharmaceutical and cosmetic industries (Clemente & Haber, 2013). Peppermint has several medicinal properties due to the presence of components in its essential oils, such as carvacrol, menthol, carvone, menthyl acetate, limonene, and menthone (Ali et al., 2015).

Harvest interval influences the phytomass production of condiment, medicinal, and aromatic plants. According to May et al. (2010a), harvesting medicinal plants at shorter intervals promotes a shorter period of recovery, which can reduce their yield. These authors found higher dry matter accumulation in the shoots of rosemary (*Rosmarinus officinalis* L.) at longer harvest intervals. The opposite result was verified by Blank et al. (2012) in geranium plants (*Pelargonium graveolens*), for which the shortest interval promoted higher fresh and dry matter weights of leaves and stems. For two species of lemongrass, May et al. (2008) observed different results in relation to shoot dry matter accumulation, with higher values at the shortest harvest interval for *Cymbopogon citratus* and at the longest harvest interval for *C. flexuosus*. Thus, it is important to study the responses of plants of each species to a given type of management, in order to expand knowledge and obtain information to assist the cultivation schedule, aiming at higher yields.

The harvesting period of peppermint plants also has influence on biomass production, as observed by Salim et al. (2014) and Machiani et al. (2018), who found that period of lower temperature resulted in lower yield.

The transplanting season also influences

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phytomass production and has been evaluated for the species *M. arvensis* L. by Desai et al. (2018) on the dates of October 1, November 1, and December 1 (autumn in the region), in which the highest phytomass was obtained with transplantation on November 1, and by Sharma (2012), with transplantation on March 15, March 30, and April 15 (spring in the region), in which the first season promoted higher fresh matter production. Akhtar et al. (2009), in a study conducted with *M. piperita*, in three seasons in Bangladesh, in winter, summer, and monsoon season (rainy season), found higher production of leaves in the monsoon season, compared to winter and summer.

It is assumed that the harvest intervals and the season of the year in which transplantation is carried out influence the phytomass of peppermint plants. Thus, the objective of this study was to determine the harvest interval for peppermint phytomass production in transplantations performed in summer and winter.

Material and Methods

Two experiments with peppermint crop (*M.* x *piperita* L.) were conducted in a soilless cultivation system, in a 115 m² (5×23 m) shelter-type protected environment, covered with 150-μm-thick anti-UV polyethylene, located in the Plant Science Department of the Federal University of Santa Maria. The first experiment was installed on December 28, 2017 (transplantation in summer) and conducted until December 23, 2018 (12 months), whereas the second experiment was installed on June 28, 2018 (transplantation in winter) and conducted until June 23, 2019 (12 months).

During the cultivation period, air temperature inside the shelter was recorded by a digital Data Logger (0.1 °C resolution and 0.5 °C accuracy), installed one meter above the plants. Solar radiation was recorded at the automatic weather station, belonging to the 8th District of Meteorology - National Institute of Meteorology (INMET), located 300 m away from the cultivation environment.

Fertigation was performed through drip tapes, positioned at the top of the pots, with one dripper per plant. The nutrient solution was prepared and stored in 500-L polypropylene boxes and supplied to plants by means of a motor pump controlled by a timer. The nutrient solution used had the following composition: 9.68 of NO_{3^-}, 0.88 of NH^{4+}, 1.36 of $H_2PO_{4^-}$, 5 of K^+, 2.58 of Ca^{2+}, 2 of Mg^{2+}, and 2 of SO_{4^-} (in mmol L^{-1}). Micronutrients were supplied at concentrations (in mg L^{-1}) of 0.03 of Mo, 0.26 of B, 0.06 of Cu, 0.50 of Mn, 0.22 of Zn, and 1.0 of Fe in the chelated form. The nutrient solution was adapted for the crop (Mambri et al., 2018), and the macronutrients were supplied through potassium nitrate (KNO_3), monobasic ammonium phosphate ($NH_4H_2PO_4$), calcium nitrate ($Ca(NO_3)_2$) (commercial product Calcinit®), and magnesium sulfate ($MgSO_4$). The electrical conductivity (EC) of the nutrient solution used was 1.84 dS m^{-1}, being monitored weekly and corrected with the addition of aliquots of a new solution whenever necessary, in order to maintain the original value.

The peppermint seedlings used in experiments 1 (transplantation in summer) and 2 (transplantation in winter) were produced at the same site of the experiment, using parent plants grown in greenhouse, in soilless cultivation. For this, cuttings of four centimeters from the apex of the branches, leaving two expanded leaves at the end, were placed in polystyrene trays containing commercial substrate. The trays with the seedlings produced were placed on a bench, inside the greenhouse, under sprinkler irrigation, where they remained until the formation of the root system. Seedling transplantation was performed when the root system was well formed, which occurred after 30 days in experiment 1 (transplantation in summer) and after 45 days in experiment 2 (transplantation in winter).

In both experiments, the seedlings were transplanted to 3 dm³ white polyethylene pots, filled with commercial substrate *MecPlant*®, composed of pine bark, vermiculite, acidity corrective, and macronutrients. The pots were arranged on benches with 1.10 m width, 4 m length, and 80 cm height from the concrete floor. Two benches were used in each experiment. Each bench had 44 pots, resulting in 88 pots and, consequently, 88 plants in each experiment. In order to standardize the experiments and provide the same growth conditions for the plants, between treatments (harvest intervals) plants were used as borders, which were pruned every 30 days. In the treatment plots, the two central plants were used as replicates and the two lateral plants were harvested on the same dates as the intervals, but discarded, being used only as borders of the treatments. Thus, the evaluations were performed in 20 plants per experiment, while the others were considered borders of the experiment and borders of the treatments.

A completely randomized design was used, with five treatments, corresponding to intervals between successive harvests of 30, 45, 60, 72, and 90 days, from the date of transplantation, with four replicates, each of which represented by one plant. The harvests (cuts) were carried out at 7 cm height from the base of the plant, in order to allow the regrowth of the branches. Fresh matter weights of leaves, branches, and shoots (leaves +

branches) were determined, in g plant^{-1}, as well as the dry matter weights of leaves, branches, and shoots (leaves + branches), in g plant^{-1}, obtained after drying the samples in a forced ventilation oven at 65 °C for seven days.

At 12 months after transplantation, the last evaluation of all intervals between harvests was performed. In experiment 1, the last harvest occurred on December 23, 2018, and in experiment 2, on June 23, 2019. Thus, at the end of the experiments, 12 harvests were obtained from the 30-day interval, eight harvests from the 45-day interval, six harvests from the 60-day interval, five harvests from the 72-day interval, and four harvests from the 90-day interval. The weights of each harvest in each plant (replicates), were summed to obtain the accumulated production.

For each plant (replicate) of each harvest interval (30, 45, 60, 72, and 90 days), in each transplantation (summer and winter), the daily growth rate was determined, in g day^{-1}. This rate was obtained by fitting the linear regression (y=a+bx) of the accumulated production of the harvests (y) as a function of the days after transplantation (x) over the 12 months, in which the slope of the line (b) is equivalent to the daily growth rate, which represents the mass increment per day, and a is the intercept value.

For each variable (weights and daily growth rates of fresh and dry matter of leaves, branches, and shoots), the normality of errors was checked by the Shapiro-Wilk test, and homogeneity of residual variances was checked by Bartlett test. Analysis of variance was performed, followed by the Scott-Knott criterion for comparison of means. Statistical analyses were carried out using the software programs Action (Estatcamp, 2014) and Sisvar 5.7 (Ferreira, 2014).

In addition to the statistical criterion, the visual aspect of the plants was considered to define the harvest interval, since the plants can reach a large volume of biomass, which is, however, also composed of senescent leaves.

Results and Discussion

The accumulated fresh matter weight of peppermint leaves for summer transplantation, at the end of the 12-month cultivation period, showed no significant difference between the harvest intervals, with values ranging from 438.49 to 547.76 g plant^{-1} (Table 1). The accumulated fresh matter weight of branches was higher for the intervals of 90 (1338.82 g plant^{-1}), 72 (1190.86 g plant^{-1}), and 60 days (1053.33 g plant^{-1}). The accumulated fresh matter weight of shoots was similar to that of branches, with the highest values verified with the intervals of 90 (1875.18 g plant^{-1}), 72 (1738.62 g plant^{-1}) and 60 days (1542.04 g plant^{-1}). The accumulated dry matter weight of leaves was higher with the intervals of 90 (90.24 g plant^{-1}) and 72 days (90.80 g plant^{-1}) (Table 1). The accumulated dry matter weight of branches showed an increment with the increase in harvest interval, with the highest production obtained with the 90-day interval (188.39 g plant^{-1}) and the lowest production with the 30-day interval (36.36 g plant^{-1}). The accumulated dry matter weight of shoots was similar to that of leaves, with the highest values verified with the intervals of 90 (278.64 g plant^{-1}) and 72 days (245.08 g plant^{-1}). As the harvest interval increased, the values of peppermint phytomass production increased.

The daily growth rate of fresh matter weight of leaves showed no significant difference between harvest intervals, in line with what was previously observed in relation to the accumulated production (Table 1). For the variables fresh matter weights of branches and shoots, the highest daily growth rates were observed with the intervals of 90 days (3.5512 g plant^{-1} and 4.9396 g plant^{-1}, respectively) and 72 days (3.0962 g plant^{-1} and 4.5946 g plant^{-1}, respectively).

The daily growth rates of dry matter weight of leaves were higher with the intervals of 90 (0.2073 g plant^{-1}), 72 (0.2253 g plant^{-1}), and 60 days (0.1835 g plant^{-1}). For the dry matter weight of branches, the highest daily growth rate was observed with the 90-day interval (0.4426 g plant^{-1}) and for the dry matter weight of shoots the highest rates were observed with the intervals of 90 (0.6499 g plant^{-1}) and 72 days (0.5843 g plant^{-1}) (Table 1).

The accumulated fresh matter weight of leaves, branches, and shoots of peppermint, at the end of the 12-month cultivation period, with transplantation performed in winter, showed a significant difference between the harvest intervals (Table 2). The intervals that promoted the highest production of accumulated fresh matter of leaves were 90 (630.40 g plant^{-1}) and 60 days (660.54 g plant^{-1}). Intermediate values (517.28 and 528.59 g plant^{-1}, respectively) were obtained with intervals of 45 and 72 days, while in the 30-day interval the production was lower than in the others (281.94 g plant^{-1}). The fresh matter weight of branches was higher with the intervals of 60, 72, and 90 days (1478.63, 1265.60, and 1438.11 g plant^{-1}, respectively), with intermediate value for the interval of 45 days (929.30 g plant^{-1}) and lower value for the interval of 30 days (355.49 g plant^{-1}). For fresh matter weight of shoots, the highest production was obtained with the intervals of 60 (2139.17 g plant^{-1}) and 90 days (2068.52 g plant^{-1}), and the lowest one with the interval of

30 days (637.43 g plant^{-1}).

The accumulated dry matter weight of leaves was higher with the intervals of 60 (107.14 g plant^{-1}), 90 (105.95 g plant^{-1}), and 72 days (92.18 g plant^{-1}), intermediate with the interval of 45 days (74.80 g plant^{-1}) and lower with the interval of 30 days (30.03 g plant^{-1}) (Table 2). The dry matter weight of branches was higher with the interval of 90 days (233.16 g plant^{-1}), with a lower value for the interval of 30 days (25.55 g plant^{-1}). The same was verified for dry matter weight of shoots, with highest production for the interval of 90 days (339.11 g plant^{-1}) and lowest production for the interval of 30 days (52.58 g plant^{-1}).

The daily growth rate of fresh and dry matter weights of leaves, branches, and shoots of peppermint, for the transplantation performed in winter, showed significant differences between the harvest intervals (Table 2). For fresh and dry matter weights of leaves and fresh matter weight of shoots, the highest rates were verified with the intervals of 60 and 90 days. The fresh matter weight of branches was higher with the intervals of 60, 72, and 90 days and the daily growth rates of dry matter weights of branches and shoots were higher with the interval of 90 days.

Table 1. Accumulated fresh and dry matter weights and daily growth rates (g plant^{-1}) of leaves, branches, and shoots of *Mentha x piperita* L. in five harvest intervals (30, 45, 60, 72, and 90 days) with transplantation performed in summer.

Harvest interval (days)	Accumulated fresh matter weight (g plant^{-1})			Daily growth rate of fresh matter weight (g plant^{-1})		
	Leaves	Branches	Shoots	Leaves	Branches	Shoots
30	438.49 a	503.48 c	941.98 c	1.1046 a	1.1353 d	2.2399 d
45	521.28 a	808.22 b	1329.50 b	1.2792 a	1.8511 c	3.1304 c
60	488.71 a	1053.33 a	1542.04 a	1.3010 a	2.4885 b	3.7894 b
72	547.76 a	1190.86 a	1738.62 a	1.4984 a	3.0962 a	4.5946 a
90	536.36 a	1338.82 a	1875.18 a	1.3884 a	3.5512 a	4.9396 a
CV%	16.08	18.85	16.65	12.84	18.37	15.30
Harvest interval (days)	Accumulated dry matter weight (g plant^{-1})			Daily growth rate of dry matter weight (g plant^{-1})		
	Leaves	Branches	Shoots	Leaves	Branches	Shoots
30	50.89 c	36.36 e	87.25 d	0.1202 b	0.0779 e	0.1980 d
45	69.73 b	76.17 d	145.91 c	0.1507 b	0.1615 d	0.3122 c
60	75.09 b	122.88 c	197.97 b	0.1835 a	0.2727 c	0.4562 b
72	90.80 a	154.27 b	245.08 a	0.2253 a	0.3590 b	0.5843 a
90	90.24 a	188.39 a	278.64 a	0.2073 a	0.4426 a	0.6499 a
CV%	16.00	15.00	14.00	12.10	16.29	13.42

Means not followed by the same letter in the column differ by the Scott-Knott criterion at 5% probability level.

Table 2. Accumulated fresh and dry matter weights and daily growth rates (g plant^{-1}) of leaves, branches, and shoots of *Mentha x piperita* L. in five harvest intervals (30, 45, 60, 72, and 90 days) with transplantation performed in winter.

Harvest interval (days)	Accumulated fresh matter weight (g plant^{-1})			Daily growth rate of fresh matter weight (g plant^{-1})		
	Leaves	Branches	Shoots	Leaves	Branches	Shoots
30	281.94 c	355.49 c	637.43 d	0.9220 c	1.1922 c	2.1142 d
45	517.28 b	929.30 b	1446.58 c	1.7908 b	3.2537 b	5.0445 c
60	660.54 a	1478.63 a	2139.17 a	2.3212 a	5.2749 a	7.5961 a
72	528.59 b	1265.60 a	1794.20 b	1.7905 b	4.4977 a	6.2882 b
90	630.40 a	1438.11 a	2068.52 a	2.1199 a	4.8967 a	7.0166 a
CV%	9.25	11.69	10.31	8.55	10.28	9.14
Harvest interval (days)	Accumulated dry matter weight (g plant^{-1})			Daily growth rate of dry matter weight (g plant^{-1})		
	Leaves	Branches	Shoots	Leaves	Branches	Shoots
30	30.03 c	22.55 d	52.58 d	0.1005 d	0.0767 d	0.1771 d
45	74.80 b	96.20 c	171.00 c	0.2704 c	0.3536 c	0.6239 c
60	107.14 a	182.04 b	289.19 b	0.3830 a	0.6581 b	1.0411 b
72	92.18 a	186.69 b	278.88 b	0.3263 b	0.6857 b	1.0120 b
90	105.95 a	233.16 a	339.11 a	0.3813 a	0.8373 a	1.2186 a
CV%	13.42	18.89	15.89	12.52	16.98	14.33

Means not followed by the same letter in the column differ by the Scott-Knott criterion at 5% probability level.

The longest harvest intervals led to better results, being more suitable for peppermint production, especially in the transplantation performed in winter, where the highest yields were verified. This result may be due to the longer regrowth period in the longer intervals, allowing the plant to have more time for recovery, production and accumulation of assimilates, without depleting metabolic reserves and losing vigor, while plants with greater frequency of cuts may become weaker and less productive (Marco et al., 2006; May et al., 2010a; Ibrahim et al., 2012). In contrast, Kumar et al. (2004), evaluating sweet wormwood (*Artemisia annua*) plants in multiple harvests found that the average yields of leaves are higher when three or more successive harvests are carried out, compared to one or two harvests. According to the authors, intermittent harvests regenerate the crop, with the production of new branches and leaves, allowing the permanence of young leaves in the plant and avoiding losses resulting from the senescence process. Considering the results of the present study, this statement leads to the assumption that intermediate harvest intervals would be more adequate, making it possible to combine qualitative and quantitative aspects, that is, younger and more productive plants.

As there was no significant difference in fresh and dry matter weights of leaves between the intervals of 60 and 90 days, for winter transplantation, the interval of 60 days should be used, because the plants were younger, with a better visual aspect (Figure1A), opposite to that observed at 90 days, when the plants were in the process of senescence (Figure 1B), since the natural cycle of peppermint is about 90 days (Pereira & Santos, 2013). This loss of visual quality of plants in longer harvest intervals was also verified by Chagas et al. (2011) in plants of *M. arvensis* L. In addition, at shorter intervals, the biomass of plants at harvest is lower, which facilitates management and reduces operating costs (May et al., 2010a). Thus, for summer transplantation, one can use the 45-day interval, which has a good visual aspect, maintaining good quality of the material throughout the cycle, besides promoting good production of accumulated fresh matter weight of leaves, as observed in the statistical analyses, showing no significant difference in comparison to the longer intervals (Figure 1C).

In a study conducted with *M. x piperita* L., Kassahun et al. (2011) verified the influence of plant age (60, 90, 120, 150, and 180 days) at the time of harvest on biomass production. In the first harvest, the authors verified the production of leaf fresh matter at 120 days, with subsequent decrease over the days. In the second harvest, the highest leaf fresh matter was verified at 180 days. The authors assume that these results are related to the phenological stages of plants. These results are similar to those obtained in the present study. However, Kassahun et al. (2011) did not verify production in successive harvests, only in single harvests.

Figure 1. A) Peppermint branch harvested at 60-day interval for transplantation performed in winter. B) Peppermint branch harvested at 90-day interval for transplantation performed in winter, with presence of senescent leaves. C) Peppermint branches harvested at 45-day interval for transplantation performed in summer.

A similar result was also verified in a study conducted with other species of medicinal and aromatic condiment plants, such as *Cymbopogon flexuosus* (lemongrass), in which May et al. (2008) studied harvest intervals (40, 60, 80, and 100 days) and found higher dry matter accumulation in the longest interval. However, the opposite was verified for the species *C. citratus*, which obtained the highest dry matter accumulation with the interval of 40 days.

For other species of the genus *Mentha*, different results were found from those observed in the present study. Evaluating the biomass production of *M. citrata* as a function of harvest intervals (40, 60, and 80 days), May et al. (2010b) verified higher accumulated biomass production at the end of the cycle in the shortest harvest interval. Chagas et al. (2011) evaluated the age of *M. arvensis* L. plants at the time of the first harvest (80, 100, and 120 days after transplantation) and its age at the second harvest (60, 75, and 90 days after the first harvest) and observed higher leaf dry matter accumulation 100 days after transplantation, i.e., in the intermediate interval, and from 60 to 75 days after the first harvest, shorter intervals.

The results of this study show that plants harvested at 30-day intervals are more productive when transplanted in summer, which occurs due to the more favorable climatic conditions for the initial establishment of the crop, such as higher temperature and radiation, allowing faster initial growth (Figure 2). The optimum temperature for peppermint growth is about 25 °C, being tolerant to great temperature variation (Pereira & Santos, 2013). As no significant differences in the fresh matter weight of leaves were observed between the intervals, in this period of transplantation, it can be concluded that plants with better initial establishment have more reserves and greater capacity to withstand successive harvests, with no damage to their yield. This result is corroborated by a study conducted with *M. arvensis* L., in India, in which Brar et al. (2014) evaluated the effect of transplanting dates (January 1, January 15, February 1, and February 15) on the growth and production of peppermint and verified that delays in the date of transplantation, for periods of higher soil temperature, reduce the time for emergence and result in higher dry matter production of peppermint.

Plants harvested at the other harvest intervals had higher accumulated production when transplanted in winter, which demonstrates good adaptation, even in periods of less favorable climatic conditions. The lower initial yield of the plants in this transplanting season was overcome throughout the cycle, resulting in higher accumulated yield at the end of the period, which occurs due to the longer time of recovery and adaptation before the next harvest, enabling their growth and production (May et al., 2010a).

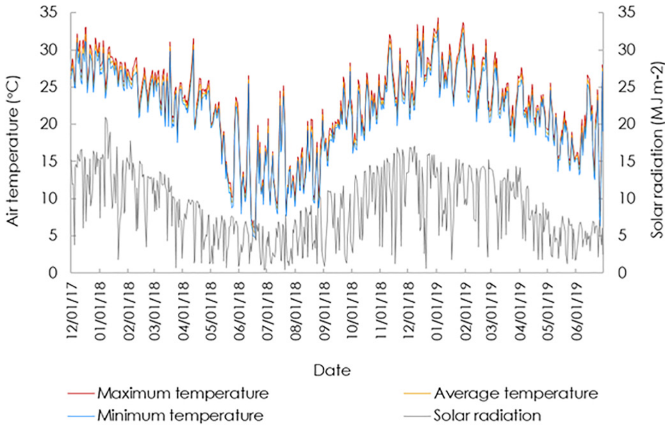

Figure 2. Average air temperature (°C) and solar radiation (MJ m^{-2}) inside the greenhouse from December 2017 to June 2019.

In studies conducted with mint species, similar results were observed regarding the influence of the transplanting season. Brar et al. (2015) evaluated four transplanting dates (January 1, January 15, January 30, and February 15) and three harvest dates (120, 135, and 150 days after transplantation) of *M. arvensis*, in India. The later transplanting season (February 15) and harvest at the longest interval (150 days after transplantation) favored the biomass production of mint. Desai et al. (2019), evaluating *M. arvensis* L. plants in transplantations performed on July 5, July 20, and August 5, corresponding to the summer in the region, found that the transplantation on July 5 favored the accumulated production of fresh and dry matter (g $plant^{-1}$). The authors attribute the results to the favorable climatic conditions during the growth period, such as ideal temperature and humidity. Akhtar et al. (2009), in a study conducted with *M. x piperita*, in three seasons in Bangladesh, in winter, summer, and monsoon season (rainy season), found higher total production of leaves (t ha^{-1}) in the monsoon season, compared to winter and summer. This report corroborates the results of the present study and demonstrates that it is necessary to consider the climatic conditions in crop management.

The influence of harvesting period on the yield of *Mentha* plants was verified by Salim et al. (2014), who observed higher values in autumn (1531.42 to 1887.08 g m^{-2}). In summer, the production was intermediate (726.75 to 835.25 g m^{-2}) and in winter it was lower (269.65 to 315.24 g m^{-2}). Evaluating the biomass production of *M. x piperita* L. in two harvest periods, July and October, in Iran, Machiani et al. (2018) verified higher production in the harvest carried out in July, period of higher temperatures and lower rainfall. Thus, the authors verified the influence of climatic conditions on the harvest period.

In this study, the influence of the interval between harvests on the production of phytomass of peppermint leaves was confirmed, which should be considered in the management and scheduling of production in the different periods of the year, in order to maximize crop production.

Conclusions

Harvests at 60-day intervals for transplantation performed in winter are more appropriate for the production of fresh and dry matter of peppermint leaves. In transplantation performed in summer, one can opt for the 45-day interval, which promoted the highest production of fresh and dry matter, associated with the better visual aspect of the plants.

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