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CU-CHLOROPHYLLIN AND IRRIGATION INTERVALS IMPACTS ON GROWTH AND PRODUCTIVITY OF *MENTHA VIRIDIS* PLANT UNDER SOUTH SINAI CONDITIONS

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This study was conducted on a private farm in the Tour Sinai region of South Sinai Governorate during the 2022 and 2023 growing seasons. The research aimed to explore how different concentrations of copper chlorophyllin formula (Cu-Chl) (0, 0.5, and 1 g L^{-1}) affect the growth, productivity, and physiological traits of Spearmint (*Mentha viridis*) plant under three different irrigation intervals (every 2, 4, and 6 days).The findings revealed that extending the irrigation interval to 6 days, compared to watering every 2 days, significantly reduced plant growth parameters, including herb fresh weight per square meter, herb fresh yield per feddan, herb dry weight per square meter, herb dry yield per feddan, and volatile oil yield. But total chlorophyll, copper content, and proline content as well as the Water Use Efficiency (WUE) of the yield were increased under this treatment. However, the application of Cu-Chl notably improved all these traits compared to plants that did not receive Cu-Chl. The most effective treatment in this study was foliar spraying of plants with Cu-Chl at 1 g L^{-1} combined with irrigation every 4 days. The study concluded that using Cu-Chl can overcome the negative effects of water deficit on the growth, yield, and physiological traits of Spearmint plant, as well as improve the Water Use Efficiency.

Keywords: *Mentha viridis*, copper chlorophyllin, irrigation intervals, volatile oil

INTRODUCTION

Aromatic and medicinal plants have gained significant attention in various industries, including natural cosmetics, food production, fragrances, and pharmaceuticals (Olfa et al., 2009). While the production of secondary metabolites in these plants is primarily determined by their genetic makeup, environmental factors also play a crucial role in their biosynthesis (Yazdani et al., 2002). This means that growth parameters, essential oil yield, and composition are influenced by both biotic and abiotic environmental conditions (Aziz et al., 2008 and Clark and Menary, 2008). Among these, abiotic stressors such as salinity and drought have the most profound impact on medicinal plants (Heidari et al., 2008).

Spearmint (*Mentha viridis* L.) is one of the most important aromatic plants, with a growing global demand for its essential oils in recent years. In Egypt, Spearmint has been cultivated for centuries, making it a significant herb in the region. In 2019, over 2,622 feddans were planted with mint, producing approximately 6,000 tons of herbs. That year, around 1,250 tons of mint were exported, generating $1.25 million in revenue (Ministry of Agriculture report - export sector, 2018). Spearmint is primarily grown for its leaves and essential oil, which are widely used in the food processing, confectionery, and cosmetic industries (Scherer et al., 2013 and Igoumenidis et al., 2016). Additionally, Spearmint is valued for its antioxidant properties and its antibacterial, antifungal, and insect-repelling qualities (Charles, 2013), largely due to the presence of limonene and carvone.

Drought is one of the most challenging environmental conditions that plants face, significantly limiting crop yields and influencing the distribution of plant species within ecological niches. For medicinal plants, drought is the most critical abiotic stressor (Heidari et al., 2008). Studies have shown that Spearmint is particularly sensitive to water stress, requiring consistent and adequate irrigation for optimal biomass production (Okwany et al., 2009).

Given the current global climate change crisis and its adverse effects on agriculture, there is a growing focus on enhancing the quantity and quality of Egyptian cultivars of aromatic and medicinal plants. In this context, improving Spearmint productivity is crucial, and further research is needed to boost this plant's potential for export markets.

Copper chlorophyllin (Cu-Chl) is a semi-synthetic derivative formed through the saponification of natural chlorophyll in alkaline conditions, such as with methanolic sodium hydroxide. This process results in the opening of the isocyclic ring and the removal of the phytol group. When the magnesium atom in chlorophyll is replaced with a copper atom in an acid solution, Cu-Chl exhibits several technological advantages over natural chlorophyll. These include greater hydrophilicity, enhanced tinctorial power, and increased stability against acid and light (Tumolo and Lanfer-Marquez, 2012).

In 2019, El-Tayeb developed an innovative technology utilizing a copper chlorophyllin formula designed to significantly enhance plant growth and improve overall plant health. This breakthrough plays a crucial role in helping plants resist various stress factors, including insect attacks and environmental changes such as drought and extreme temperatures. By strengthening the plant's natural defenses, this technology not only promotes healthier and more robust plants but also addresses critical challenges in agriculture, particularly in regions facing harsh environmental conditions. El-Tayeb’s invention represents a major advancement in agricultural practices, offering a sustainable solution to improve crop resilience and productivity, which is increasingly vital in the face of global climate change and the growing demand for food security (El-Tayeb, 2019).

The other studies following the revolving this novel technology have shown that Cu-Chl enhances antioxidant defense, osmotic regulation, photosynthesis, and root development in in tomatoes plants experiencing drought stress (Zhang et al., 2019). Additionally, the application of Cu-Chl has been found to significantly improve plant growth and yield in drought conditions (Merghany et al., 2019).

Due to the eco-geographic isolation of the Tour Sinai region, implementing "Good Agricultural Practices" (GAP), including the use of diverse irrigation techniques and natural growth stimulants, is essential for sustaining agricultural production in the area. Mints are perennial plants, and their herbs are harvested multiple times a year, making proper nutrition critical for achieving optimal yields. However, a review of existing literature on *Mentha viridis* in the Tour Sinai region revealed a gap in research, with no studies found on its response to different irrigation intervals or the application of copper chlorophyllin.

Therefore, this study aimed to determine the optimal irrigation intervals and Cu-chlorophyllin concentrations to enhance herb yield, essential oil yield, and composition under the unique conditions of the Tour Sinai region. Addressing these factors is crucial for improving agricultural productivity and ensuring sustainable cultivation practices in this isolated area.

MATERIALS AND METHODS

This study was conducted over two consecutive seasons, 2022 and 2023, at a private farm located in the Tour Sinai region (28°17′56″ N, 33°37′45″ E) in South Sinai Governorate. The soil and irrigation water analyses for the experimental site are detailed in Tables 1 and 2 as recorded by Hashem et al. (2022). Before planting in each season, 20 m³ feddan^{-1} of organic compost manure was incorporated during soil preparation. The analysis of the organic manure is provided in Table (3). Additionally, meteorological data for the El-Tour area, averaged over the past 10 years, are presented in Table (4).

Table (1). Physical and chemical properties of the experimental soil site.

Soil depth (cm)	Soluble anions (me L^{-1})			pH of soil paste	EC (ds m^{-1})	Soluble cations (me L^{-1})			
	HCO_3^-	SO_4^{2-}	Cl^-			Ca^{2+}	Mg^{2+}	Na^+	K^+
0-30	2.10	17.65	23.64	7.24	4.36	8.23	12.56	20.20	2.40

Clay (%)	Slit (%)	Sand (%)	Texture
11.35	24.15	64.50	Sandy loam

pH: Acidity, E.C.: Electrical conductivity, me L^{-1}: milli equivalent per liter

Table (2). Chemical analysis of the irrigation water.

pH	EC (dsm^{-1})	Soluble anions (me L^{-1})			Soluble cations (me L^{-1})			
		HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
7.88	0.77	1.44	1.89	4.37	2.60	3.86	0.78	0.46

pH: Acidity, E.C.: Electrical conductivity, dSm^{-1}: decseime per meter

Table (3). Analysis of organic manure used.

Moisture (%)	Organic matter (%)	Total C%	C/N ratio	Total N%	Total P%	Total K%
11.00	21.36	13.86	10.10	1.38	0.86	1.40

Table (4). Meteorological data of El-Tour area as average of 10 years ago.

Month	Prc. (mm m^{-1})	Temp. mean (C°)	Tmp. Max. (C°)	Tmp. min. (C°)	Rel. humidity %	Sunshine %	Wind m^2 (m s^{-1})	ETo (mm m^{-1})	ETo (mm d^{-1})
Jan.	10	14.8	18.7	10.8	42.0	79.6	3.6	95	3.1
Feb.	7	16.5	21.1	11.9	38.8	81.5	4.1	111	4.0
March	45	19.5	24.5	14.6	37.2	78.6	4.6	164	5.3
April	0	23.3	28.4	18.2	32.1	78.9	5.3	219	7.3
May	0	28.0	33.5	22.5	27.1	83.0	5.4	273	8.8
June	0	30.4	35.9	25.0	26.8	90.7	6.2	311	10.4
July	0	32.1	37.1	27.0	30.5	91.7	6.5	326	10.5
Aug.	0	32.2	37.3	27.2	31.0	91.3	5.6	299	9.6
Sept.	0	31.5	37.0	26.1	37.9	89.0	5.1	240	8.0
Oct.	0	28.1	33.6	22.6	39.0	88.3	4.0	185	6.0
Nov.	0	21.5	25.7	17.4	41.1	84.8	3.9	122	4.1
Dec.	0	18.9	23.6	14.2	93.2	78.3	3.1	99	3.2
Total	62							2444	

ET0 = reference evapotranspiration

Spearmint rhizomes, each 20 cm in length, were planted in the field on March 1st in both seasons, using a drip irrigation system with a flow rate of 4 L h^{-1}. The rows were spaced 75 cm apart, with 30 cm between plants within each row. The experiment was arranged in a split-plot design with three replicates. The main plots were assigned to three different irrigation intervals (2, 4, and 6 days), while the sub-plots included varying concentrations of Cu-chlorophyllin (Cu-Chl) at 0, 0.5, and 1 g L^{-1}. The Cu-Chl was provided by Prof. Tarek A. El-Tayeb, the inventor of chlorophyllin use as a foliar fertilizer and plant growth enhancer.

To ensure seedling survival, irrigation was maintained every two days at the beginning of the planting process. The treatments for irrigation intervals of 2, 4, and 6 days began 15 days after planting. The irrigation water was delivered through a trickle irrigation system with a 95% application efficiency. The number of irrigation events and the water quantities used are detailed in Table (5).

Table (5). Number of irrigations and water quantities (m^3 $feddan^{-1}$) during the two seasons (2022 and 2023).

Character / Treatment	Number of irrigations		Water quantities (m^3 $feddan^{-1}$)		Total number of irrigation	Total water quantities (m^3 $feddan^{-1}$)
	1st cut	2nd cut	1st cut	2nd cut		
			First season			
2 days	69	61	4416	3904	130	8320
4 days	46	33	2944	2112	79	5056
6 days	37	25	2368	1600	62	3968
			Second season			
2 days	69	61	4416	3904	130	8320
4 days	46	34	2944	2176	80	5120
6 days	34	26	2368	1664	63	4032

Cu-Chl treatments were evenly applied to the plants using a handheld sprayer until runoff occurred. The plants were treated with Cu-Chl at 3, 6, and 9 weeks after sowing, and the treatments were repeated at the same intervals 3, 6, and 9 weeks after the first harvest. Additionally, the recommended chemical fertilizers were applied according to the guidelines provided by Swaefy et al. (2007).

Two harvests were conducted per season, on July 10th and November 5th. The plants were harvested by cutting the herbs 10 cm above the soil surface to assess the following parameters:

1. Yield Parameters

- Herb fresh weight per square meter (g)
- Herb fresh yield per feddan (kg)
- Herb dry weight per square meter (g)
- Herb dry yield per feddan (kg)

2. Volatile Oil Parameters

- The volatile oil percentage was determined from air-dried herbs using hydrodistillation for 3 hours with a Clevenger-type apparatus (British Pharmacopoeia, 1963). The volatile oil yield was measured in milliliters per square meter (ml m^{-2}).
  This can be calculated as follows: Oil % * herb dry weight (g m^{-2}).
- Volatile oil yield per feddan (L): This was calculated using the formula: Volatile oil yield per square meter × 4000 m^2.
- Volatile oil composition: Gas Chromatography-Mass Spectrometry (GC-MS) analyses of the extracted volatile oil from the second season were conducted using a GC-MS instrument at the Laboratory of Medicinal and Aromatic Plants, National Research Center, Egypt.

3. Chemical Constituents

- Total chlorophyll (SPAD) in leaves: The total chlorophyll content in plant leaves was measured in SPAD units using a Minolta chlorophyll meter (model SPAD 502). Chlorophyll measurements were taken from the most recently fully expanded leaf, with 10 readings averaged per experimental unit, following the method described by Markwell et al. (1995).

- Cu Content in dry herb (mg kg^{-1}): The copper content in the dry herb was measured in milligrams per kilogram (mg kg^{-1}) using an Atomic Absorption Spectrophotometry (AAS) device (Varian Spectra AA 220 FS) according to the method of Ostrowska et al., (1991). The plant material was ground and ashed in a furnace (CZYLOK, FCF5SH) at 450˚C for six hours after being dried at 60˚C. The ash was then dissolved in 5 ml of 6 mol HCl, diluted with distilled water to a consistent volume, and analyzed to determine the copper content.
- Free proline content (ppm): Free proline in fresh herb was measured as ppm according to Chinard (1952). Fresh plant sample (0.5 g) in mortar + 10 ml salphosalysilic acid 3% add during grinding. Filter the sample and take 2 ml from filtrate in test tube + 2 ml of acid ninhydrin + 2 ml of glacial acetic acid. Put in boiling water bath for 1h then cooling. Add 4ml toluene then separate the upper layer (proline) and measured at 520nm. This can be calculated as follows:

$$X = (Y - 0.173) / 0.065$$

X =concentration (ppm), Y = absorbance.

4. Water Use Efficiency (WUE), kg m^{-3}

Crop Water Use Efficiency (WUE) was calculated by dividing the crop yield by the total amount of applied irrigation water, according to Talha and Aziz (1979).

Statistical analysis

The means of the treatments were compared using the Least Significant Difference (LSD) test at $P \leq 0.05$. All data were subjected to analysis of variance, and the statistical calculations were performed using Statistic software version 9 (Analytical Software, 2008).

RESULTS AND DISCUSSION

1. Yield Parameters

The data presented in Table (6) demonstrate that irrigation intervals had significant effects on herb fresh and dry yields per square meter and per feddan in both seasons. Specifically, irrigating plants every 4 days resulted in significantly higher herb fresh and dry yields compared to irrigation every 2 or 6 days in both cuts of the second season. However, in the second cut of the first season, the increase in herb fresh yield between the 2-day and 4-day irrigation intervals was not statistically significant. Similarly, there were no significant differences in herb dry yield between the 2-day and 4-day intervals compared to the 6-day interval in the first cut of the first season. These findings align with previous studies by Khorasaninejad et al. (2011) on mint, Bahreininejad et al. (2013) on *Thymus* sp., Abdel-Kader et al. (2014) on lemongrass, Farzad et al. (2016) on oregano and Hanafy et al. (2018) on rosemary.

The reduction in herb fresh and dry yields at longer irrigation intervals may be due to changes in canopy structure and reduced photosynthesis, or to decreased turgor pressure, which limits cell enlargement and increases leaf senescence (Shao et al., 2008 and Farooq et al., 2009). Leithy et al. (2006) also suggested that reduced plant growth is associated with a lower photosynthesis rate due to decreased stomatal conductance. Leaf area development is essential for photosynthesis and dry herb production (Jaleel et al., 2009) because a smaller leaf area reduces the ability to capture light, thereby lowering the photosynthesis rate (Khalid, 2006).

Additionally, reduced moisture availability in the rhizosphere and decreased nutrient absorption may also impact plant growth under limited irrigation (Singh et al., 1997). Under water deficit conditions, plants typically produce less biomass and allocate more to root growth to enhance water absorption (Albouchi et al., 2003).

The data in Table (6) also show that the application of Cu-chlorophyllin (Cu-Chl) had a significant positive impact on herb fresh weight per square meter, herb fresh yield per feddan, herb dry weight per square meter, and herb dry yield per feddan. These parameters improved as the concentration of Cu-Chl increased, with the highest values observed when plants were treated with 1 g L^{-1} of Cu-Chl compared to 0.5 g L^{-1} and the control treatments in both cuts of the two growing seasons. These results are consistent with those reported by Merghany et al. (2019) and Ramadan (2023) support the data from El-Tayeb's patent (2019). The addition of Cu-Chl to plants may enhance root growth, osmotic regulation, photosynthetic function, antioxidant defense capacity, and resistance to microbial attack, all of which contribute to improved plant growth and productivity (Tumolo and Lanfer-Marquez, 2012 and Zhang et al., 2019). Exogenous Cu-Chl treatment also increases the expression of genes associated with stress protection and various classes of ROS detoxifying genes. Moreover, under stress conditions, Cu-Chl reduces the restriction of leaf growth, indicating its potential to improve plant growth and yield (Islam et al., 2021).

The interaction between irrigation intervals and foliar spraying with Cu-Chl treatments had a significant impact on both the fresh and dry yield of Spearmint herb per square meter and per feddan across both cuts in the two seasons (Table 6). The highest yields were achieved with irrigation every 4 days in combination with foliar application of Cu-Chl at 1 g L^{-1}. In contrast, the lowest yields were observed with irrigation every 6 days and no Cu-Chl treatment.

Table (6). Effect of Irrigation Intervals, Cu-chlorophyllin and their interaction treatments on herb fresh and dry yield of *Mentha viridis* plant during two cuts in the two seasons (2022 and 2023).

Treatment \ Character		Herb fresh yield m^{-2} (g)		Herb fresh yield feddan^{-1} (kg)		Herb dry yield m^{-2} (g)		Herb dry yield feddan^{-1} (kg)	
		First season							
		1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
Every 2 days		906.3^{B}	1108.4^{A}	3625.1^{B}	4433.8^{A}	312.4^{A}	340.7^{A}	1249.6^{A}	1362.8^{A}
Every 4 days		1009.9^{A}	1119.9^{A}	4039.5^{A}	4479.6^{A}	334.4^{A}	327.4^{B}	1337.7^{A}	1309.7^{B}
Every 6 days		728.4^{C}	858.1^{B}	2913.5^{C}	3432.5^{B}	266.5^{B}	286.5^{C}	1066.0^{B}	1146.0^{C}
		Second season							
Every 2 days		592.7^{B}	833.5^{B}	2370.9^{B}	3334.0^{B}	144.9^{B}	172.2^{B}	579.6^{B}	688.8^{B}
Every 4 days		646.8^{A}	874.9^{A}	2587.4^{A}	3499.6^{A}	157.3^{A}	184.9^{A}	629.0^{A}	739.5^{A}
Every 6 days		553.6^{C}	733.6^{C}	2214.4^{C}	2934.4^{C}	125.8^{C}	158.3^{C}	503.4^{C}	633.2^{C}
		First season							
Control		625.7^{C}	762.7^{C}	2502.8^{C}	3050.8^{C}	224.8^{C}	240.1^{C}	899.3^{C}	960.6^{C}
Cu-chl at 0.5 g L^{-1}		947.4^{B}	1084.1^{B}	3789.8^{B}	4336.2^{B}	314.2^{B}	346.1^{B}	1257.0^{B}	1384.4^{B}
Cu-chl at 1 g L^{-1}		1071.4^{A}	1239.7^{A}	4285.6^{A}	4958.9^{A}	374.2^{A}	368.38^{A}	1497.0^{A}	1473.5^{A}
		Second season							
Control		420.3^{C}	645.4^{C}	1681.4^{C}	2581.5^{C}	103.6^{C}	145.2^{C}	414.2^{C}	580.6^{C}
Cu-chl at 0.5 g L^{-1}		637.3^{B}	847.5^{B}	2549.2^{B}	3389.9^{B}	151.4^{B}	177.4^{B}	605.5^{B}	709.6^{B}
Cu-chl at 1 g L^{-1}		735.5^{A}	949.1^{A}	2942.1^{A}	3796.6^{A}	173.1^{A}	192.8^{A}	692.3^{A}	771.2^{A}
		First season							
Every 2 days	**Control**	735.4^{f}	969.2^{e}	2941.7^{f}	3876.7^{e}	259.6^{d}	282.8^{e}	1038.4^{d}	1131.1^{e}
	Cu-chl at 0.5 g L^{-1}	951.5^{d}	1040.4^{d}	3806.1^{d}	4161.7^{d}	334.7^{bc}	358.5^{b}	1338.9^{bc}	1433.9^{b}
	Cu- chl at 1 g L^{-1}	1031.9^{c}	1315.8^{a}	4127.4^{c}	5263.0^{a}	342.9^{bc}	380.8^{a}	1371.4^{bc}	1523.3^{a}
Every 4 days	**Control**	631.5^{g}	751.5^{g}	2526.0^{g}	3006.0^{g}	254.9^{d}	252.7^{f}	1019.7^{d}	1010.8^{f}
	Cu-chl at 0.5 g L^{-1}	1134.4^{b}	1279.2^{b}	4537.6^{b}	5116.9^{b}	315.8^{bc}	352.5^{bc}	1263.2^{bc}	1410.1^{bc}
	Cu-chl at 1 g L^{-1}	1263.7^{a}	1329.0^{a}	5054.9^{a}	5316.0^{a}	432.5^{a}	377.0^{a}	1730.0^{a}	1508.1^{a}
Every 6 days	**Control**	510.2^{h}	567.4^{h}	2040.6^{h}	2269.7^{h}	159.9^{e}	184.9^{g}	639.7^{e}	739.7^{g}
	Cu-chl at 0.5 g L^{-1}	756.4^{f}	932.5^{f}	3025.7^{f}	3730.1^{f}	292.2^{cd}	327.3^{d}	1168.7^{cd}	1309.2^{d}
	Cu-chl at 1 g L^{-1}	918.6^{e}	1074.4^{c}	3674.3^{e}	4297.8^{c}	347.4^{b}	347.3^{c}	1389.6^{b}	1389.2^{c}
		Second season							
Every 2 days	**Control**	491.7^{e}	724.8^{f}	1967.0^{e}	2899.0^{f}	123.8^{f}	154.0^{e}	495.1^{f}	616.0^{e}
	Cu-chl at 0.5 g L^{-1}	596.8^{d}	843.5^{d}	2387.3^{d}	3374.1^{d}	145.2^{d}	169.9^{d}	580.7^{d}	679.4^{d}
	Cu-chl at 1 g L^{-1}	689.6^{bc}	932.2^{b}	2758.3^{bc}	3728.9^{b}	165.7^{b}	192.75^{b}	662.9^{b}	771.0^{b}
Every 4 days	**Control**	390.9^{f}	675.9^{g}	1563.8^{f}	2703.7^{g}	100.4^{g}	147.1^{f}	401.7^{g}	588.4^{f}
	Cu-chl at 0.5 g L^{-1}	706.7^{b}	896.7^{c}	2826.7^{b}	3586.7^{c}	170.6^{b}	197.1^{b}	682.5^{b}	788.4^{b}
	Cu-chl at 1 g L^{-1}	842.9^{a}	1052.1^{a}	3371.6^{a}	4208.3^{a}	200.7^{a}	210.4^{a}	802.8^{a}	841.7^{a}
Every 6 days	**Control**	378.3^{f}	535.5^{h}	1513.3^{f}	2141.8^{h}	86.5^{h}	134.4^{g}	345.9^{h}	537.5^{g}
	Cu-chl at 0.5 g L^{-1}	608.4^{d}	802.3^{e}	2433.6^{d}	3209.0^{e}	138.3^{e}	165.3^{d}	553.2^{e}	661.0^{d}
	Cu-chl at 1 g L^{-1}	674.1^{c}	863.1^{d}	2696.2^{c}	3452.5^{d}	152.8^{c}	175.2^{c}	611.1^{c}	701.0^{c}

Means having the same letter (s) within the same column are not significantly different according to LSD for all pairwise comparisons test at 5% level of probability.

2. Volatile Oil Production

The data in Table (7) show that irrigation intervals have a significant impact on volatile oil percentage, yield per square meter, and yield per feddan. The highest percentage of volatile oil was observed in plants irrigated every 6 days, compared to those irrigated every 2 or 4 days. However, in the first cut of the first season, there was no significant difference in volatile oil percentage between irrigation every 2 days and every 4 days. Similarly, in the second cut of the second season, no significant difference was found between irrigation intervals of 4 and 6 days. The highest volatile oil yield per square meter and per feddan was achieved with irrigation every 4 days, outperforming the yields from 2-day and 6-day irrigation intervals across both cuts in both seasons. Additionally, no significant difference in yield was noted between the 2-day and 4-day irrigation treatments during the first cut of the first season.

These findings align with previous research by Khorasaninejad et al. (2011) and Hanafy et al. (2018) on mint, Farzad et al. (2016) on oregano and Baher et al. (2002) on *Satureja hortensis*, all of which found that essential oil percentage increases under water deficit conditions.

The effect of irrigation intervals on essential oil percentage can be attributed to their influence on enzyme activity and the metabolism involved in essential oil production **(**Simon et al., 1992 and Khalid, 2006). Water stress may lead to an increase in essential oil content in many aromatic and medicinal plants due to the formation of more metabolites and the prevention of compound oxidation in stressed cells (Farahani et al., 2009). Additionally, Penka (1978) suggested that water deficit intensifies respiratory catabolic mechanisms that produce essential oils.

The data in Table (7) also indicate that foliar spraying with Cu-Chl treatments significantly affects volatile oil percentage and yield. The volatile oil yield increased progressively with higher Cu-Chl concentrations, with the highest values recorded in plants sprayed with Cu-Chl at 1 g L^{-1}, compared to other concentrations and the control treatment. This trend was consistent across both cuts in both growing seasons.

The substantial rise in volatile oil yield with Cu-Chl treatment is likely attributed to improvements in the plant's morphology and biochemical processes. These enhancements lead to more efficient oil production and increased stress tolerance, providing practical advantages for Spearmint cultivation and potentially for other essential oil crops. Manivasagaperumal et al. (2011) and Hasbullah and Taha (2023) also reported significant increases in essential oil yield in *Vigna radiata* and *Ocimum basilicum*, respectively, when treated with copper. This indicates that copper may be crucial in boosting essential oil production.

Moreover, the interaction between irrigation intervals and Cu-Chl concentrations showed significant effects on volatile oil percentage and yield per square meter and feddan. The highest volatile oil yield was observed in the treatment combining irrigation every 4 days with spraying Cu-Chl at 1 g L^{-1}, compared to all other interaction treatments. The lowest yields were recorded in the treatment with no Cu-Chl spraying and irrigation every 6 days in both seasons.

Table (7). Effect of Irrigation Intervals, Cu-chlorophyllin and their interaction treatments on volatile oil yield of *Mentha virids* plant during two cuts in the two seasons (2022 and 2023).

Treatment \ Character		Volatile oil (%)		Volatile oil yield m^{-3} (ml)		Volatile oil yield feddan^{-1} (L)	
		1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
				First season			
Every 2 days		3.48^{B}	3.33^{C}	11.05^{A}	11.28^{B}	44.18^{A}	45.11^{B}
Every 4 days		3.51^{B}	3.52^{B}	12.05^{A}	12.04^{A}	48.19^{A}	48.15^{A}
Every 6 days		3.66^{A}	3.72^{A}	9.91^{B}	10.96^{B}	39.64^{B}	43.86^{B}
				Second season			
Every 2 days		3.16^{C}	3.17^{C}	4.66^{B}	5.53^{B}	18.65^{B}	22.13^{B}
Every 4 days		3.34^{B}	3.40^{A}	5.42^{A}	6.41^{A}	21.69^{A}	25.63^{A}
Every 6 days		3.48^{A}	3.46^{A}	4.50^{C}	5.53^{B}	17.99^{C}	22.11^{B}
				First season			
Control		3.10^{C}	2.92^{C}	6.87^{C}	6.97^{C}	27.46^{C}	27.88^{C}
Cu-chl at 0.5 g L^{-1}		3.62^{B}	3.62^{B}	11.39^{B}	12.51^{B}	45.56^{B}	50.05^{B}
Cu-chl at 1 g L^{-1}		3.94^{A}	4.02^{A}	14.75^{A}	14.79^{A}	58.99^{A}	59.19^{A}
				Second season			
Control		2.83^{C}	2.84^{C}	2.91^{C}	4.10^{C}	11.68^{C}	16.42^{C}
Cu-chl at 0.5 g L^{-1}		3.36^{B}	3.46^{B}	5.09^{B}	6.14^{B}	20.35^{B}	24.57^{B}
Cu-chl at 1 g L^{-1}		3.80^{A}	3.74^{A}	6.58^{A}	7.22^{A}	26.31^{A}	28.89^{A}
				First season			
Every 2 days	**Control**	2.83^{e}	2.68^{g}	7.36^{d}	6.78^{d}	29.43^{d}	27.12^{d}
	Cu-chl at 0.5 g L^{-1}	3.68^{b}	3.44^{d}	12.32^{bc}	12.32^{b}	49.28^{bc}	49.28^{b}
	Cu-chl at 1 g L^{-1}	3.93^{a}	3.87^{bc}	13.46^{b}	14.73^{a}	53.84^{b}	58.94^{a}
Every 4 days	**Control**	3.06^{d}	2.93^{f}	7.80^{d}	8.29^{c}	31.22^{d}	33.18^{c}
	Cu-chl at 0.5 g L^{-1}	3.48^{c}	3.60^{d}	11.05^{c}	12.68^{b}	44.19^{c}	50.70^{b}
	Cu-chl at 1 g L^{-1}	4.00^{a}	4.02^{ab}	17.29^{a}	15.14^{a}	69.17^{a}	60.57^{a}
Every 6 days	**Control**	3.40^{c}	3.16^{e}	5.44^{e}	5.84^{e}	21.75^{e}	23.35^{e}
	Cu-chl at 0.5 g L^{-1}	3.70^{b}	3.83^{c}	10.80^{c}	12.54^{b}	43.21^{c}	50.16^{b}
	Cu-chl at 1 g L^{-1}	3.88^{a}	4.18^{a}	13.49^{b}	14.51^{a}	53.96^{b}	58.06^{a}
				Second season			
Every 2 days	**Control**	2.67^{f}	2.55^{f}	3.31^{d}	3.93^{e}	13.25^{d}	15.71^{e}
	Cu-chl at 0.5 g L^{-1}	3.16^{d}	3.35^{c}	4.59^{c}	5.70^{d}	18.34^{c}	22.79^{d}
	Cu-chl at 1 g L^{-1}	3.67^{b}	3.62^{b}	6.09^{b}	6.97^{b}	24.37^{b}	27.90^{b}
Every 4 days	**Control**	2.84^{ef}	2.85^{e}	2.85^{e}	4.19^{e}	11.42^{e}	16.78^{e}
	Cu-chl at 0.5 g L^{-1}	3.45^{c}	3.52^{b}	5.89^{b}	6.94^{b}	23.55^{b}	27.74^{b}
	Cu-chl at 1 g L^{-1}	3.74^{b}	3.84^{a}	7.52^{a}	8.09^{a}	30.10^{a}	32.38^{a}
Every 6 days	**Control**	3.99^{df}	3.12^{d}	2.59^{e}	4.19^{e}	10.35^{e}	16.76^{e}
	Cu-chl at 0.5 g L^{-1}	3.46^{c}	3.50^{b}	4.79^{c}	5.79^{d}	19.16^{c}	23.17^{d}
	Cu-chl at 1 g L^{-1}	3.99^{a}	3.77^{a}	6.11^{b}	6.60^{c}	24.46^{b}	26.40^{c}

Means having the same letter (s) within the same column are not significantly different according to LSD for all pairwise comparisons test at 5% level of probability.

3. Volatile Oil Composition

Twenty-four compounds, representing more than 98% of the total volatile content in most Spearmint samples, were detected and identified (Table 8). The composition of the volatile oil varies depending on the irrigation intervals and/or Cu-Chl applications. The main compounds found across all treatments were Carvone (33.3-36.42%), 1,8-Cineole (17.66-19.12%), Caryophyllene (5.08-6.10%), α-Pinene (5.25-6.10%), D-Limonene (2.13-3.39%), Sabinene (3.16-5.45%), α-Bourbonene (3.04-3.84%), and 2-Cyclohexen-1-ol (3.05-3.88%). The content of other oil constituents varied without a consistent pattern.

Table (8). Effect of irrigation intervals, Cu-chlorophyllin and their interaction treatments on volatile oil components of *Mentha viridis* plant.

Compound (%)		RT	Treatments			
			T1	T2	T3	T4
1	α-Pinene	5.99	5.47	6.10	5.25	5.81
2	Sabinene	6.71	4.96	5.45	4.18	3.16
3	α-Myrcene	7.05	2.55	2.81	2.41	2.61
4	α-Terpinene	7.65	0.61	0.66	0.76	0.85
5	1,8-Cineole	7.92	19.12	17.66	17.70	18.45
6	D-Limonene	8.02	2.74	3.18	2.13	3.39
7	Terpinene	8.56	0.97	0.97	1.24	1.39
8	2-Cyclohexen-1-ol	9.92	3.05	3.88	3.46	3.39
9	Cyclohexanone	10.51	1.18	-	0.47	-
10	Endo-borneol	10.90	1.29	1.30	1.13	1.20
11	Dihydrocarvone	11.40	1.11	1.44	1.15	1.08
12	Trans-carveol	12.21	0.67	1.34	0.46	0.82
13	Carvone	12.51	36.42	33.31	36.18	34.79
14	Ethanone	14.03	0.42	0.47	0.45	0.52
15	2,4-Cycloheptadien-1-one	14.60	0.50	-	-	0.47
16	Cis-jasmone	15.87	0.41	0.48	-	0.42
17	α-Bourbonene	16.22	3.04	3.68	3.84	3.71
18	Elemene	16.31	1.74	2.63	2.75	3.08
19	Caryophyllene	16.95	5.08	5.98	6.10	5.57
20	Germacrene-D	17.13	4.78	5.93	6.19	4.99
21	1S, cis-calamenene	19.25	-	-	0.51	0.47
22	Spathulenol	19.94	1.02	0.76	1.14	1.09
23	Caryophyllene oxide	20.05	1.16	1.23	1.47	1.31
24	α-Cadinol	21.39	0.48	0.53	0.56	0.61
	Total		98.77	99.79	99.53	99.18

*T_1= irrigation intervals every 2 days + Cu-chl at 2 g L^{-1}, T_2 = irrigation intervals every 2 days + Cu-chl at 0 g L^{-1}, T_3= irrigation intervals every 4 days + Cu-chl at 2 g L^{-1}, T_4 = irrigation intervals every 6 days + Cu-chl at 0 g L^{-1}.

The interaction between irrigation intervals and Cu-Chl applications had varying effects on the concentrations of Carvone and 1,8-Cineole, the major compounds in Spearmint oil in this study. The highest concentrations of Carvone (36.42%) and 1,8-Cineole (19.12%) were achieved with irrigation every 2 days combined with Cu-Chl at 1 g L^{-1}, followed by irrigation every 4 days with Cu-Chl at 1 g L^{-1}. The lowest concentrations were recorded with irrigation every 2 days combined with no Cu-Chl application, resulting in Carvone at 33.31% and 1,8-Cineole at 17.66%.

4. Total Chlorophyll and Copper Contents

In most cases across both seasons, irrigation intervals had an insignificant effect on total chlorophyll content. However, Table (9) shows that irrigation every 2 days significantly decreased total chlorophyll content in the first cut of the first season and the second cut of the second season compared to other irrigation treatments. Extending the irrigation interval to 6 days resulted in a slight, though not significant, increase in total chlorophyll content in both cuts of both seasons compared to other treatments. Generally, longer irrigation intervals tend to increase total chlorophyll content. These findings are consistent with those of El-Leithy et al. (2018) on rosemary and Shokhmgar et al. (2014) on fenugreek (*Trigonella foenum-gracum*), which reported that reduced water usage led to a decrease in chlorophyll content. Yazdiani and Taheri (2014) also found that drought stress had a significant positive effect on total chlorophyll content in marigold (*Calendula officinalis*).

The decrease in chlorophyll content may be attributed to increased ethylene synthesis under drought stress. This stress boosts ethylene production, leading to lipid breakdown and a subsequent loss of cell membrane integrity. When ethylene directly contacts the chloroplast due to lipid breakdown, it activates the chlorophyllase (chlase) gene, which significantly damages chlorophyll (Matile et al., 1997 and Karimpour, 2019). Significant differences in total chlorophyll content were observed in Spearmint plants treated with various concentrations of Cu-Chl (Table 9). Total chlorophyll content increased as Cu-Chl concentrations increased, reaching a maximum at the highest concentration (1 g L^{-1}), with increases of 23.53% and 22.67%, and 20.42% and 17.89% in the first and second cuts of both seasons, respectively, compared to the control treatment. These results align with those reported by El-Tayeb (2019), Zhang et al. (2019) and Ramadan (2023), who found that foliar application of Cu-Chl under drought stress conditions increased chlorophyll a, chlorophyll b, and carotenoid concentrations in spinach and tomato plants. Merghany et al. (2019) also observed increased chlorophyll content in onions with Cu-Chl application. The improvement in photosynthetic pigments from Cu-Chl application may be due to synthetic pigments' ability to protect chlorophyll from UV-B radiation (Schmidt and Zhang, 2001) and safeguard plants from ROS-induced damage to the photosynthetic apparatus (Tumolo and Lanfer-Marquez, 2012).

Table (9). Effect of irrigation intervals, Cu-chlorophyllin and their interaction treatments on total chlorophyll and Cu contents of *Mentha virids* plant during two cuts in the two seasons (2022 and 2023).

Treatment \ Character		Total chlorophyll content (SPAD)		Cu (mg kg^{-1})	
		1st cut	2nd cut	1st cut	2nd cut
First season					
Every 2 days		35.24^{B}	40.12^{A}	49.36^{A}	50.12^{A}
Every 4 days		39.00^{A}	39.81^{A}	36.06^{B}	40.14^{B}
Every 6 days		39.75^{A}	40.16^{A}	29.56^{C}	30.70^{C}
Second season					
Every 2 days		35.22^{A}	38.81^{A}	50.89^{A}	50.51^{A}
Every 4 days		35.14^{A}	37.35^{B}	44.22^{B}	42.18^{B}
Every 6 days		35.47^{A}	37.04^{B}	31.84^{C}	31.27^{C}
First season					
Control		32.10^{C}	33.94^{C}	22.49^{C}	24.85^{C}
Cu-chl at 0.5 g L^{-1}		39.92^{B}	42.25^{B}	37.73^{B}	39.66^{B}
Cu-chl at 1 g L^{-1}		41.98^{A}	43.89^{A}	54.78^{A}	56.45^{A}
Second season					
Control		31.18^{C}	33.68^{C}	27.21^{C}	26.03^{C}
Cu-chl at 0.5 g L^{-1}		35.48^{B}	38.51^{B}	41.60^{B}	40.63^{B}
Cu-chl at 1 g L^{-1}		39.18^{A}	41.02^{A}	58.13^{A}	57.29^{A}
First season					
Every 2 days	**Control**	30.90^{f}	34.07^{e}	28.60^{e}	31.21^{f}
	Cu-chl at 0.5 g L^{-1}	36.27^{d}	42.53^{cd}	49.33^{b}	49.90^{c}
	Cu-chl at 1 g L^{-1}	38.55^{c}	43.77^{ab}	70.15^{a}	69.26^{a}
Every 4 days	**Control**	32.10^{ef}	33.55^{e}	22.01^{f}	25.69^{h}
	Cu-chl at 0.5 g L^{-1}	42.32^{b}	42.55^{bcd}	35.65^{d}	40.62^{e}
	Cu-chl at 1 g L^{-1}	42.60^{b}	43.32^{abc}	50.53^{b}	54.11^{b}
Every 6 days	**Control**	33.30^{e}	34.22^{e}	16.85^{g}	17.64^{i}
	Cu-chl at 0.5 g L^{-1}	41.17^{b}	41.67^{d}	28.19^{e}	28.47^{g}
	Cu-chl at 1 g L^{-1}	44.78^{a}	44.60^{a}	43.65^{c}	45.99^{d}
Second season					
Every 2 days	**Control**	31.90^{e}	34.73^{d}	33.82^{f}	32.52^{f}
	Cu-chl at 0.5 g L^{-1}	35.33^{d}	39.80^{b}	50.48^{c}	50.19^{c}
	Cu-chl at 1 g L^{-1}	38.43^{b}	41.90^{a}	68.36^{a}	68.81^{a}
Every 4 days	**Control**	31.03^{ef}	32.30^{e}	29.37^{g}	27.53^{g}
	Cu-chl at 0.5 g L^{-1}	36.27^{c}	38.10^{c}	45.60^{e}	43.11^{e}
	Cu-chl at 1 g L^{-1}	38.13^{b}	41.67^{a}	57.69^{b}	55.90^{b}
Every 6 days	**Control**	30.60^{f}	34.00^{d}	18.44^{h}	18.04^{h}
	Cu-chl at 0.5 g L^{-1}	34.83^{d}	37.63^{c}	28.74^{g}	28.60^{g}
	Cu-chl at 1 g L^{-1}	40.97^{a}	39.50^{b}	48.33^{d}	47.16^{d}

Means having the same letter (s) within the same column are not significantly different according to LSD for all pairwise comparisons test at 5% level of probability.

The results showed that the highest total chlorophyll content was found in plants treated with 1 g L^{-1} Cu-Chl under irrigation every 6 or 4 days, while the lowest values were observed in plants without Cu-Chl application and irrigated every 2 or 4 days in most cases across both seasons.

The data in Table (9) also suggests that irrigation intervals significantly influence Cu content in Spearmint plants. The highest Cu content was recorded with irrigation every 2 days across both cuts of both seasons. In contrast, irrigation every 6 days resulted in the lowest Cu content in Spearmint herb in both cuts of both seasons. These findings are consistent with those reported by Ramadan (2023) on spinach plants. Tadayyon et al. (2018) and Aqaei et al. (2020) found that water deficit conditions led to a decrease in plant Cu content, which aligns with the results of this study. A water deficit may reduce nutrient uptake by lowering enzyme activity involved in nutrient assimilation and reducing transpiration, which limits nutrient transport and uptake (Robredo et al., 2011 and Liang et al., 2018).

Table (9) also shows that Cu-Chl treatments significantly influenced Cu content in Spearmint herbs. Cu content increased with Cu-Chl treatment in both seasons, with the highest values recorded at 1 g L^{-1} Cu-Chl, compared to untreated plants in both cuts of both seasons. These findings are consistent with those reported by Ramadan (2023) on spinach plants and Hasbullah and Taha (2023) on sweet basil plants.

The interaction between irrigation intervals and Cu-Chl foliar application significantly affected Cu content. Irrigation every 2 days with 1 g L^{-1} Cu-Chl resulted in the highest Cu content (70.15, 69.26, 68.36, and 68.81 mg kg^{-1}) in Spearmint herb in the first and second cuts of both seasons, respectively. In contrast, deficit irrigation (every 6 days) without Cu-Chl application resulted in the lowest Cu content (16.85, 17.64, 18.44, and 18.04 mg kg^{-1}) in dry Spearmint herb in the first and second cuts of both seasons. The differences among treatments were significant in both seasons, consistent with the findings of Ramadan (2023) on spinach plants.

5. Free Proline Content

Fig. (1) shows that extending irrigation intervals to every 6 days led to an increase in free proline content in fresh herbs compared to irrigation every 2 days. Plants irrigated every 6 days accumulated significantly more proline, with increases of 30.8% and 29.5% over plants irrigated every 2 or 4 days, respectively. This suggests that plants subjected to drought stress tend to have higher levels of free proline than those grown under less stressful conditions (Bayer, 2007). Similarly, Simon-Sarkadi et al. (2006) found that drought stress elevated proline levels in coriander (*Coriandrum sativum* L.). Osmotic pressure regulators include amino acids, sugars, mineral ions, hormones, and proteins (Chun et al., 2018). As a soluble compound, proline plays a role in regulating osmotic pressure, reducing water loss from cells, and preserving cell integrity (Hayat et al., 2021).

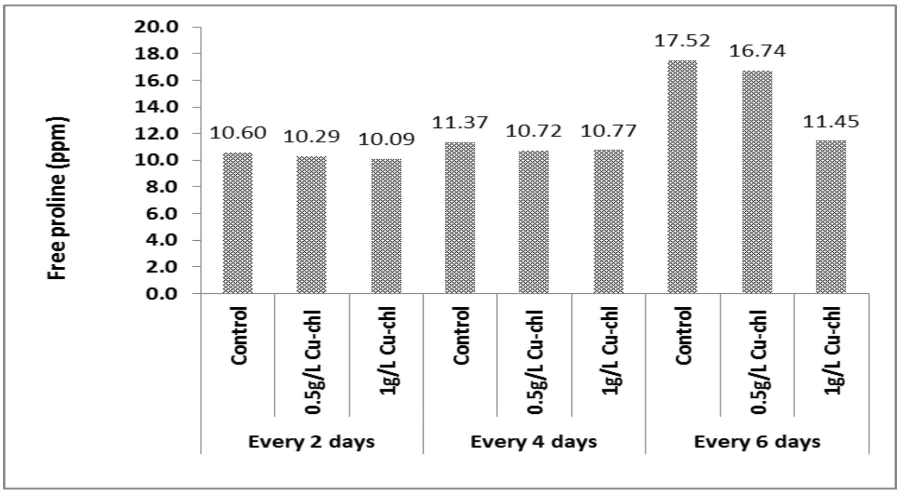

Fig. (1). Effect of irrigation intervals, Cu-chlorophyllin and their interaction treatments on free proline contents of *Mentha virids* plant during two cuts in the two seasons (2022 and 2023).

Additionally, free proline content decreased gradually with increasing Cu-Chl concentrations from 0.5 g L^{-1} to 1 g L^{-1}. The highest proline content (17.52 ppm) was observed in the treatment combining irrigation every 6 days with the control treatment (without Cu-Chl), compared to other treatments.

The application of Cu-Chl at a concentration of 1 g L^{-1} appears to have a significant impact on the overall health of the plant, particularly in relation to its response to drought stress. The reduction in free proline content observed with increasing Cu-Chl concentration suggests that the plants are experiencing less drought stress when exposed to higher levels of Cu-Chl. Proline accumulation is a common response in plants under drought conditions, acting as an osmoprotectant to help maintain cell turgor and protect cellular functions. However, the decreased proline levels at 1 g L^{-1} Cu-Chl indicate that the plants may be under less osmotic stress, possibly due to improved water retention, better root function, or enhanced stress tolerance provided by the Cu-Chl. This implies that at this concentration, Cu-Chl might be mitigating some of the negative effects of drought, thereby improving overall plant health and reducing the plant's need to produce and accumulate proline as a stress response.

6. Water Use Efficiency (WUE)

As shown in Table (10), irrigation intervals of every 6 days resulted in the highest water use efficiency (WUE) for fresh yield, reaching 2.145 kg m^{-3} fresh yield m^{-3} water in the second cut of the first season. In contrast, the lowest values of herb fresh yield, 0.821 and 1.136 kg m^{-3}, were recorded when plants were irrigated every 2 days in both cuts of the first season. A similar trend was observed in the second season, where the maximum WUE values were 0.935 and 1.763 kg m^{-3} water, while the minimum values were 0.537 and 0.854 kg m^{-3} for the same respective cuts.

Table (10). Effect of Irrigation Intervals, Cu-chlorophyllin and their interaction treatments on water use efficiency (WUE) of *Mentha virids* plant during two cuts in the two seasons (2022 and 2023).

Treatment \ Character		Herb fresh yield WUE/FW (kg m^{-3})		Herb dry yield WUE (kg m^{-3})		Volatile oil yield WUE (L m^{-3})	
		1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
		First season					
Every 2 days		0.821^{C}	1.136^{B}	0.283^{B}	0.349^{C}	0.010^{B}	0.012^{C}
Every 4 days		1.372^{A}	2.121^{A}	0.454^{A}	0.620^{B}	0.016^{A}	0.023^{B}
Every 6 days		1.230^{B}	2.145^{A}	0.450^{A}	0.716^{A}	0.017^{A}	0.027^{A}
		Second season					
Every 2 days		0.537^{C}	0.854^{C}	0.131^{B}	0.176^{C}	0.004^{B}	0.006^{C}
Every 4 days		0.879^{B}	1.608^{B}	0.214^{A}	0.340^{B}	0.007^{A}	0.012^{B}
Every 6 days		0.935^{A}	1.763^{A}	0.213^{A}	0.380^{A}	0.008^{A}	0.013^{A}
		First season					
Control		0.796^{C}	1.278^{C}	0.284^{C}	0.410^{C}	0.009^{C}	0.012^{C}
Cu-chl at 0.5 g L^{-1}		1.227^{B}	1.940^{B}	0.409^{B}	0.618^{B}	0.015^{B}	0.023^{B}
Cu-chl at 1 g L^{-1}		1.401^{A}	2.184^{A}	0.495^{A}	0.658^{A}	0.019^{A}	0.026^{A}
		Second season					
Control		0.539^{C}	1.091^{C}	0.132^{C}	0.250^{C}	0.004^{C}	0.007^{C}
Cu-chl at 0.5 g L^{-1}		0.843^{B}	1.480^{B}	0.199^{B}	0.311^{B}	0.007^{B}	0.011^{B}
Cu-chl at 1 g L^{-1}		0.970^{A}	1.655^{A}	0.227^{A}	0.335^{A}	0.009^{A}	0.013^{A}
		First season					
Every 2 days	**Control**	0.667^{f}	0.993^{h}	0.235^{d}	0.290^{h}	0.007^{f}	0.010^{g}
	Cu-chl at 0.5 g L^{-1}	0.863^{e}	1.066^{g}	0.303^{cd}	0.367^{g}	$0.011d^{e}$	0.013^{f}
	Cu-chl at 1 g L^{-1}	0.935^{d}	1.348^{f}	0.311^{cd}	0.390^{f}	0.012^{cd}	0.015^{e}
Every 4 days	**Control**	0.858^{e}	1.423^{e}	0.346^{c}	0.479^{e}	0.011^{de}	0.016^{e}
	Cu-chl at 0.5 g L^{-1}	1.541^{b}	2.423^{c}	0.429^{b}	0.668^{d}	0.015^{c}	0.024^{d}
	Cu-chl at 1 g L^{-1}	1.717^{a}	2.517^{b}	0.588^{a}	0.714^{c}	0.024^{a}	0.029^{c}
Every 6 days	**Control**	0.862^{e}	1.419^{e}	0.270^{cd}	0.462^{e}	0.009^{ef}	0.015^{e}
	Cu-chl at 0.5 g L^{-1}	1.278^{c}	2.331^{d}	0.494^{b}	0.818^{b}	0.018^{b}	0.031^{b}
	Cu-chl at 1 g L^{-1}	1.552^{b}	2.686^{a}	0.587^{a}	0.868^{a}	0.023^{a}	0.036^{a}
		Second season					
Every 2 days	**Control**	0.446^{f}	0.743^{g}	0.112^{f}	0.158^{i}	0.003^{e}	0.004^{h}
	Cu-chl at 0.5 g L^{-1}	0.541^{e}	0.864^{f}	0.132^{e}	0.174^{h}	0.004^{d}	0.006^{g}
	Cu-chl at 1 g L^{-1}	0.625^{d}	0.955^{e}	0.150^{d}	0.197^{g}	0.005^{c}	0.007^{f}
Every 4 days	**Control**	0.531^{e}	0.242^{d}	0.136^{e}	0.270^{f}	0.004^{d}	0.008^{f}
	Cu-chl at 0.5 g L^{-1}	0.960^{c}	1.648^{c}	0.232^{c}	0.362^{d}	0.008^{b}	0.013^{d}
	Cu-chl at 1 g L^{-1}	1.145^{a}	1.934^{b}	0.273^{a}	0.387^{c}	0.010^{a}	0.015^{b}
Every 6 days	**Control**	0.639^{d}	1.287^{d}	0.146^{d}	0.323^{e}	0.004^{d}	0.010^{e}
	Cu-chl at 0.5 g L^{-1}	1.028^{b}	1.929^{b}	0.234^{c}	0.397^{b}	0.008^{b}	0.014^{c}
	Cu-chl at 1 g L^{-1}	1.139^{a}	2.075^{a}	0.258^{b}	0.421^{a}	0.010^{a}	0.016^{a}

Means having the same letter (s) within the same column are not significantly different according to LSD for all pairwise comparisons test at 5% level of probability.

The data also revealed that the WUE for dry herb yield increased gradually with longer irrigation intervals. The highest values were recorded from plants irrigated every 6 days, with 0.450 and 0.716 kg m^{-3} in the first season and 0.213 and 0.380 kg m^{-3} in the second season. On the other hand, the lowest WUE values for dry herb yield were observed when plants were irrigated every 2 days, with 0.283 and 0.349 kg m^{-3} in the first season and 0.131 and 0.176 kg m^{-3} in the second season, respectively. This trend was consistent with the results observed for volatile oil yield in this study.

The data from both seasons clearly demonstrated that decreasing irrigation intervals or increasing water application reduced WUE in both cuts. These findings are in line with those reported by Abd-Elghany et al. (2017) on Fenugreek plant, Okwany et al. (2011), Behera et al. (2014) and Serag El-Din and Mokhtar (2020), who stated that water-use efficiency in Spearmint crops significantly improved with increased water deficit.

The data in Table (10) also indicated that WUE for fresh herb yield, dry herb yield, and volatile oil yield significantly increased with higher Cu-Chl concentrations. The most effective treatment was the application of 1 g L^{-1} Cu-Chl, while the lowest values were observed in the control treatment, where Spearmint plants were not sprayed with Cu-Chl in both seasons.

The interaction between irrigation intervals and Cu-Chl concentrations resulted in significant differences in WUE for fresh herb yield, dry herb yield, and volatile oil yield. The best interaction treatment was irrigation every 6 days combined with spraying plants with 1 g L^{-1} Cu-Chl, which recorded 2.686, 1.139, and 2.075 kg of fresh herb m^{-3}; 0.587, 0.868, 0.258, and 0.424 kg of dry herb m^{-3}; and 0.023, 0.036, 0.010, and 0.016 L of volatile oil m^{-3} in both cuts of the two seasons, respectively. The lowest WUE values for fresh herb yield, dry herb yield, and volatile oil yield were observed in plants irrigated every 2 days without Cu-Chl application, compared to other interaction treatments.

CONCLUSIONS

It is recommended to cultivate Spearmint in the Tour Sinai region of South Sinai using an irrigation interval of every 4 days combined with foliar spraying of Cu-Chl at 1 g L^{-1}. This approach resulted in the highest productivity, saved 34.8% of water when cultivating new areas and increased productivity by 62.81% compared to irrigation every 2 days with the same Cu-Chl treatment. In situations of severe water shortage, an irrigation interval of every 6 days with Cu-Chl at 1 g L^{-1} can be used, as the reduction in productivity under these conditions was minimal.

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تأثيرات كلوروفللين النحاس وفترات الري على نمو وإنتاجية نبات النعناع تحت ظروف جنوب سيناء

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أجريت هذه الدراسة في مزرعة خاصة بمنطقة طور سيناء بمحافظة جنوب سيناء خلال موسمي الزراعة ٢٠٢٢ و٢٠٢٣. يهدف البحث إلى معرفة تأثير التركيزات المختلفة لكلوروفيللين النحاس (Cu-Chl) (صفر، ٠,٥ و ١ جرام لتر-١) على النمو والإنتاجية والصفات الفسيولوجية لنبات النعناع (*Mentha viridis*) تحت ثلاث فترات ري مختلفة (كل ٢، ٤ و ٦ أيام). كشفت النتائج أن إطالة فترة الري إلى ٦ أيام مقارنة بالري كل يومين أدى إلى انخفاض معنوي في صفات النمو، بما في ذلك وزن العشب الطازج لكل متر مربع، محصول العشب الطازج لكل فدان، وزن العشب الجاف لكل متر مربع، محصول العشب الجاف للفدان ومحصول الزيت الطيار. ولكن، تم زيادة الكلوروفيل ومحتوى النحاس والبرولين بالإضافة إلى كفاءة استخدام المياه (WUE) للمحصول في ظل هذه المعاملة. ومع ذلك، فإن تطبيق كلوروفللين النحاس أدى إلي تحسين جميع هذه الصفات بشكل ملحوظ مقارنة بالنباتات التي لم تعامل بكلوروفللين النحاس. كانت المعاملة الأكثر تأثيرًا في هذه الدراسة هي الرش الورقي للنباتات بـ Cu-Chl بمعدل ١ جم لتر-١ مع الري كل ٤ أيام. استنتجت الدراسة أن إستخدام كلوروفللين النحاس يمكن أن يتغلب على الآثار السلبية لنقص الماء على النمو والمحصول والصفات الفسيولوجية لنبات النعناع بالإضافة الي تحسين كفاءة استخدام المياه.