

Effects of planting density and cutting height on herbage and water use efficiency of thyme (*Origanum syriacum* L.) grown under protected soilless and open field conditions

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ABSTRACT

This study was conducted to determine the effects of planting density and cutting height on growth, herbage yield and water use efficiency of thyme (*Origanum syriacum* L.) grown under protected soilless vs. open field conditions. Two experiments were conducted during the period November 2010 to September 2011 using three planting densities (16, 20 and 26 plants/m²). Results showed that planting density and cutting heights had significant effects on fresh and dry herbage yields, number of branches and water use efficiency. The total fresh yield under protected soilless condition was obtained from four harvests, while the total dry yield under open field was obtained from two harvests during the experiment. The highest fresh herbal yield (5.289 kg/m²) under soilless condition was obtained at planting density (26 plants/m²) and cutting height (10 cm). The highest total dry yield (0.973 kg/m²) was obtained at highest planting density (26 plants/m²) at lowest level of cuts (10 cm) under protected soilless conditions. The higher WUE (2.5 and 2.6 kg/m³) values were obtained under planting density (20 plants/m²) at 10 and 15 cm of cutting height under protected soilless conditions, respectively. The results showed that planting density and cutting height had significant effects on fresh and dry herbage yields, number of branches and water use efficiency.

Key words : Cutting height, planting density, soilless culture, thyme, water use efficiency

INTRODUCTION

Thyme (*Origanum syriacum* L.) is an important commercial crop which has medicinal and aromatic properties. It is a perennial shrub which belongs to family Lamiaceae (Alma *et al.*, 2003; Sharafzadeh and Zare, 2011), and is found as wild plant, and it is native to Mediterranean regions (e. g. Jordan) (Zein *et al.*, 2011). Thyme is an aromatic and medicinal plant that has gained popularity for both open field and soilless culture conditions in all over the world. Cultivated thyme has increased in recent years in response to increasing local demands in Jordan (Shiyab *et al.*, 2012). Moreover, *O. syriacum* recently has a great interest as potential therapeutic substances and as natural additives to replace synthetic products in food industry (Aslim and Yucel, 2008; De Souza *et al.*, 2010; Hendawy *et al.*, 2010; Ocana-Fuentus *et al.*, 2010; Sharafzadeh and Zare, 2011).

In recent years, protected horticulture has changed from soil-based to soilless culture systems. Soilless culture is gaining interest in horticulture production in countries which have limited water resources and land, agricultural resources and salinity problems in soils. Closed soilless techniques can be adopted to minimize water losses and maximize fertilizer use efficiency in greenhouse conditions as well as reduce environmental pollution caused by fertilizer runoff (Voogt and Sonneveld, 1997; Siddiqi *et al.*, 1998; Savvas, 2002; Schroder and Lieth, 2002; Rouphael *et al.*, 2004; Savvas, 2007; Al-Karaki and Othman, 2009; Al-Karaki *et al.*, 2009). However, Soilless culture is important on a commercial scale, where the soilless culture production of medicinal herbs has many valuable advantages such as : high yields, cleaner production, yearlong cultivation, and production of drugs with minimum herbicide and pesticide residues (Van Os, 1999;

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Van Os and Benoit, 1999; Van Os *et al.*, 2002; Savvas, 2007; Hassanpouraghdam *et al.*, 2010). However, agricultural factors have a critical effect on growth and productivity of crop plants that influence agronomic characteristics, fresh and dry herbage yields and water use efficiency of thyme plants. Among these factors, cultivation method, planting density, cutting height at harvest, plant nutrition and harvesting time (Nadjafi, 2006; Topcu *et al.*, 2007; Awada *et al.*, 2012).

It was important to know the effects of cultural practices like planting densities and cutting height at harvesting on herbage yield, yield components, and water use efficiency of medicinal plants like thyme plants. The plant density might affect the maximum availability and utilization of soil moisture (Nekonam and Razmjoo, 2007). Therefore, the optimization of plant density can lead to a higher yield in the medicinal plants by favourably affecting the absorption of nutrient and exposure of the plant to light (Khorshidi *et al.*, 2009).

The main criteria for selection of ideal planting density and cutting height under soil-based vs. soilless conditions should be based on the higher herbal yield and water saving due to those agronomical factors mentioned above has a great effect on both quality and quantity of herbage yield of herbs, medicinal and aromatic plants. Studies to evaluate and compare different planting density and cutting height under soil vs. soilless conditions are necessary to provide farmers option to manage their crops according to their cultural practices. For this reason, thyme plants (*Origanum syriacum*) were grown in soil conditions and closed soilless system to determine the effects of different planting density and cutting height in terms of herbage yield, plant height, number of branches, water use and water use efficiency to determine optimum levels of these factors. The main aim of this research was to examine the fresh and dry herbage yields, WUE of thyme in response to different planting density and cutting height under soil-based and soilless conditions.

MATERIALS AND METHODS

Experiment 1 (Under Protected Soilless Conditions)

Thyme (*Origanum syriacum* L.) was transplanted at four-leaf stage in greenhouse

at Jordan University of Science and Technology (JUST) campus in growing season of 2010-11. The cultivation started at the ending of November 2010 to September 2011. Transplants were under natural light conditions; ventilation was provided automatically when the air temperature exceeded 26°C by cooling system. Seedling of thyme was transplanted at three planting densities (16, 20 and 26 plants/m²) into wood beds (120 × 110 × 25 cm D) (W × L × D) filled with tuff zeolite (3-8 mm) under soilless conditions. The base of beds was lined with plastic sheets and elevated at 1.5% with hole in the base of wood beds which channel attached to drain excess water to be collected in tanks for reuse.

Nutrition Solution for Soilless Culture Experiment

Water and nutrient requirements of the plants were covered with complete nutrient solutions prepared according to Clark solution and were applied in all irrigations through a drip irrigation system. The nutrient solutions were prepared manually once per two weeks. The concentration of ions expressed as (mg/l) was : N 360, P 2, K 283, Ca 302, Mg 48, S 64, Fe 2.76, Mn 0.974, B 0.536, Zn 0.3, Cu 0.076 and Mo 0.155. In the drip-irrigation system of closed soilless system, the nutrient solution was pumped from independent tanks. Pressure compensated drippers with 2.4 l/h flow rate. In closed soilless systems, the procedures for nutrient replenishment and water discharge were applied contemporaneously to all replicates. EC and pH values of the applied nutrient solution in the closed system were maintained at 2.0-2.5 and 5.5-6.5 dS/m, respectively.

Irrigation System for Soilless Experiment

Irrigation scheduling and management under soilless culture conditions used drip irrigation systems in the experiment. The total volume of nutrient solution (irrigation) applied to the entire thyme area of the greenhouse was measured with a plastic bag that was read manually at 6 : 00 am and 6.00 pm each day after irrigation to read the volume of irrigation water for calculation of water use and water use efficiency. The wood trays had a 1.5%

longitudinal slope; drainage was collected separately from each tray in underground-enclosed 400 l containers. Each day at 6 : 00 h, drainage volumes were measured and representative samples were collected for each drainage wood tray. The drainage fraction for each day was calculated as the volume of irrigation collected the following morning by the volume of irrigation for that day. The individual daily samples of applied nutrient solution and drainage were analyzed for EC and pH immediately after collection.

Experiment 2 (Under Soil-based Conditions)

This study was carried out in open field at Jordan University of Science and Technology (JUST) campus in growing season of 2010-11. The cultivation started at the ending of November 2010 to September 2011 in Northern Jordan (32°34'N latitude, 36°01' E longitude and 520 m altitude). The location had Mediterranean climate of mild rainy winter and dry hot summer. The soil was fine-loamy, thermic and calcic paleargid. Thyme (*Origanum syriacum* L.) was transplanted at four-leaf stage in concrete blocks (95 × 100 × 75) in cm (W × L × D) filled with soil mix with peatmoss under soil conditions. Peatmoss was applied at 33 l/m² at the top layer of soil (20 cm) to improve for water holding capacity of soil.

Irrigation and Fertilizer Application

Proper scheduling of drip irrigation is

critical for efficient water management in thyme production under soil conditions, particularly under conditions of water scarcity. The total actual amount of irrigation water applied is presented in Table 1. During the initial stage of growth, when thyme started in vegetative growth and plants up to developmental stage were irrigated daily to encourage establishment, but thereafter irrigation frequency was running every three days. The purpose of this irrigation was to bring the soil in the 50 cm root zone to field capacity and to create a good transplanting bed. Subsequent irrigation scheduling was determined using daily water need by transplanting which was determined for each of the irrigation times. Inorganic fertilizer was applied from NPK fertilizer, had formula N₂, P₂O₅ and K₂O with 20 : 20 : 20 ratio was applied at the rate 30 g/m² at the planting time. After each harvest of thyme plants, 25 g/m² of NPK fertilizer was added. In addition, 6 g/m² nitrogen fertilizer was added in the form of urea (46% N) after each harvest and every month depending on growth stage.

The following meteorological variables were recorded daily throughout the thyme-growing season under soilless and soil conditions : maximum and minimum air temperature, air relative humidity and rainfall. Meteorological data were those of a typically Mediterranean environment.

Soil Experiment Site

Maximum temperature during the

Table 1. Total rainfall and total applied irrigation of thyme plants during the course of experiment under soil cultivation conditions (22 November 2010 to September 2011)

Date of rainfall		Total rainfall (mm/m ²)	Total irrigation water (l/m ²)
Month	Year		
November	2010	-	1572
December	2010	92.7	4626
January	2011	59.1	4476
February	2011	103.1	4159
March	2011	69.3	3418
April	2011	59.1	4185
May	2011	5.5	4894.8
June	2011	-	4278
July	2011	-	3889.8
August	2011	-	4862.4
September	2011	-	709.8
Total		389.104	45348.8

growing period (November 2010-September 2011) was 27.1°C in 2010 and 34.7°C in 2011. Minimum temperature was 12.8°C in 2010 and 4.8°C in 2011. Total rainfall during the experiment for the soil site is presented in Table 1. Soil water availability was almost totally due to irrigation. Mean daily relative humidity during growth was 78%.

Plant Growth and Biomass and Yield Measurements

Fresh and dry herbal yield (kg/m²), was measured by harvesting thyme plants at three planting densities (16, 20 and 26 plants/m²) and at three cutting heights (10, 15 and 20 cm) above the ground levels for the four harvesting times under soilless culture conditions and for the two harvesting times under soil-based conditions. Plant height as well as number of branches were measured for the first cuts only.

Measurements and Calculations of Water Use Efficiency

In closed soilless system, daily water use was determined by recording with meter the amount of nutrient solution used to refill mixing tank. The total added and drained water were recorded every day to compute for total water use and water use efficiency (liters water used/kg fresh herbal yield). The accuracy of water meter was checked weekly. On the other experiment, the water use measurement as well as in soilless experiment but no drained water due to the system for soil-based conditions was open. Water use efficiency (WUE) values as kg fresh herbal yield/m³ of the applied water were calculated for different treatments after thyme harvest according to Eq. (1).

$$\text{WUE} = \frac{\text{Fresh total yield (kg/m}^2\text{)}}{\text{total water use (m}^3\text{/m}^2\text{)}} \dots(1)$$

Experimental Design and Statistical Analysis

Experimental design was arranged in split plot in basis of randomized completely block design with planting density (16, 20 and 26 plants/m²) as main plots and sub-plots were three cutting heights (10, 15 and 20 cm) used in four replicates under both the cultivation methods. Three planting densities (16, 20 and

26 plants/m²) at three cutting heights (10, 15 and 20 cm) were evaluated. All data were statistically analyzed using analysis of variance (ANOVA) according to the statistical package MSTAT-C (Michigan State Univ., East Lansing, MI, USA). Probabilities of significance among treatments and LSD ($P \leq 0.05$) were used to compare means among treatments.

RESULTS AND DISCUSSION

Fresh Herbal Yield

Fresh herbage yield was considered an important indicator required by thyme growers to judge the economic value of its conditions. For this purpose, some agronomic practices such as planting density and cutting height were used in this study to evaluate the fresh herbal yield under protected soilless and open field conditions. Moreover, optimum planting density was a key to achieve maximum crop production especially when water was a limiting factor.

Fresh herbal yields of third and fourth harvests and total biomass yield were significantly higher under protected soilless conditions than under open field conditions. Fresh herbal yield of first harvest was not significant under both the cultivation methods. Results showed that higher fresh herbal yield (1091 g/m²) for the first harvest was obtained under interaction of planting density (26 plants/m²) and cutting height (10 cm) under open field conditions. It can be resulted from Table 2, that lower cutting height above soil surface increased the fresh yield for all planting densities for the first harvest. No significant differences were observed for second harvest. The higher yield (1668 g/m²) for second harvest was obtained under interaction between the lowest planting density (16 plants/m²) and highest cutting height (20 cm) under protected soilless conditions.

For the third harvest, the highest fresh herbal yield (1340 g/m²) was obtained under interaction of highest planting density (26 plants/m²) and highest cutting height (20 cm) followed by 1250, 1162 and 1108 g/m² interaction of planting density (20 plants/m²) at cutting height 10 cm, planting density (26 plants/m²) at cutting height 15 and 10 cm, respectively, under protected soilless conditions which were significantly high than that other

Table 2. Effect of planting density and cutting height on fresh herbal yield at all harvesting times and on total fresh yield during growing season under soilless and soil-based conditions

Planting density (Plants/ m ²)	Cutting height (cm)	1st harvest (g/m ²)		2nd harvest (g/m ²)		3rd harvest (g/m ²)		4th harvest (g/m ²)		Total dry yield (kg/m ²)	
		Soil	Soilless	Soil	Soilless	Soil	Soilless	Soil	Soilless	Soil	Soilless
		7 April	1 March	6 September	7 June	-	13 July	-	7 September		
26	10	1091a	660.5defg	1336a-e	1657a	-	1108c	-	1865a	3.125h	5.289a
	15	791.5cd	655.75defg	882.3g	1391a-e	-	1162bc	-	1474b	2.293kl	4.616cd
	20	445.75hi	631.5defg	429h	1186defg	-	1340a	-	1263b	1.481n	4.420de
20	10	1078ab	758cde	1199c-g	1534abc	-	1250ab	-	1326b	2.967hi	5.025ab
	15	913.5bc	615.75efg	1158efg	1591ab	-	802.8d	-	1802a	2.750ij	4.804bc
	20	377.8i	419.75hi	958.3fg	1533abc	-	590.8ef	-	1362b	1.896m	3.755g
16	10	1056.3ab	394.75hi	1408a-e	1522a-d	-	527.8f	-	1713a	3.085h	4.132f
	15	732.5def	564.25fgh	1252b-f	1633a	-	667e	-	1419b	2.523jk	4.324ef
	20	524.5ghi	414.5hi	1129efg	1668a	-	661.8e	-	1400b	2.066lm	4.145ef
LSD (P=0.05)		170.0		346.6		115.6		225.5		0.2796	

yield under different densities and cuts. Fresh herbal yield for fourth harvest was significantly high. The highest fresh herbal yield (1865 g/m²) was obtained at planting density (26 plants/m²) at 10 cm of cutting height followed by 1802 g/m² under planting density (20 plants/m²) at 15 cm of level of cuts followed by 1713 g/m² under planting density (16 plants/m²) at lower cutting height (10 cm), respectively, which were significantly high than that other fresh herbal yield under different densities and cuts.

The results presented in Table 2 show that in thyme the only significant (P>0.05) difference for total herbage biomass was obtained at the different planting densities (26, 20 and 16 plants/m²) at different cutting heights under protected soilless conditions compared to the all planting densities and cutting heights under open field conditions. The interaction between both the factors planting density and cutting height significantly affected the total yield under both the cultivation methods (Table 2). Finding optimum planting density and suitable cutting height in this study is a key to achieve maximum thyme production especially when water is a limiting factor. The highest total fresh yield (5.289 kg/m²) was obtained at highest planting density (26 plants/m²) at lowest level of cuts (10 cm) under protected soilless conditions. Fresh herbal yield under protected soilless condition was significantly high than that fresh yield under all densities and cuts under open field

condition. The total fresh yield under protected soilless condition was obtained from four harvests, while the total yield under open field was obtained from two harvests during the experiment.

In comparison to total fresh yield under soilless condition (5.289 kg/m²) with open field condition (3.125 kg/m²) at the same planting density (26 plants/m²) and cutting height (10 cm) it was found that there were highly significant differences between both the cultivation methods. The higher fresh herbal yield at lowest planting density (16 plants/m²) and lowest cutting height (10 cm) was obtained under soilless (4.132 kg/m²) which was significantly higher than that under open field condition (3.085 kg/m²) (Table 2). The highest fresh herbal yield (5.289 kg/m²) under soilless condition was obtained at planting density (26 plants/m²) and cutting height (10 cm). The lowest fresh herbal yield ((3.755 kg/m²) under soilless condition was obtained at planting density (20 plants/m²) and highest cutting height (20 cm) (Table 2).

Dry Herbage Yield

Dried thyme is one of the main components of medicinal and aromatic herb plants which are used for the production of essential oil and aromatic water (Dundar *et al.*, 2008) and used as stimulants, analgesics, antitussives, expectorants and sedatives in folk medicine; but mostly for gastrointestinal

complaints (Bas_er, 2002). The obtained results during this study revealed clear variation of quantity dry herbage yields at planting densities, as well as, cutting height, which influence on dry herbage yields of thyme under soilless conditions. Dry herbal yields of third and fourth harvests and total biomass yield were significantly higher under protected soilless conditions than under open field conditions. Dry herbal yield of first harvest was significant under open field condition than that under protected soilless condition. Results showed that higher dry herbal yield (267.8, 244 and 259.8 g/m²) for the first harvest was obtained under interaction of planting density (26, 20 and 16 plants/m²) with cutting height (10 cm) under open field condition, respectively (Table 3). It can be seen from Table 3 that the higher yield (585.3 and 600 g/m²) for second harvest was obtained under interaction of the planting density (26 and 20 plants/m²) with cutting height (10 cm) under open field condition, respectively (Table 3).

For the third harvest, the highest dry herbal yield (368 g/m²) was obtained under interaction of highest planting density (26 plants/m²) and highest cutting height (20 cm) followed by 314.5, 313 and 290 g/m² at interaction of planting density (20 plants/m²) at cutting height (15 cm), planting density (26 plants/m²) at cutting height (15 and 10 cm), respectively, under protected soilless conditions which were significantly high than that other yield under different densities and cuts. Dry

herbal yield for fourth harvest was significantly high. The highest fresh herbal yields (894, 864 and 822 g/m²) were obtained at planting density (26, 20 and 16 plants/m²) at 10, 15 and 10 cm of cutting height, respectively (Table 3).

The results (Table 3) showed that total dry herbal yields under protected soilless condition at all planting densities and cutting heights were significantly high than that under open field conditions at ($P>0.05$) all the planting densities and cutting heights. The interaction between both the factors planting density and cutting height significantly affected for total yield under both cultivation methods (Table 3). Finding optimum planting density and suitable cutting height in this study is a key to achieve maximum thyme production especially when water is a limiting factor.

The highest total dry yield (0.973 kg/m²) was obtained at highest planting density (26 plants/m²) at lowest level of cuts (10 cm) under protected soilless conditions. Total dry herbal yield under protected soilless condition was significantly high than that fresh yield under all densities and cuts under open field condition. The total dry yield under protected soilless condition was obtained from four harvests, while the total dry yield under open field conditions was obtained from two harvests during the experiment.

In comparison to total dry yield under soilless condition (0.973 kg/m²) with open field condition (0.589 kg/m²) at the same planting density (26 plants/m²) and cutting height (10

Table 3. Effect of planting density and cutting height on dry yield at all harvesting times and on total dry yield during growing season under soilless and soil-based conditions

Planting density (Plants/m ²)	Cutting height (cm)	1st harvest (g/m ²)		2nd harvest (g/m ²)		3rd harvest (g/m ²)		4th harvest (g/m ²)		Total dry yield (kg/m ²)	
		Soil		Soil		Soil		Soil		Soil	
		April	March	September	June	-	July	-	September		
26	10	267.8a	191b	585.3a	490.5abc	-	290.8b	-	894.8a	0.589ef	0.973a
	15	186.5bc	169b-e	368cd	379cd	-	313.8b	-	707.5b	0.497fg	0.863abc
	20	108.25fg	144.3c-f	166.8e	311.8de	-	368a	-	606.3b	0.443g	0.824bcd
20	10	244.8a	167.3b-e	450a-d	460.5a-d	-	314.5b	-	648.8b	0.473fg	0.946ab
	15	194.5b	131.3d-g	354cd	479a-d	-	206.8c	-	864.8b	0.359g	0.817bcd
	20	99.25fg	113.8fg	398.3bcd	392.8bcd	-	138.3de	-	653.b	0.371g	0.645e
16	10	259.8a	124efg	600.3a	455.3a-d	-	119.8e	-	822.3a	0.491fg	0.700de
	15	172.5bcd	104fg	557ab	548.75ab	-	171.3cde	-	680.8b	0.408b	0.810bcd
	20	113fg	97.25g	554.3ab	517.8abc	-	181.5cd	-	672.3b	0.206h	0.797cd
LSD ($P=0.05$)		46.04		167.6		52.36		112.7		0.1434	

cm) it was found that there were highly significant differences between both the cultivation methods.

Effect of Plant Spacing on Plant Growth, Plant Height and Branches/Plant

The variation of plant height for the first cut at different planting density was not significant under soilless culture conditions. Najafi and Moghadam (2002) reported that plant density had no significant effect on plant height in blond psyllium. In addition, the variation of plant height between cutting height was not significant. However, the interaction between planting density and cutting height was significant. Significantly taller thyme plant (46.75 cm) was obtained under interaction of planting density (16 plants/m²) and cutting height (10 cm) under soilless culture conditions. Number of branches per plant under soilless cultivation conditions increased with increasing planting density. Higher number of branches (28.4) of thyme plant was obtained at planting density (26 plants/m²). Cutting height did not significantly affect the number of branches per plant under soilless culture conditions. However, the interaction between planting density and cutting height was significant. The highest thyme number of branches per plant (30.5) was obtained under interaction planting density (26 plants/m²) and cutting height (10 cm) under soilless culture conditions.

Water Use Efficiency and Water Use

Water is one of basic requirements for

plant growth. Due to water scarcity, water efficiency is a key concept to solve water-shortage problems in semi-arid areas. Irrigation water must be scheduled and designed to ensure the optimal use of water for maximizing crop production per unit of irrigation water applied. Growing water scarcity and increasing demands for agricultural products generate much debate about improving the agricultural sector's water use efficiency and productivity. Data given in Table 4 show that WU and WUE were significantly affected by planting density and cutting height at both the cultivation methods. The results in Table 4 indicate that WU under open field conditions decreased with decreased planting density regardless cutting height. The highest WU was obtained at planting density (26 plants/m²) under open field conditions. In comparison to the amount of irrigation water that was applied under soilless and open field at the same planting density, the differences were significantly high. The amount of irrigation water under open field at planting density (26 plants/m²) was 4.0 m³/m², while under soilless conditions at the same planting density, the amount of irrigation water applied was lower (2.56 m³/m²).

Growing water scarcity and increasing demands for agricultural products generate much debate about improving the agricultural sector's water use efficiency and productivity. Irrigation water use efficiency (IWUE) is defined as the relationship between units produced and volume of irrigation water applied.

The higher WUE (2.5 and 2.6 kg/m³) values were obtained under planting density (20 plants/m²) at 10 and 15 cm of cutting

Table 4. Water use (WU) and water use efficiency (WUE) under soilless culture and soil-based conditions as affected by planting density and cutting height

Planting density (Plants/m ²)	Cutting height (cm)	WU (m ³ /m ²)		WUE (kg fresh yield/m ³)	
		Soil	Soilless	Soil	Soilless
26	10	4.02a	2.55k	0.603g	2.07bc
	15	4.01b	2.58j	0.417h	1.8d
	20	3.99c	2.55k	0.218i	1.7d
20	10	3.24f	1.89p	0.703fg	2.6a
	15	3.25e	1.90o	0.641fg	2.5a
	20	3.27d	1.92n	0.410h	2.025c
16	10	2.63h	1.90o	0.937e	2.2b
	15	2.63g	2.009l	0.754f	2.134bc
	20	2.60i	1.977m	0.633fg	2.097bc
LSD (P=0.05)		0.001434		1.168	

height under protected soilless conditions, respectively. According to the results in Table 3, there were some indications which approved the relationship between interaction with planting density, cutting height and WUE. At all planting densities, higher WUE was obtained at lower cutting level (10 and 15 cm) above the ground due to cutting more fresh yield/m² at these levels.

The values of WUE for thyme plants under open field conditions ranged (0.410 to 0.937 kg/m³) and under soilless condition ranged (1.7 to 2.6 kg/m³) (Table 4). According to the results in Table 2, in comparison to the lowest value of WUE under soilless cultivation (1.7 kg/m³) with the highest value of WUE under soil cultivation (0.937 kg/m³) indicated that soilless condition had more efficiency in arid and semi-arid regions by improving the agricultural sector's water use efficiency and productivity. This confirmed that soilless culture conditions produced not only higher fresh herbage thyme yield, but also saved irrigation water under soilless culture conditions in arid and semi-arid regions. According to the results in Table 2, the WUE at cutting height (10 and 15 cm), produced significantly thyme fresh herbage yields, which were 2.3 and 2.15 kg/m³, respectively, and which were higher than that WUE (1.95 kg/m³) at cutting height (20 cm). The WUE under soilless cultivation conditions increased with decreasing cutting height.

As mentioned earlier in the results that planting density and cutting height under soilless culture conditions increased quantity and quality characteristics of *Origanum syriacum* such as fresh and dry herbage yields and number of branches per plant as well as plant height. Moreover, it was found that soilless culture was one of most important techniques to grow thyme plants under arid and semi-arid conditions. Growing thyme under soilless culture conditions permits the crop to mature earlier by response to more favourable growing conditions (Mean nutrient solution contains all elements of the plants needed with more efficiency in response to nutrient solution). Soilless culture conditions allowed producing marketable and enhanced thyme growth earlier compared to conventional agriculture. Moreover, soilless culture had multiple harvest instead single or twice-harvest in comparison to conventional agriculture.

These results may be attributed to the efficiency of soilless culture under scarcity of water in Jordan. These results are comparable to those obtained by Al-Karaki and Othman (2009) who reported that the thyme fresh yield under soilless conditions was higher.

Cutting height had significant effect on herbage yield. Similar result (Topcu *et al.*, 2007) was reported about sage herbage yield at low level of cutting height which showed increasing herbage yield, but the plants needed longer time for regrowth in comparison to high level of cutting due to the reduced photosynthesis capacity, less growing points and reduced storage carbohydrate. In this study, the fresh herbage yield was obtained from four harvest times and highest total fresh herbal yield from lower cutting height, that mean soilless culture conditions are ideal cultivation due to accurate management of all factors involved in thyme nutrition as composition of nutrient solution, water supply, EC and pH of the nutrient solution. The higher fresh herbage yield was obtained at 10 and 15 cm of cutting height and these results are comparable with the results obtained by Zutic *et al.* (2003). It was reported that the highest fresh yield was achieved with cutting plants level (10 and 15 cm) above the ground level. Shalaby and Razin (1992) reported that herbage biomass of thyme increased at lower planting distances and that is in agreement with this study for herbage yield production under open field condition. The lower planting density means individual plants in wider distances had more branches and lower competition with absorbance mineral elements and water for the lower number of plants per unit and herbage yield compared to the narrow distances. (Table 2). Najafi and Moghadam (2002) reported that the highest herbage biomass and essential oil yield of punesa (*N. binaludensis*) was observed at a planting distance of 25 cm compared to 50 cm. Hossein *et al.* (2006) showed that wider plant distances of dragonhead (*Dracocephalum moldavica*) increased the herbage biomass.

In protected soilless condition the highest fresh herbage yield was obtained at highest planting density due to all the factors available such as mineral elements, water irrigation for optimum growth and production of high fresh herbal yield. Dried thyme herb is widely used in flavorings and herbal tea preparations in general. Thus, it is important

to know the yield of dry matter of thyme plants. According to the obtained results, dry herbage yield of thyme was significantly influenced by planting density under soilless culture conditions. There are many studies about the effect of planting density on dried yield of crops and some of these studied the sweet basil using three planting densities (20, 40 and 60 plants/m²). It was reported that higher amount of dry matter and the yield was achieved by using planting density (20 plants/m²) (Arabasi and Bayran, 2004). Also, Al-Ramamneh (2009) reported that the higher dry herbage yield was obtained with narrow inter-row spacing which is in agreement with the results obtained in this study, where three planting densities 16, 20 and 26 plants/m² were used and the higher dry herbage yield was obtained under planting density (26 and 20 plants/m²) and significantly high. In addition, cutting height significantly affected the dry herbage yield.

Water is the most important limiting factor to agricultural production in the arid and semi-arid regions such as Jordan, and likely will be exacerbated by increasing food demand and deteriorating soil and water quality. Improving water efficiency in irrigated agriculture is a priority for better environmental and economic performance. It can be achieved by reducing the amount of water used and optimizing the timing of application. Among numerous methods, soilless culture is one of most important approaches to saving water and improving WUE at the scarce of water recourses and limited land. In any culture, an accurate and dynamic control of the water supply is needed to meet plant water requirement, improving irrigation delivery system, optimal water allocation to different crops, and optimizing irrigation time. However, WUE can be optimized by the adoption of more efficient irrigation practices (Costa *et al.*, 2007) in closed soilless culture. In order to carry out an effective management of irrigation under soilless culture conditions, which are used to approach the suitable methods with maximizing water use for higher yields per unit irrigation of applied water. Optimum plant density is important to be determined when water is a limiting factor (Khazaie *et al.*, 2008). According to results, the water use efficiency was significantly affected by planting density under soilless culture conditions. Also, WUE was significantly affected by cutting height. Combining thyme water

requirements with soilless culture system is the key for excellent water irrigation management and for achieving higher WUE. Water-saving irrigation strategies based on soilless culture system should improve the WUE significantly depending on efficiency in water using under this culture.

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