Original scientific paper
Journal of Central European Agriculture, 2019, 20(3), p.852-865
DOI: /10.5513/JCEA01/20.3.2282

Enhancing spearmint productivity and water use efficiency under alternative planting practices

Alia AMER[1] (✉), Mona ABDALLAH[1], Tahany NORELDIN[2]

[1] Medicinal and Aromatic Plants Research Department, Horticulture Research Institute, Agricultural Research Center, Giza, Egypt

[2] Water Requirements and Field Irrigation Research Department, Soils, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt

✉ Corresponding author: dr_aliaamer@yahoo.com

ABSTRACT

Egypt faces water scarcity to meet the increasing demand. Therefore, better management of irrigation water for crops assumes high priority among which spearmint is a high water demanding plant. Hence, the current study was undertaken at the Medicinal and Aromatic Research Department Experimental Farm, El-Kanater El-Khairiya, Egypt. It is intended to investigate the effect of different planting practices "raised bed, furrows and convention" on yield productivity and water saving, under three irrigation treatments "120%, 100% and 80% of ETo". The results of two seasons 2016 and 2017 showed that the best vegetative growth and fresh herb yield were obtained using raised bed followed by furrows then conventional planting method under 100% ETo. Essential oil was increased up to 0.7% at 100% ETo under raised bed. It was observed that when compared to planting using conventional methods at 120% ETo, under 80% ETo spearmint yield was increased by about 8.76% and 26.14% for furrows and raised bed in the first season, second season showed same trend. In addition, raised bed under 80% of irrigation applied water produced the maximum amount of water saved when compared to conventional at 120% ETo being 36.14 and 48.38% for 1st and 2nd season, respectively.

Keywords: alternative planting practices, *Mentha spicata*, Spearmint, water use efficiency

INTRODUCTION

Native spearmint (*Mentha spicata* L.) is an aromatic plant belonging to the *Lamiaceae* family. It is cultivated mainly for its aromatic oil produced from its leaves. The oil is used as a flavoring ingredient in chewing gum and different food, confectionary products, perfumes, pharmaceutical dental products, hygiene products and pesticides. Moreover, the herb can be used as tea. Native spearmint gets its characteristic smell from carvone, an oxygenated terpene, whose composition is about 70% of the oil. The Egyptian mint has a good reputation in the USA, Australia, and Europe which are the major markets (Ministry of Agriculture, 2015). Spearmint leaves has a synergistic action of antioxidant phytochemicals, carotenoids and flavonoids. Consuming spearmint leaves used to combat oxidative stress that causes chronic disease like diabetes (Rajeshwari et al., 2012).

Spearmint is considered a shallow rooted, high water demanding plant, and potential shortage of water can severely reduce its productivity and quality (Ley et al., 2003). By providing optimum irrigation and different methods of planting in exact quantity, the yield, water use efficiency and water productivity of the medicinal plant could be increased to sustain the ever-increasing demand (Behera et al., 2014).

While water is an essential resource to sustain life, Egypt is characterized by limited water and soil resources, in addition to high population rate. Irrigation water management has become very important task to be implemented in Egypt due to the prevailing conditions of water scarcity. In addition, low application efficiency of surface irrigation, which is the prevailing irrigation system (Abou Zeid, 2002). Surface irrigation as traditional method has lower application efficiency because the water losses under such system due to deep percolation, causing several problems i.e., raising ground water table, leaching of nutrients etc. Consequently, such problems are negatively affecting crop yield and reducing fertilizers use efficiency (Downey, 1971a, 1971b). This situation creates challenges for agricultural scientists to manage water more efficiently, taking into consideration soil and water resources conservation. Thus, innovations are required to increase water and land productivity under water scarcity conditions. Furthermore, these innovations need to easy to be implemented by farmers to increase their adoption to these new technologies. Studies have indicated that Raised bed is one of these technologies that can be used to reduce the applied water without any losses in crops productivity; however, it is needed to be assisting in medicinal plants. In this respect, cultivation on raised beds can save 20% of the applied irrigation water. It was also reported that cultivation on raised beds increased productivity by 15%, as a result of increase in radiation used efficiency as crops are more exposed to solar radiation, increase nitrogen use efficiency and increase water used efficiency (Abouelenein et al., 2010; Karrou et al., 2012; Majeed et al., 2015). The major reason behind using this system is to sustain and improve soil fertility and increase farmers' income (Sheha et al., 2014).

Keeping this in view, this research is intended to evaluate raised bed and other methods such as, furrows and conventional planting systems for improving water productivity and yield of spearmint under three different irrigation quantities.

MATERIALS AND METHODS

Site description and setup

Field experiments were undertaken during the summer season of 2016 and 2017 at the Farm of Medicinal and Aromatic Plants Research Department, El-Kanater El-Khairiya, Kalubeia Governorate, Egypt. The aim of this study is to clarify the influence of three different planting methods and three different irrigation water amounts on growth, yield, oil yield, essential oil composition, water use efficiency, water consumptive use and water productivity for spearmint herb.

The experimental site is located at 30°08′ N, 31°15′ E, 16.9 m a.s.l. Average of meteorological data from 2013 to 2017 are presented in Table 1.

Plant materials

Spearmint (*Mentha spicata* L.) stolons “15–20 cm in length, with 10–12 leaves” were obtained from the Farm of Medicinal and Aromatic Plants Department and were transplanted 25 cm a part on 15th of March for each season.

Fertilization with ammonium nitrate (20.5% N), calcium super phosphate (16% P_2O_5), and potassium sulfate (48% K_2O) as well as other routine cultural practices until harvest of spearmint crop were followed as recommended.

Two harvests were taken each year by cutting the vegetative parts of plants 10-15 cm above the soil surface without bruising or injuring the leaves and stems. The first cut was when 50% of the spearmint plants reached flowering stage, and the second cut was one month after the 1st cut in each season.

Field experiment

The field treatments were designed in a split plot with three replications. Each trial unit area was 27.5 m^2 (5*5.5 m) containing 96 plants.

The Physical properties of the soil at the experimental site were analysed (Table 2). Particle size distribution was conducted using the pipette method and bulk density according to Klute (1986).

Table 1. Average of monthly meteorological data from 2013 to 2017 at the experimental site during the study period

Months	SRAD (cal/cm^2/day)	TMAX (°C)	TMIN (°C)	WS (m/sec)	Td (%)	ETo (mm/month)
March	18.6	25.6	10.5	3.1	7.2	4.8
April	23.8	28.7	12.4	3.3	8.4	6.2
May	27.1	33.5	17	3.2	12.6	7.5
June	25	35.3	19.1	3.5	15.2	7.9
July	29.2	36.4	20.2	3.3	16.2	8.4
August	27.1	37.6	22	3.1	17.7	8.1
September	23.1	35.3	20.8	3	16.8	6.9

SRAD - solar radiation; TMAX, TMIN - maximum and minimum temperatures; WS - wind speed; Td – temperature dew; ETo – evapotranspiration.
Data were obtained from the agro-meteorological Unit at SWERI, ARC.

Table 2. Physical properties of the soil

Parameter	Value
Particle size distribution (%)	
Clay	30.9
Silt	33.4
Fine sand	34.6
Coarse sand	1.1
Texture class	Clay loam

Soil moisture constants (Table 3) were determined using the pressure membrane apparatus, considering the saturation percent (SP) at 0 kPa, field capacity (FC) at 33 kPa (0.33 bar) and wilting point (WP) at 1.5 MPa (15 bar). Available water was considered as the difference between FC and WP (Stackman, 1966). Soil bulk density values were determined using the core method.

Field experiment treatments

Irrigation treatments

Three irrigation treatments were assigned to main plots as follows:

- I1 - Irrigation at 0.8 evapotranspiration pan coefficient,
- I2 - Irrigation at 1.0 evapotranspiration pan coefficient and,
- I3 - Irrigation at 1.2 evapotranspiration pan coefficient.

Water pump, provided with a calibrated water meter, was used for all water measurement.

Planting methods treatments

Three cultivation methods treatments were devoted to sub-plots as follows:

- P1 - Convention basin planting,
- P2 - Furrows planting, each furrow containing six dropper lines with 4 m length, 60 cm width and 25 cm between furrows. Seedlings were grown 25 cm a part on the top on the furrows and,
- P3 - Raised-bed planting, each bed divided into 3 raised bed with 120 cm width, 4 m length and 25 cm between beds. Seedlings were grown 25 cm a part on the top and both side of the raised-bed.

To avoid the lateral movement of water and more water control, each main plot was separated by 2 meters wide ditches.

Table 3. Soil-moisture parameters and bulk density of the soil

Depth	Field capacity		Wilting point		Available water		Bulk density (mg/m^3)
	% by weight	cm	% by weight	cm	% by weight	cm	
0-15	38.9	6.94	18.2	3.25	20.7	3.69	1.19
15-30	36.5	6.57	17.1	3.11	19.4	3.49	1.2
30-45	33.9	6.46	16.5	3.14	17.4	3.31	1.27
45-60	32.8	6.84	16.4	3.42	16.4	3.42	1.39
Total		26.81		12.92		13.91	

Studied characters

Vegetative growth and yield parameters

At each harvest, Plant samples were randomly collected from all treatments. The following parameters were recorded for the two cuts during both seasons:

- Plant height (cm),
- Fresh and dry weight of herb (g/plant),
- Fresh yield (kg/fed).

Chemical analysis

- Essential oil percentage (%): Fresh leaves (100 g) at harvest time were subjected to the hydro-distillation using Clevenger apparatus according to the methods described by British Pharmacopoeia (1963).
- Oil Yield (l/fed)
- Gas Liquid Chromatography (GLC): The volatile oil obtained from the fresh leaves was analysed in Laboratory of Medicinal and Aromatic Plants Research Department, Horticulture Research Institute, (ARC) using Ds Chrom 6200 Gas Chromatograph apparatus, fitted with capillary column BPX-5, 5 phenyl (equiv.) polysillphenylene-siloxane 30 x 0.25 mm ID x 0.25 µ film. Temperature program ramp increase rate of 10 °C/min from 70 °C to 200 °C. Flow rates of gases were nitrogen at 1 ml/min, hydrogen at 30 ml/min and 330 ml/min for air Detector and injector temperatures were 300 °C and 250 °C respectively. The identification of the different constituents was achieved by comparing their retention times with those of the authentic samples.

Crop water relation parameters

- Amount of applied irrigation water (AIW)

Submerged flow orifice with fixed dimension was used to measure the amount of water applied, according to (Michael, 1978):

$$Q = CA\sqrt{2gh}$$

where:

Q - Discharge through orifice (1/sec),

C - Coefficient of discharge (0.61),

A - Cross-sectional area of the orifice (cm^2),

G - Acceleration due to gravity (981 cm/sec^2),

H - Pressure head, causing discharge through the orifice (cm).

- Water consumptive use (WCU)

Water consumptive use or actual evapotranspiration (ETc) values were calculated for each irrigation using the following formula (Israelsen and Hansen, 1962):

$$WCU = \sum_{i=1}^{i=4} (Q2 - Q1)/100 \star Bd \star D$$

where:

WCU - Seasonal water consumptive use (cm),

Q_2 - Soil moisture content after irrigation (on mass basis, %),

Q_1 - Soil moisture content before irrigation (on mass basis, %),

Bd - Soil bulk density (g/cm^3),

D - Depth of soil layer (15 cm each),

I - Number of soil layer.

Soil moisture content was gravimetrically determined in soil samples taken from consecutive depths of 15 cm down to 60 cm. Soil samples were collected just before each irrigation, 48 hours after irrigation and at harvest time.

- Water use efficiency (WUE)

Water use efficiency (WUE) is used to describe the relationship between production and the amount of water used. It was determined according to the following equation (Vites, 1965):

WUE=Yield (kg/fed.)/ET (m^3 water consumed/fed.)

- Crop water productivity (WP)

Crop Water Productivity is defined as crop yield per unit applied irrigation water that is looking into the efficient use of applied irrigation water (Zhang, 2003) and is given as follow:

WP=Yield (kg/fed.)/AIW(m^3 water applied/fed.)

- Increasing yield (%)

The increase in yield (%) was calculated as under, Tagar et al. (2012):

Increase in Yield (%)= ((Y1-Y2))/Y1 X 100

where:

Y1 - Total yield obtained in raised bed irrigation system (kg/fed),

Y2 - Total yield obtained under furrows or convention irrigation system (kg/fed).

- Water Saving (WS, %)

The water saving for spearmint plant in the 3 different planting methods under the three irrigations treatment was calculated by Soomro et al. (2017):

WS (%)=(WUa-WUb)/Wa X100

where:

WS - Water saving (%),

WUa - Total water used in furrows or convention irrigation system (m^3/fed),

WUb - Total water used in raised bed irrigation system (m^3/fed).

Experimental design and statistical analysis

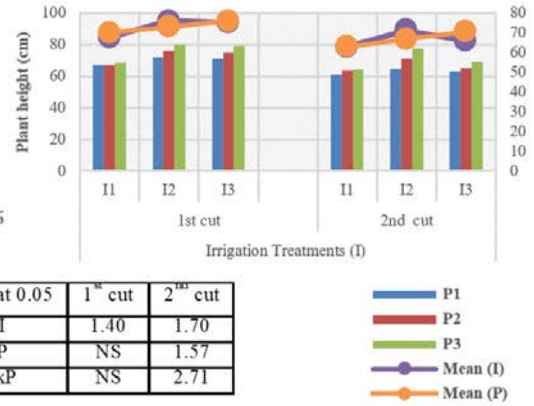
The experiment was laid out at split plot design with 3 replicates in the two seasons. This statistical analysis was done by using the computer program Mstat Software program as proposed by Gomez and Gomez (1984). LSD test at 0.05 was used to compare the means.

RESULTS

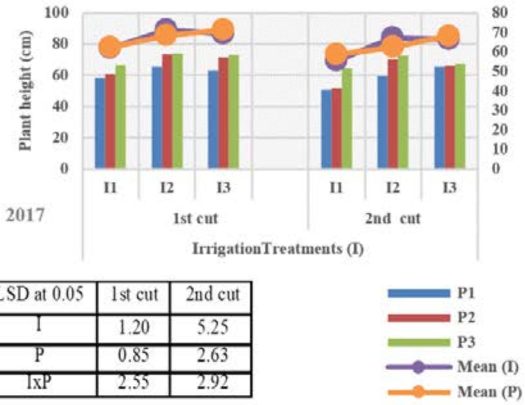
Vegetative growth and yield parameters

The differences in plant height, herb fresh weight (FW/plant) and dry weight (DW/plant), biological yield (FW/fed) were significantly affected by the planting methods under the three different irrigation treatments during two harvests for both seasons and presented in Figure 1. Generally, all studied characters showed significant increasing of values under 100% ETo. In addition, the highest significant data resulted using raised bed. Moreover, for the interaction; the highest significant values of plant height (Figure 1a), herb fresh weight (Figure 1b) and dry weight (Figure 1c) as well as biological yield (Figure 1d) were obtained for raised bed under 100% ETo irrigation treatment compared to other treatments in both seasons. Maximum plant height (80.22 cm) on raised beds was obtained with 100% ETo treatment in the first cut during the first season. Non-significant values of plant height in 1st cut during 1st season were observed under planting practices and under the interaction between planting practices and irrigation treatments. Also, superior

(a)

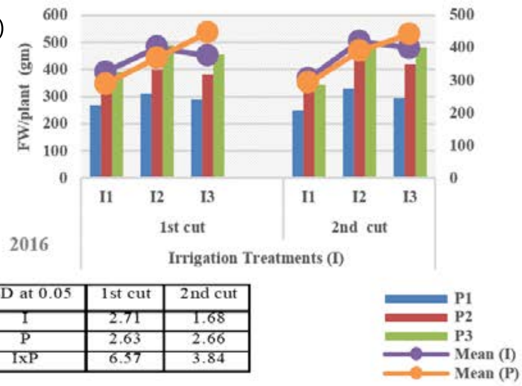


LSD at 0.05	1st cut	2nd cut
I	1.40	1.70
P	NS	1.57
IxP	NS	2.71

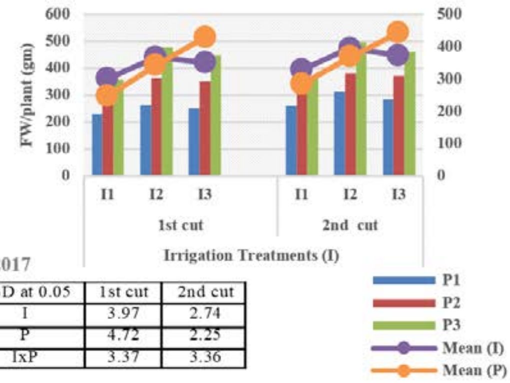


LSD at 0.05	1st cut	2nd cut
I	1.20	5.25
P	0.85	2.63
IxP	2.55	2.92

(b)

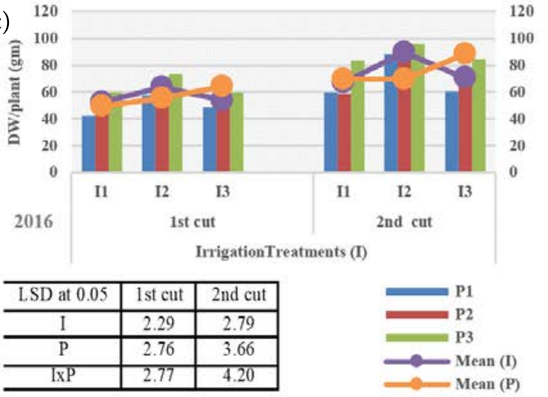


LSD at 0.05	1st cut	2nd cut
I	2.71	1.68
P	2.63	2.66
IxP	6.57	3.84

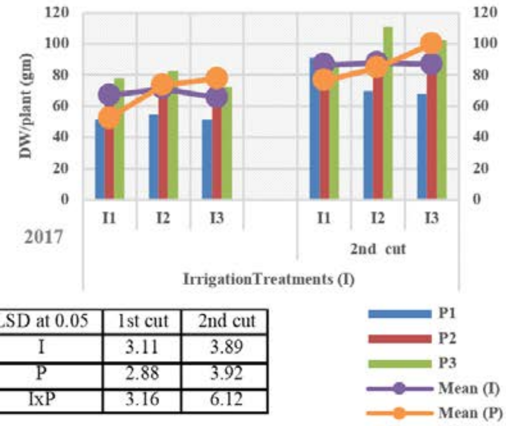


LSD at 0.05	1st cut	2nd cut
I	3.97	2.74
P	4.72	2.25
IxP	3.37	3.36

(c)

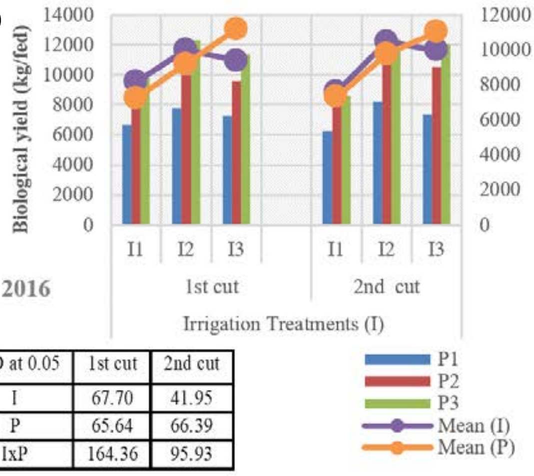


LSD at 0.05	1st cut	2nd cut
I	2.29	2.79
P	2.76	3.66
IxP	2.77	4.20

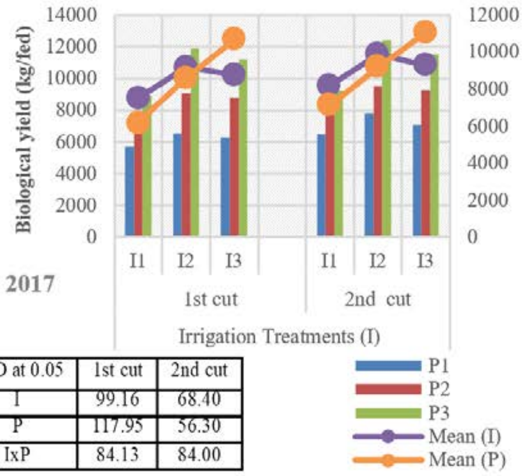


LSD at 0.05	1st cut	2nd cut
I	3.11	3.89
P	2.88	3.92
IxP	3.16	6.12

(d)



LSD at 0.05	1st cut	2nd cut
I	67.70	41.95
P	65.64	66.39
IxP	164.36	95.93



LSD at 0.05	1st cut	2nd cut
I	99.16	68.40
P	117.95	56.30
IxP	84.13	84.00

Figure 1. Correlation of irrigation treatments (I) and planting methods (P) on spearmint vegetative growth: Plant height (a), FW/plant (b), DW/plant (c), FW/fed for two successive seasons

FW/plant and DW/plant as well as FW/fed (496.31, 110.78 g/plant and 12,407 kg/fed), respectively were realized with 100% ETo under raised bed method in the 2nd cut during second season. In contrast, comparable low values with 80% ETo under convention planting method were 58.39 cm, 229.06 g/plant and 5,726.5 kg/fed for plant height, fresh weight per plant as well as fresh yield, respectively.

Chemical analysis

Essential oil percentage

Essential oil content per 100 g of spearmints fresh biomass is given in Figure 2, for both seasons, irrigation at 100% ETo showed the maximum values. Furthermore, in first season where the highest values reached up to 0.7% under raised bed at 100% ETo were obtained. At both cuts during 2nd season, non-significant data were observed. In addition, it was observed a reduction in oil content at 80 or 120% ETo under furrow and conventional methods. A percentage of 0.25 was the lowest value of essential oil given at 80% ETo under conventional practice. While in second season, slight changes were noted in essential oil composition under all treatments.

Oil yield (l/fed)

Generally, essential oil yielded the highest amount under raised bed method at 100% ETo (Figure 3), but showed decreasing trend as the amount of irrigation water reduced at 80% ETo under tested treatments.

GLC analysis of essential oil composition

The three major monoterpenes (carvone, limonene, and 1,8 cineol) that comprise over 80% of the significant monoterpenes are presented in Figure 4. The results showed that the major component is carvone. Under raised bed method there is no significant difference in carvone content, being 65.79, 65.63 and 67.3% under 80, 100 and 120% ETo, respectively.

The highest content of carvone (72.08%) was given under furrows at 120% ETo. Moreover, under convention method there were significant reduction in carvone percentage, being 57.26, 36.92 and 62.8 at 80, 100 and 120% ETo, respectively. For 100% ETo, the maximum limonene percentages 18.37 and 18.18% was realized under raised bed and furrows, respectively. Similar value of 18.18% was found under conventional method at 120% ETo. Whereas, the least value of 14.2% was obtained with

LSD at 0.05	1st cut	2nd cut
I	0.01	0.04
P	0.02	0.03
IxP	0.02	0.04

LSD at 0.05	1st cut	2nd cut
I	NS	NS
P	0.02	0.02
IxP	NS	0.03

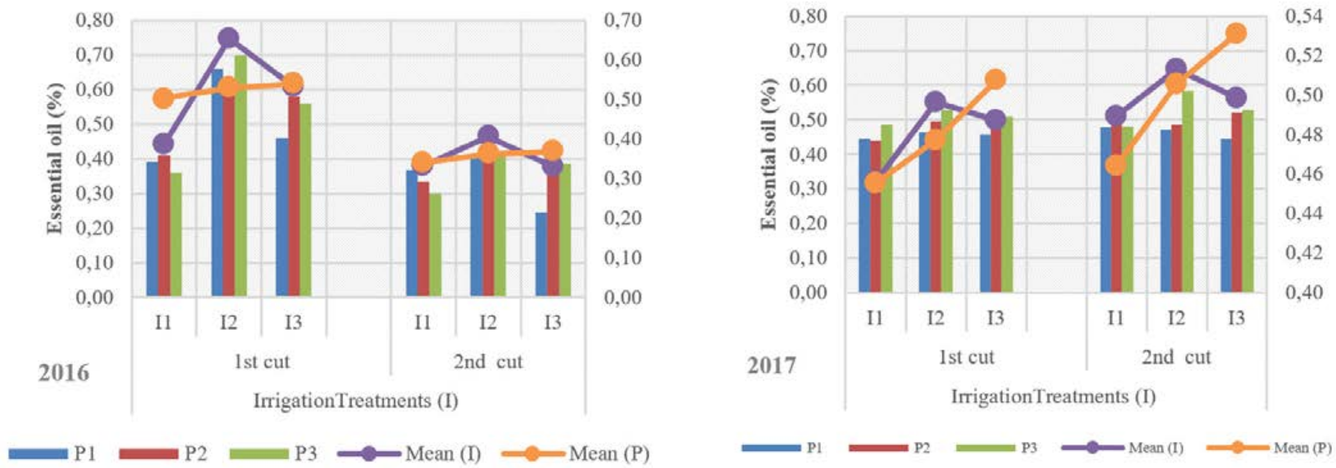


Figure 2. Effect of different planting methods (P) with different irrigation treatments (I) on spearmint essential oil (%) for two successive seasons

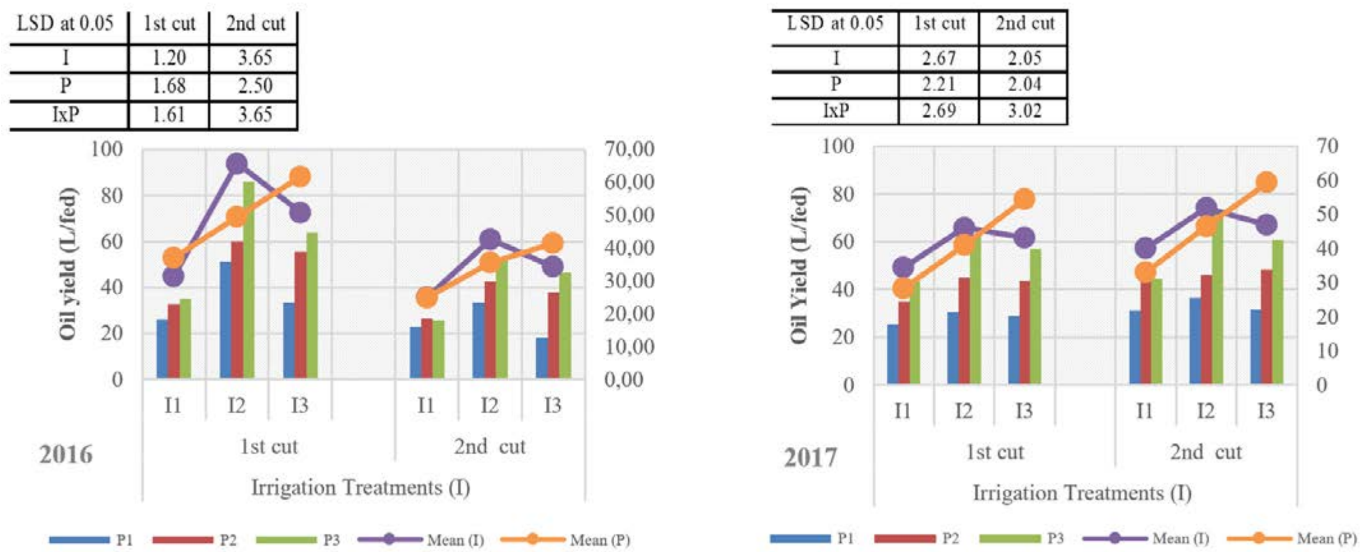


Figure 3. Oil yield (l/fed) under different planting methods (P) at different water irrigation treatments (I) for two successive seasons

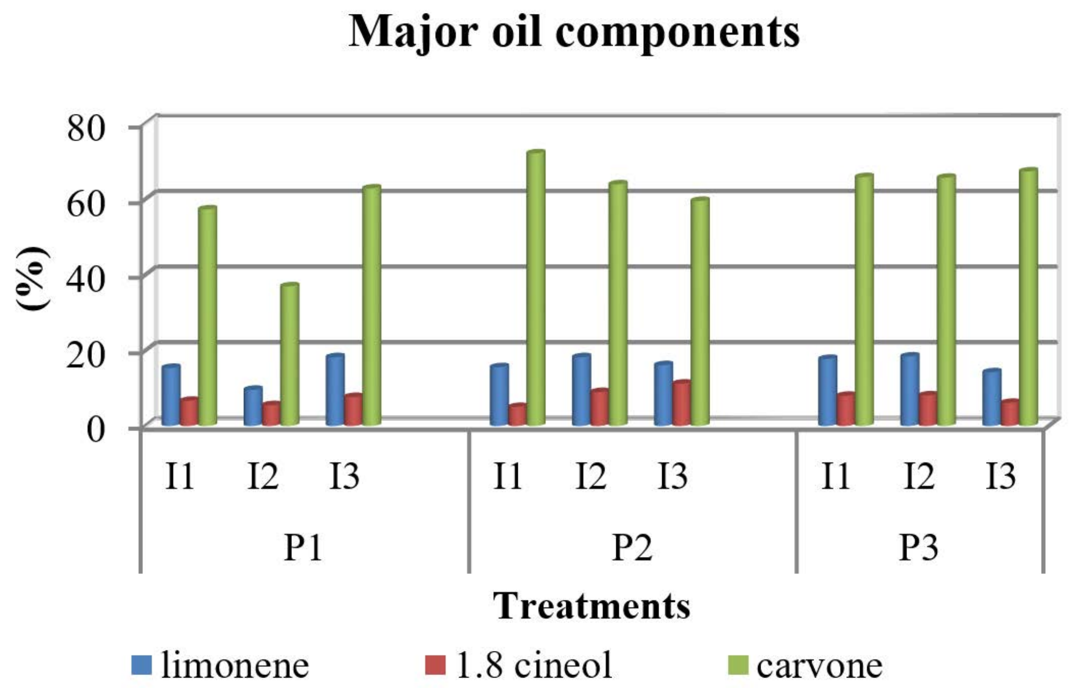


Figure 4. Percentage composition of the major spearmint oil monoterpenes under planting methods (P) and water irrigation (I) treatments in 1st cut during 1st season

raised bed at 120% ETo. As for 1,8 cineol percent value of 11.2% was realized under furrows method at 120% ETo being the superior value compared to other treatments.

Crop water relation parameters

Applied irrigation water (AIW)

Generally, AIW were increased significantly with increasing levels of irrigation up to 120% ETo under the different planting methods. Data in Figure 5a demonstrated that in the first season the amount of applied water was found to be 2,622 m^3/fed under raised bed planting method at 80% ETo. Contrariwise to this, the highest applied irrigation water was 4,106 m^3/fed obtained from 120% ETo under convention planting method. Similar trend was found in the second season, whereas, the least value of applied irrigation water was 2,839 m^3/fed at 80% ETo under raised bed planting method. On the other hand, the maximum value of applied irrigation water was 5,500 m^3/fed at 120% ETo under convention planting method.

Water consumptive use (WCU)

Overall, WCU values (Figure 5b) followed similar trend to AIW whereas the least value was found to be 2,221.6 m^3/fed for raised bed under 80% ETo. While, the highest value was attained by 3,706 m^3/fed under convention at 120% ETo in the first season. respective values for the second season were 4,987 m^3/fed with 120% ETo under convention method, furthermore, the least value was 2,589 m^3/fed under 80% ETo with raised bed method.

Water use efficiency (WUE)

Water use efficiency represents the amount of yield produced for every cubic meter of water used by the crop. Results in the current study illustrated in Figure 5c showed that the highest WUE (8.9 m^3/fed) was obtained from 100% of ETo under raised bed followed by (8.3 m^3/fed) at 80% of ETo under raised bed. Whereas the minimum value (3.9 m^3/fed) was found at 120% ETo under conventional surface irrigation method in first season. The same tendency was cleared in the second season.

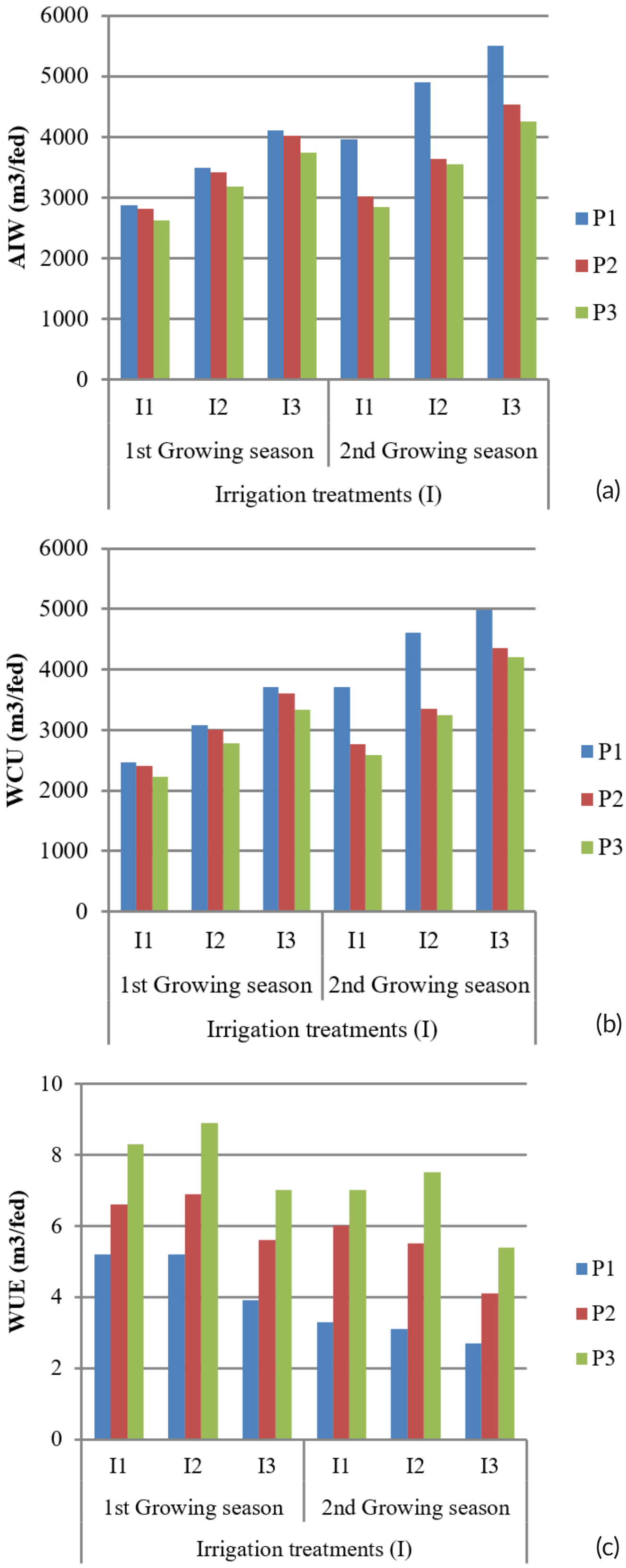


Figure 5. Applied irrigation water (AIW) (a), water consumptive use (WCU) (b) and water use efficiency (WUE) (c) under the tested planting methods (P) and irrigation (I) treatments for 2016 and 2017 seasons

Crop water productivity (WP)

Crop water productivity is a quantitative term used to define the relationship between crop produced and the amount of water involved in crop production. It is a useful indicator for quantifying the impact of irrigation regimes decisions, with regard to water management (Food and Agriculture Organization, 2002).

Data in Figure 6 indicated that water productivity increased using raised bed producing 7.8 yield kg/m^3 water applied at 100% ETo in the first season. Comparable value is 6.8 yield kg/m^3 water applied in the second season. On the other hand, WP was low under with conventional surface irrigation being 3.6 and 2.4 yield kg/m^3 at 120% ETo in first and second growing season, respectively.

It follows that it can be indicated; raised bed planting methods for spearmint realized the maximum WP compared to the other assisted treatments.

Yield and water relations as affected by planting methods

Figure 7 illustrated that generally, raised bed under 80% of irrigation applied water produced the highest water saving being about 17.47% and 20.01% compared to the recommended irrigation water (raised bed at 100% ETo) for 1st and 2nd season, respectively. In addition, as compared to the furrows at 120% ETo, the saved water was 34.63% and 37.47% for 1st and 2nd season, respectively. Indeed, the maximum amount of water saved was increased when compared to conventional basin irrigation at 120% ETo being 36.14 and 48.38% for 1st and 2nd season, respectively. As for yield reduction as affected by planting methods under 80%, it was found that the least yield reduction being 25.22% was realized under raised bed compared to 35.53 and 47.41% under furrows and conventional planting methods relative to the recommended irrigation water in the first season. Data in the 2nd season showed the same trend. It was observed that when compared to planting using conventional methods at 120% ETo, under 80% ETo the yield was increased by about 8.76% and 26.14% for Furrows and raised bed in the first season, second season showed the same trend. On the other hand, when compared with planting on furrows at 120% ETo, the reduction in yield under 80% ETo was 8.28, 20.92 and 35.5% for raised bed, furrows and conventional methods, respectively in the first season. As for the second growing season the reduction was 7.2 and 32.15% for furrows and conventional, while under raised bed increased by 0.53%.

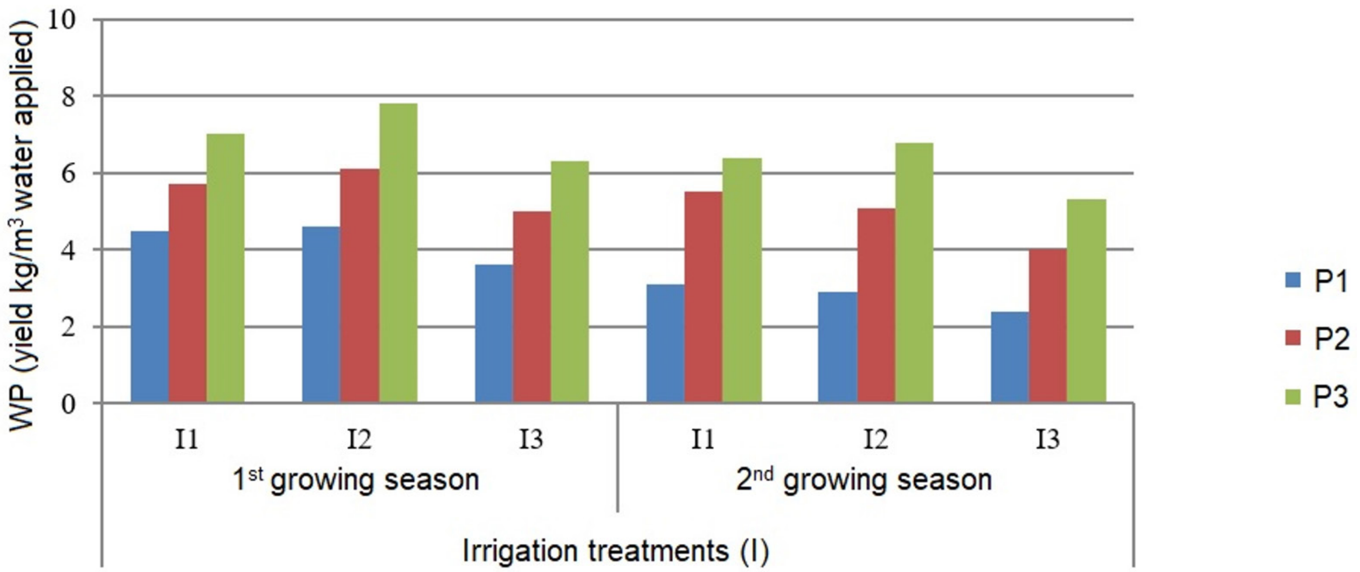


Figure 6. Crop water productivity (WP) under the tested planting methods (P) and irrigation (I) treatments for 2016 and 2017 seasons

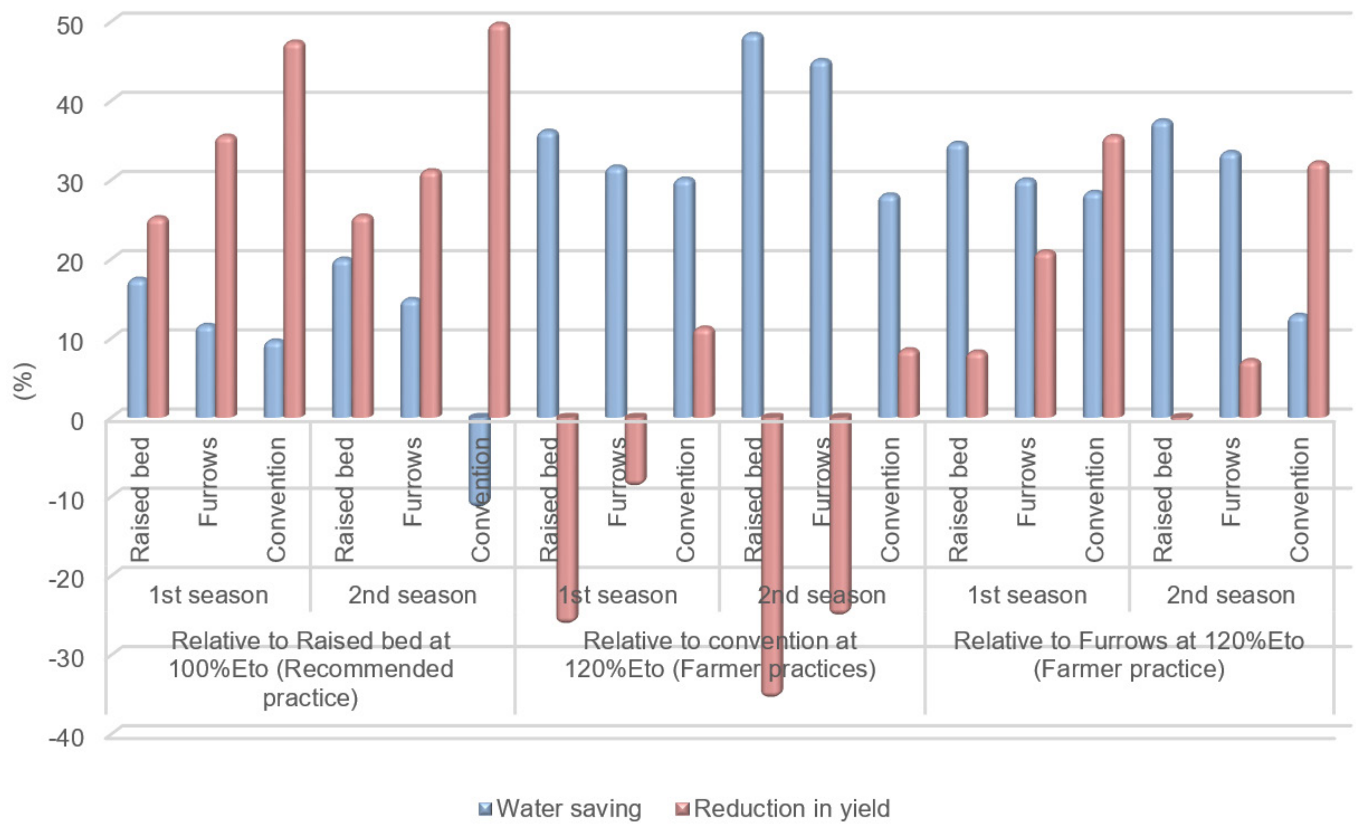


Figure 7. Interventions effect on yield and water productivity

DISCUSSION

The aim of the adoption of alternative planting practices is to use less water to grow spearmint without affecting the yield. The results showed that the superiority of the studied parameters "plant height, fresh weight, dry weight per plant as well as the weight of biological yield per fed" using raised beds was possibly due to exposure of more surface area to incident solar radiation in raised bed than in furrows or convention planting methods, the higher temperature on raised bed can help the growth of the plants. These results are in agreement with Hossain et al. (2006), Alam (2012) and Osman et al. (2015). What's more, changing from convention to bed technology improves the hydrology system and authorizes greater irrigation monitoring, better surface drainage and possibly superior capture and use of irrigation water. Where the irrigation water moves laterally from the furrow into the bed, and is driven upwards towards the bed surface by evaporation and capillarity, and downwards largely by gravity. The altered hydrology affects nutrient transformations and transport compared with irrigation on the convention (Farooq et al., 2009; Naresh et al., 2014). Otherwise, the adoption of permanent beds led to controlled traffic, thereby providing a healthy root environment, on Bergamot mint; Ram et al. (1995) stated that increased irrigation with pronounced effect on growth may be attributed to the availability of sufficient moisture due to extensive shallow root system of the crop which created a conducive environment to absorb more water for better growth. On the contrary, planting on conventional irrigation system reduces the growth yield may be due to the higher penetration resistance which associated with increased bulk density and shallow hard pans in sub-surface layers that reduce the root growth of crop. These results are in agreement with (Naresh et al., 2014). Just the same, the decreasing of growth and yield components at 80%, this could may be due to that reducing available soil moisture resulted in reducing absorption of soil solutions (water and nutrients). These outcomes are affirmed by the findings of Okwany et al. (2009) and Meskelu et al. (2014) on spearmint, Bahreininejad et al. (2013) on *Thymus daenensis* and Said-Al Ahl and Hussein (2010) on oregano plant and Sharmin et al. (2009) on Japanese mint. Water is very important on physiological process e.g. photosynthesis, protein synthesis, enzyme activity etc., and these effect the metabolites transpiration (Naceur et al., 1999). Kramer (1995) pointed out that water plays a central role in the cell division, enlargement and differentiation of plant organs and its availability often becomes limiting. It appeared that the promoting effect of enough water on plant height was automatically reflected to the fresh weight of plant. Total fresh and dry weights of plants were decreased due to exposure to injurious levels of water stress (80%) or excessive water (120%). This could be the result of a reduction in chlorophyll content and, consequently, photosynthesis efficiency, as reported by Abdul-Hamid et al. (1990), Castonguay and Markhart (1991), Nunez-Barrious (1991) and Viera et al. (1991).

On the other hand, it was observed a reduction in oil content under 80 or 120% ETo while increasing using raised bed at 100% ETo which may be related to the change in vegetative growth, which caused greater senescence of lower leaves due to mutual shading. The leaves being the sites of oil synthesis and its accumulation are of great significance in increasing oil concentration. Kothari et al. (1987) also reported lower leaf/stem ratio and oil content with increased herbage production in Japanese mint (*Mentha arvensis* L.). The accumulation of essential oils in plants is usually limited to specialized secretory structures which are present in several different types, namely glandular trichomes. They are multicellular epidermal hairs found in some families like the Lamiaceaes, Asteraceaes, and Solanaceae, which secrete terpenes in the extracellular cavity at the apex of the trichome (Werker et al., 1993; Werker, 2000). The storage of terpenoid in these structures can be used to limit the toxicity risk to the plant itself, because it is proven that many terpenoids are potentially toxic to plant tissues when monoterpenes are released to the surrounding cells (Loveys et al., 1992). Injuries were also found when some sesquiterpenes were artificially deposited on sheets during tests on their ability to deter herbivores (Polonsky et al., 1989). Therefore, sequestration of terpenoids in specific compartments by sensitive metabolic processes can be essential to avoid harmful effects. However, the morphology of these structures varies with the irrigation conditions. The decrease of water content in leaves causes a plasmolysis of cells following the decrease of the water content at the glands, which leads to a decrease of their volume and deflation. This decrease of volume is even more pronounced in stress condition (Hazzoumi et al., 2017). Generally, essential oil yielded the highest amount under raised bed method at 100% ETo, but showed decreasing trend as the amount of irrigation water reduced at 80% ETo under tested treatments. This is in line with reports of Okwany et al. (2012) and Meskelu et al. (2014) on spearmint. Bahreininejad et al. (2013) on *Thymus daenensis*, Said-Al Ahl and Hussein (2010) on oregano and Sharmin et al. (2009) on Japanese mint.

The results indicated that raised bed planting method saved irrigated water comparable by convention and furrows planting methods. The idea behind the raised bed planting method is to reduce water losses and decreasing evaporation, deep percolation, surface run-off, and seepage. These advantages come from the fact that the irrigation water advances faster in raised bed than in furrows and convention method and less water percolation loss happens. These findings are in agreement with Ram et al. (2013) and Osman et al. (2015). In this respect, changing growing crop from flat planting with flood irrigation to raised bed planting with furrow irrigation improved water use efficiency by 21-30% combined with an approximate 17% saving in applied irrigation water Fahong et al. (2004). These results are in agreements with the findings of Naresh et al. (2014), they concluded that there was about 20.4% and 16.5% water saving with an increase in grain yield about 13.5% and 11.8% for crops with raised bed planting compared to traditional planting. In addition, Khoso (1994) reported that crop yield increased under raised bed due to rich nutritional soil, being loose, had a better environment for aeration, water movement, root development and sufficient moisture content for mineralization of native as well as applied nutrients. Furthermore, these results are in line with Hobbs et al. (2000) who stated that raised-bed planting contributes in improvement of water distribution and its efficiency. Moreover, these results are in accordance with the findings of Bhuyan et al. (2012), who concluded from their study that water use efficiency and crop productivity for production were higher in bed planting over conventional method. In the same direction, Soomro et al. (2017) proved the superior effect with planting on raised bed over conventional irrigation systems for yield and water productivity.

CONCLUSIONS

On the basis of growth patterns and yields of herb and essential oil of spearmint studied under different planting methods and irrigation amounts, it can be concluded that the proposed raised bed planting method under 80% ETo produced the highest yield of spearmint up to 26% as well as water saving increased up to 48% compared to the conventional planting methods at 120% ETo. The adoption of this efficient technology could be reflected on saving labor, time, water, energy and production cost as well as increasing farmer income. Furthermore, applying the raised beds in Egypt suffering from limited water resources will contribute to improving water productivity.

REFERENCES

Abdul-Hamid, A.F., Kubota, F.A., Morokuma, M. (1990) Photosynthesis, transpiration, dry matter accumulation and yield performance of Mungbean plant in response to water stress. Journal of the Faculty of Agriculture, Kyushu University, 35, 81-92.

Abouelenein, R., Oweis, T., Sherif, M., Khalil, F.A., Abed El-Hafez, S.A., Karajeh, F. (2010) A new water saving and yield increase method for growing berseem on raised seed bed in Egypt. Egyptian Journal of Applied Science, 25, 26–41.

Abou Zeid, K. (2002) Egypt and the world water goals: Egypt statement in the world summit for sustainable development and beyond. New York: United Nations.

Alam, M.S. (2012) Effect of sowing patterns and nitrogen rates on quality traits and yield of wheat. Journal of Environmental Science and Natural Resources, 25, 267-272. DOI: http://dx.doi.org/10.3329/jesnr.v5i1.11591

Bahreininejad, B., Razmjooa, J., Mirzab, M. (2013) Influence of water stress on morpho-physiological and phytochemical traits in *Thymus daenensis*. International Journal of Plant Production, 7, 151-166.

Behera, M.S., Mahapatra, P.K., Singandhupe, R.B., Kundu, D.K., Kannan, K., Mandal, K.G., Amarpreet, S. (2014) Effect of drip fertigation on yield, water use efficiency and water productivity of Mint (*Mentha arvensis* L.). Journal of Agricultural Physics, 14, 37-43.

Bhuyan, M.T. (2012) Yield and growth response to transplanted Aman rice under raised bed over conventional cultivation method. ISRN Agronomy, 1-8.

British Pharmacopoeia (1963) Determination of volatile oil in drug. London: The Pharmaceutical Press.

Castonguay, Y., Markhart, A.H. (1991) Leaf gas exchange in water stress common bean and tepary bean. Crop Science, 32, 980-986.

Downey, L.A. (1971a) Effect of sypsum and drought stress on maize (*Zea mays* L.), I. Growth, light absorption and yield. Agronomy Journal, 63, 569-572.

Downey, L.A. (1971b) Effect of gypsum and drought stress on maize (*Zea mays* L.), II. Consumptive use of water. Agronomy Journal, 63, 597-600.

Fahong, W., Xuqing, W., Sayre, K. (2004) Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. Field Crops Research, 87, 35-42.

Farooq, M.N., Kobayashi, A., Wahid, O.I., Basra, S.M.A. (2009) Strategies for producing more rice with less water. Advances in Agrononomy, 101, 351–388. DOI: http://dx.doi.org/10.1016/S0065-2113(08)00806-7

Food and Agriculture Organization (2002) Deficit irrigation practices. Water Reports 22. Rome: Food and Agriculture Organization. Available at: ftp://ftp.fao.org/agl/aglw/docs/wr22e.pdf [Accessed on 12 March 2012].

Gomez, K.A., Gomez, A.A. (1984) Statistical procedures for agricultural research. 2nd edition. New York: John Wiley & Sons Inc.

Hazzoumi, Z., Moustakime, Y., Amrani Joutei, K.H. (2017) Effect of arbuscular mycorrhizal fungi and water stress on ultrastructural change of glandular hairs and essential oil compositions in *Ocimum gratissimum*. Chemical and Biological Technologies in Agriculture, 4, 20. DOI: https://doi.org/10.1186/s40538-017-0102-z

Hobbs, P.R., Singh, Y., Giri, G.S., Lauren, L.G., Duxbury, J. (2000) Direct seeding and reduced tillage options in the rice-wheat systems of the Indo-Gangetic Plains of South Asia. IRRI Workshop, Bangkok, Thailand, 2000, International Rice Research Institute, 25-26.

Hossain, I., Islam, K., Abu Sufian, M.D., Meisner, C.A., Islam, M.D.S. (2006) Effect of planting methods and nitrogen levels on the yield and yield attributes of wheat. Journal of Biological Science, 14, 127-130.

Israelsen, O.W., Hansen, V.E. (1962) Irrigation principles and practices. 3rd edition. New York: John Willey and Sons Inc.

Karrou, M., Oweis, T., El Enein, R., Sherif, M. (2012) Yield and water productivity of maize and wheat under deficit and raised bed irrigation practices in Egypt. African Journal of Agricultural Research, 7, 1755–1760. DOI: http://dx.doi.org/10.5897/AJAR11.2109

Khoso, A.W. (1994) Growing vegetables in Sindh and Balochistan. Tandojam: Department of Agronomy, Sindh Agriculture University Tandojam.

Klute, A. (1986) Methods of soil analysis (Part 1). 2nd edition. Madison, Wisconsin: American Society of Agronomy, Soil Science Society of America.

Kothari, S.K., Singh, V., Singh, K. (1987) Response of Japanese mint (*Mentha arvensis* L.) to varying levels of N application in U. P. foot hills. Indian Journal of Agricultural Science, 57, 795-800.

Kramer, P.J., Boyer, J.S. (1995) Water relations of plants and soils. San Diego: Academic Press.

Ley, W.T., Stevens, G.R., Leib, B. (2003) Mint irrigation management. Drought Advisory, EM4827. Available at: http://cru.cahe.wsu.edu/CEPublications/em4827/em4827.pdf

Loveys, B.R., Rorinson, S.P., Bropl, J.J., Chacko, E.K. (1992) Mango sapburn: components of fruit sap and their role in causing skin damage. Australian Journal of Plant Physiology, 19, 449–457.

Majeed, A., Muhmood, A., Niaz, A., Javid, S., Ahmad, Z.A., Shah, S.S.H., Shah, A.H. (2015) Bed planting of wheat (*Triticum aestivum* L.) improves nitrogen use efficiency and grain yield compared to convention planting. The Crop Journal, 3, 118 –124. Available at: http://creativecommons.org/licenses/by-nc-nd/4.0/

Meskelu, E., Mohammed, M., Yimenu, F., Derese, Y. (2014) Spearmint (*Mentha spicata* L.) Response to deficit irrigation. International Journal of Recent Research in Life Sciences (IJRRLS), 1, 22-30. Available at: www.paperpublications.org

Michael, A.M. (1978) Irrigation theory and practice. New Delhi, Bombay: Vikas Publishing House PVTLTD.

Ministry of Agriculture (2015) Agricultural statistics. Cairo, Egypt: Agricultural Statistics Department, Ministry of Agriculture.

Naceur, M.B., Naily, M., Selmi, M. (1999) Effect of water deficiency during different growth stages of wheat on soil humidity, plant physiology and yield components. Medit, 10, 60-63.

Naresh, R.K., Tomar, S.S., Kumar, D., Samsher, Purushottam, Singh, S.P., Dwivedi, A., Kumar, V. (2014) Experiences with rice grown on permanent raised beds: Effect of crop establishment techniques on water use, productivity, profitability and soil physical properties. Journal of Rice Science, 21, 170-180. DOI: https://doi.org/10.1016/S1672-6308(13)60185-7

Nunez-Barrious, A. (1991) Effect of soil water deficits on the growth and development of dry bean at different stages of growth. Dissertation Abstracts International. B, The sciences and engineering, 52 (5), 2359B.

Okwany, O.R., Peters, T.R., Ringer, K.L. (2009) Effect of sustained deficit irrigation on hay and oil yield of native spearmint (*Mentha spicata*). In irrigation and drainage for food, energy and the environment. In: 5th international conference on irrigation and drainage, Salt Lake City, 3–6 November 2009, 239–252.

Okwany, O.R., Peters, R.T., Ringer, L.K., Walsh, B.D., Rubio, M. (2012) Impact of sustained deficit irrigation on spearmint (*Mentha spicata* L.) biomass production, oil yield, and oil quality. Irrigation Science, 30, 213–219. DOI: http://dx.doi.org/10.1007/s00271-011-0282-4

Osman, E.A.M., Swelam, A.A., Manal, A.H., Sheren, N.N. (2015) Effect of raised bed planting technology on productivity, macro nutrients uptake of bread wheat and saving irrigation water. Fayoum Journal of Agricultural Research and Development, 30, 49-62.

Polonsky, J., Bhatnagar, S.C., Grifths, D.C., Pickett, J.A. Woodcock, C.M. (1989) Activity of quassinoids as antifeedants against aphids. Journal of Chemical Ecology, 15, 993–998. DOI: https://doi.org/10.1007/bf0101519

Rajeshwari, C.U., Preeti, M., Andallu, B. (2012) Efficacy of mint (*Mentha spicata* L.) leaves in combating oxidative stress in type 2-diabetes. International Journal of Life Sciences, 1, 28-34.

Ram, M., Ram, D., Singh, S. (1995) Irrigation and nitrogen requirements of Bergamot Irrigation and nitrogen requirements of Bergamot mint on a sandy loam soil under sub-tropical conditions. Agricultural Water Management, 27, 45-54. DOI: https://doi.org/10.1016/0378-3774(95)91231-U

Ram, H., Dadhwa, V., Vashist, K.K., Kaur, H. (2013) Grain yield and water use efficiency of wheat (*Triticum aestivum* L.) in relation to irrigation levels and rice straw mulching in North West India. Agricultural Water Management, 128, 92–101.

Said-Al Ahl, H.A.H., Hussein, M.S. (2010) Effect of water stress and potassium humate on the productivity of oregano plant using saline and fresh water irrigation. Ozean Journal of Applied Sciences, 3, 125-141.

Sharmin, T., Khan, M.A.H., Alamgir, M. (2009) Response of different level of nitrogen fertilizer and water stress on growth and yield of Japanese mint (*Mentha arvensis* L.). Bangladesh Journal of Scientific and Industrial Research, 44, 137-145.

Sheha, A., Ahmed, M., Nagwa, R., Abou-Elela, A.M. (2014) Effect of crop sequence and nitrogen levels on rice productivity. Annals of Agricultural Science, Moshtohor, 52, 451–460.

Soomro, A., Nauman, M., Soomro, S.A., Tagar, A.A., Soomro, S.A., Buriro, M., Gandahi, A.W., Memon, A.H. (2017) Evaluation of raised-bed and conventional irrigation systems for yield and water productivity of wheat crop. Journal of Basic and Applied Sciences, 13, 143-149. DOI: http://dx.doi.org/10.6000/1927-5129.2017.13.24

Stackman, W.P. (1966) Determination of pore size by the air bubbling pressure method. Proceedings of the Wageningen Symposium on water in the unsaturated zone, Netherlands, UNESCO, 366- 372.

Tagar, A., Chandio, F.A., Mari, I.A., Wagan, B. (2012) Comparative study of drip and furrow irrigation methods at farmer's field in Umarkot. World Academy of Science, Engineering and Technology, 69, 863-867.

Viera, H.J., Bergamaschi, H. Angelocci, L.R., Libardi, P.L. (1991) Performance of two bean cultivars under two water availability regimes. II. Stomatal resistance to vapor diffusion, transpiration flux density and water potential in the plant (in Portugal). Pesquisa Agropeularia Brasileira, 9, 1045-1035.

Vites, F.G. (1965) Increasing water use efficiency by soil management. American Society of Agronomy, 259-274.

Werker, E., Putievsky, E., Ravid, U., Dudai, N., Katzir, I. (1993) Glandular hairs and essential oil in developing leaves of *Ocimum basilicum* L. (*Lamiaceae*). Annals of Botany, 71, 43–50. DOI: https://doi.org/10.1006/anbo.1993.1005

Werker, E. (2000) Trichome diversity and development. Advances in Botanical Research, 31, 1–35. DOI: https://doi.org/10.1016/S0065-2296(00)31005-9

Zhang, H. (2003) Improving water productivity through deficit irrigation: Examples from Syria, the north China Plain and Oregon, USA. In: Kijne, J.W., Barker, R., Molden, D., eds. Water productivity in agriculture: Limits and opportunities for improvement. Wallingford: CABI publishing.