Article

Effect of irrigation system and soil conditioners on growth and essential oil of *Rosmarinus officinalis* L. cultivated in Egypt

Elsayed Omer[1]*, Saber Hendawy[1], Abdel Nasser G. ElGendy[1], Alberto Mannu[2,3], Giacomo L. Petretto[2] and Giorgio Pintore[2]*

[1] Medicinal and Aromatic Plants Research Department, National Research Centre, Dokki (12622), Cairo, Egypt; hendawysaber@yahoo.com; aggundy_5@yahoo.com
[2] Department of Chemistry and Pharmacy, Sassari University, Sassari, Italy; gpetretto@uniss.it
[3] Dipartimento di Chimica, Università di Torino, Via Pietro Giuria, 7, I-10125 Torino, Italy; alberto.mannu@unito.it
* Correspondence: sayedomer2001@yahoo.com (EO); pintore@uniss.it (GP)

Abstract: A relevant improvement of the cultivar conditions of *Rosmarinus officinalis L.* in desert areas was achieved by a specific combination between irrigation system and soil conditioner. A drastic reduction of water employment was obtained without affect the quality of the plants, determined by monitoring growth parameters and essential oil characteristics. In particular, the effect of surface and subsurface drip irrigation systems and different soil conditioners on growth parameters, yield, and essential oil constituents of rosemary plant was assessed. Field experiments at the Agricultural Research Station (Al-Adlya farm), SEKEM group Company, El-Sharkiya Governorate, Egypt, conducted over the two seasons revealed the effectiveness of the subsurface irrigation system in obtaining better performances, especially in terms of water saving. The combination of subsurface irrigation and the conditioner Hundz soil with bentonite showed the maximum mean values of growth characters compared with other soil amendments during both seasons. The possibility to employ a water-saving irrigation system as the subsurface one without any drawback in the resulting plants was also explored in terms of molecular composition. GC-MS analysis of the essential oil extracted from plants growth under different irrigation conditions revealed a comparable composition in both cases. The goodness of the most performing system was also confirmed by the comparable yield of the essential oil.

Keywords: *Rosmarinus officinalis L.*, surface and subsurface drip irrigation, bentonite, Hundz conditioner, essential oil.

1. Introduction

Water is a very important and economical resource and it represents a major limiting factor for sustainable agriculture in arid and semi-arid regions [1]. In Egypt, all cultivated lands are characterized by an arid or semi-arid climate and the water required for agricultural and horticultural crops is obtained mainly through irrigation systems which consume about 83% of the country's available fresh water [2]. The demanding need of water is in part determined by the *low field* application efficiency [3], which in most traditional irrigation methods is less than 50% or lower, often under 30% [4]. Thus, the interest toward developing and adopting new and efficient water irrigation systems, particularly in arid and semi-arid regions, is very high [5]. In areas like Egypt, this problem is particularly evident, as the growing competition for optimizing the scarce water resources has led to the development of new techniques for maximizing the water use efficiency and improving crop yields and quality [6].

The first step toward the optimization of water demand should consist in reducing the current excessive application of water in agricultural lands. This, generally entails losses due to surface runoff from the field and to deep percolation below the root zone within the field [7]. Both phenomena are difficult to control under furrow irrigation system, where a large volume of water is applied at a single instance. Alternative water application methods, such as the drip irrigation system, have some advantages as a more uniform irrigation distribution, a more precise control of the amount of water employed, and the decrease of nutrient leaching, a reduction of subsurface drainage, a better control of soil salinity, and increased yields of growth parameters [8-11]. Nevertheless, drip irrigation system has some drawbacks as its cost, which can reach $ 2470 ha^{-1} [12]. Also, drip irrigation requires the presence of small and diffused irrigation systems to saturate the soil and fulfill plant water requirements. In addition, there are specific problems related to the management of sandy soils, including their excessive permeability and low water and nutrient holding capacities [13]. The water use efficiency can be increased by using a subsurface drip irrigation system, which is characterized by a reduced soil and plant surface evaporation and allows to irrigate exclusively the root zone or the partial root zone as opposed to sprinkler irrigation where the entire field area is wetted [14-16]. Also, subsurface drip irrigation allows improving the salinity management and the water use efficiency. Phene [8] and Oron [17] reported that surface drip irrigation decreases the accumulation of salts at the root zone level of plants, producing an improved yield and fruit quality. Oliveira reported that subsurface drip irrigation reduces evaporation from the soil and increases wetted soil volume and surface area more than surface systems, allowing a deeper rooting pattern [18]. Subsurface drip irrigation system has been successfully employed for the irrigation of a wide range of crop patterns [19] but, on the other hand, no studies had been conducted under intensive field crops. The use of these modern irrigation systems (surface and subsurface drip) in cultivating ornamental plants has improved the growth and quality of flowers [20,21]. It is known that drip irrigation can increase the water use efficiency in crop production. Even more efficient in terms of water amount needed, is the subsurface drip irrigation [22], which differs from the standard drip irrigation in the way that the lateral pipes are buried below the ground surface [23]. In subsurface drip irrigation, the water losses through evaporation and deep percolation are minimized, resulting in an increased overall efficiency and nutrient conservation. Lamm and coworkers achieved a water savings of ~25% with respect to classical techniques in the case of corn cultivation [24]. Nevertheless, it is impossible to establish a priori the best irrigation mechanism in terms of general efficiency, and a comparison between the available irrigation techniques is mandatory before to choose the more appropriate system. In this context, the assessment of the best combination between irrigation system and soil conditioner for the cultivation of *Rosmarinus officinalis* L. (Lamiaceae) in Egypt is herein reported for the first time. *Rosmarinus officinalis* is a flowering plant widely present in Mediterranean countries, southern Europe and in the littoral region through Minor Asia areas. Several studies on the chemical composition of the phenolic compounds [25] as well as on the steam distilled essential oils (EOs) from plants belonging to different regions in the world have been reported [26,27]. Many aspects of the EO of *Rosmarinus officinalis* has been object of research, as the antioxidant activity [28,29], the antibacterial [30,31], the toxicity toward insects [32] the anti-inflammatory [33], antinociceptive [34], and antifungal activity [35,36]. Also, in recent years EOs of *Rosmarinus officinalis* have been commercialized as pest control products [37]. A detailed study about several growth parameters, including the EO composition, is herein presented. In particular, growth, yield, and chemical composition of the EO extracted from different parts of the plant will be described and related to the specific irrigation system (surface or subsurface drip irrigation) and soil conditioner. The possibility to optimize, in terms of water harvesting, rosemary cultivation in arid lands is thus explored. In order to reach such target, the following parameters have been monitored and related with irrigation system and soil conditioner: plant height, branches number, weight yield of fresh and dry herb, EO content and yield.

2. Results and Discussion

Rosmarinus officinalis L. plants were growth in Egypt, at Agricultural Research Station (Al-Adlya farm), SEKEM group Company, El-Sharkiya Governorate.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 31 July 2020 doi:10.20944/preprints202007.0748.v1

The environmental characteristics, as well as the climatic and physical data of the soil employed for the present research are reported in table 1.

Table 1. Geographic positions, climatic data and specifications of the soil under study.

Al-Adlya site				
Some environmental data				
Latitude (N)	30.397098	O.M. %		1.38
Longitude (E)	31.551662	CaCO3 %		4
Elevation (m)	13	pH (1:2:5)		8.28
Distance (km)[a]	80	EC (dS/m)		2.72
Direction	North-East	Available macronutrients (mg/100 g soil)	Ca^{++}	369
Max. temperature [b]	27.4		Mg^{++}	100
Min. temperature [b]	16.3		Na^{+}	231
◎T[b]	11.1		P	1.82
Relative humidity (%)[b]	56.7		K	27
Average temperature [b] (C)	23.6	Available micronutrients (ppm)	Fe	10.2
RH (%)	61		Mn	13.4
WS (Km/day)	144.7		Zn	2.6
PSSH (hr)	9.3		Cu	0.3
Course sand (%)	76.8			
Silt %	8			
Clay %	15.2			
Texture	Sand loamy			

[a] From Cairo [b] Year average RH = relative humidity; WS = wind speed; PSSH = potential sunshine hours.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 31 July 2020 doi:10.20944/preprints202007.0748.v1

2.1. Plant height (cm) and branches/plant number

At first, growth factors as plant height and number of branches have been monitored for plants growth with surface or subsurface irrigation and with conditioners. The aim of this first analysis was to check how different irrigation systems and by conditioners affect the overall growth of the plants. The results of the monitoring conducted over two seasons are reported in Table 2.

Table 2. Plant height and number of branches/plants of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Treatment		Plant height (cm)						Number of Branches					
		First Season			Second season			First Season			Second season		
		Mean	(±Δ)		Mean	(±Δ)		Mean	(±Δ)		Mean	(±Δ)	
Surface	C	37.3	±	1.9	48.8	±	2.1	7.0	±	0.3	9.2	±	0.5
	H	39.1	±	2.9	52.0	±	3.6	7.3	±	0.3	9.8	±	0.6
	BIO	38.5	±	2.7	50.8	±	2.6	7.2	±	1.2	9.5	±	1.6
	H + B10	38.6	±	1.8	51.5	±	3.5	7.7	±	1.9	10.2	±	0.8
Surface irrigation		38.4	±	2.3	50.8	±	2.9	7.3	±	0.9	9.7	±	0.9
Sub surface	C	39.6	±	1.2	51.4	±	1.5	8.1	±	1.3	10.5	±	2.7
	H	39.4	±	1.7	52.3	±	2.5	9.3	±	1.0	12.3	±	0.6
	BIO	37.2	±	2.6	50.9	±	1.8	8.3	±	1.2	11.2	±	1.0
	H + B10	42.8	±	2.8	53.8	±	2.1	10.9	±	1.7	13.8	±	2.7
Sub-surface		39.7	±	2.1	52.1	±	2.0	9.2	±	1.3	12.0	±	1.8
Soil conditioners	C	38.4	±	1.5	50.1	±	1.8	7.6	±	0.8	9.8	±	1.6
	H	39.3	±	2.3	52.1	±	3.1	8.3	±	0.7	11.0	±	0.6
	BIO	37.9	±	2.6	50.8	±	2.2	7.8	±	1.2	10.4	±	1.3
	H + B10	40.7	±	2.3	52.6	±	2.8	9.3	±	1.8	12.0	±	1.8
LSD 5 % irrigation		ns			ns			ns			ns		
LSD 5 % soil conditioners		ns			ns			ns			ns		
LSD 5 % Interaction		ns			ns			ns			ns		

C = control, H = Hundez soil, BIO. = bentonite, H + B10 = Hundez soil + bentonite, *Δ* = standard deviation, LSD = Least Significant Differences, ns = not significant.

Looking at the data reported in the Table 2, is possible to notice that no significant variation in terms of plant height and number of branches occurred by changing the irrigation system or growing the plants with different sources of soil conditioners. This suggests that the more water-saving subsurface irrigation system can be employed for rosemary cultivation without any loss in terms of growth parameters. The same analysis was conducted in terms of different soil conditioners: HUNDZ soil combined with bentonite reached showed the maximum mean values in terms of plant height and branches number under sub surface irrigation system. The correlation between growth parameters and irrigation systems, herein presented for the first time, represents an important novelty for the rosemary growth, as allows the optimization of the cultivation conditions in arid lands. The data reported in Table 2 suggest the possibility to growth *Rosmarinus officinalis* in a high quality employing less water as usual. Similar results were reported by Phene [38], who observed significant differences between subsurface drip and surface irrigation systems for tomatoes crops. The finding of significative differences between the two irrigation systems was not obvious. In fact, Bidondo reported no significant variations between the two irrigation systems as regards to the phenological response [39].

2.2. Herb Fresh and Dry Weights (g/plant and Kg/Fad.)

 doi:10.20944/preprints202007.0748.v1

In order to assess the effect of the different irrigation systems and soil conditioners on the growth of the *Rosmarinus officinalis* L., the yields in terms of g per plant obtained (fresh and dry weight, table 3 and 4), and int terms of cultivated area (tables 5 and 6) have been determined.

Table 3. Fresh herb of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Treatment		Fresh weight (g/plant)					
		First Season			Second season		
		1st cut Mean (±Δ)	2nd cut Mean (±Δ)	Total Mean (±Δ)	1st cut Mean (±Δ)	2nd cut Mean (±Δ)	Total Mean (±Δ)
Surface	C	35.89 (1.65)	6.98 (0.80)	42.87 (0.60)	46.93 (2.43)	9.67 (0.81)	56.61 (1.15)
	H	36.33 (2.67)	10.12 (1.76)	46.46 (0.64)	48.48 (1.41)	12.02 (0.67)	60.49 (0.52)
	BIO	35.67 (2.00)	9.40 (1.06)	45.07 (0.67)	46.45 (2.98)	14.04 (1.70)	60.49 (0.91)
	H + B10	38.55 (2.04)	8.62 (0.57)	47.17 (1.03)	51.39 (1.43)	10.15 (0.98)	61.54 (0.32)
Surface irrigation		36.61 (2.09)	8.78 (1.05)	45.39 (0.74)	25.89 (0.22)	13.79 (0.37)	59.78 (0.10)
Sub surface	C	38.78 (1.71)	10.52 (0.84)	49.30 (0.62)	50.41 (3.35)	13.29 (1.26)	63.70 (1.48)
	H	41.22 (1.50)	12.95 (1.30)	54.18 (0.14)	54.40 (3.12)	17.49 (1.14)	71.89 (1.40)
	BIO	39.33 (2.33)	15.92 (1.75)	55.25 (0.41)	53.66 (3.01)	19.41 (1.38)	73.07 (1.15)
	H + B10	42.33 (1.86)	11.84 (1.72)	54.17 (0.10)	53.51 (3.66)	17.76 (1.42)	71.27 (1.58)
Sub-surface		40.42 (1.85)	12.81 (1.40)	53.22 (0.32)	28.58 (0.77)	17.43 (0.32)	69.98 (0.32)
Soil conditioners	C	37.33 (1.68)	8.75 (0.82)	46.09 (0.61)	26.40 (0.15)	13.92 (0.33)	60.15 (0.13)
	H	38.78 (2.08)	11.54 (1.53)	50.32 (0.39)	27.42 (0.80)	16.19 (0.29)	66.19 (0.36)
	BIO	37.50 (2.17)	12.66 (1.40)	50.16 (0.54)	26.52 (0.61)	16.72 (0.05)	66.78 (0.50)
	H + B10	40.44 (1.95)	10.23 (1.15)	50.67 (0.57)	28.60 (0.41)	15.61 (0.11)	66.41 (0.21)
LSD 5% irrigation		ns	**1.69**	**2.08**	ns	**2.83**	**2.46**
LSD 5% soil conditioners		ns	0.2	**2.94**	ns	ns	**3.48**
LSD 5% Interaction		ns	ns	ns	ns	ns	ns

C = control, H = Hundez soil, BIO. = bentonite, H + B10 = Hundez soil + bentonite, *Δ* = standard deviation, LSD = Least Significant Differences, ns = not significant.

Table 4. Dry herb of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Treatment		Dry weight (g/plant) First Season 1st cut Mean (±Δ)	2nd cut Mean (±Δ)	total Mean (±Δ)	Second season 1st cut Mean (±Δ)	2nd cut Mean (±Δ)	total Mean (±Δ)
Surface	C	8.97 (0.84)	3.16 (0.57)	12.14 0.20)	11.73 (0.99)	3.53 (0.55)	15.26 (0.32)
	H	9.08 (0.67)	4.81 (0.57)	13.89 (0.06)	12.12 (1.29)	4.67 (1.19)	16.79 (0.07)
	BIO	8.84 (0.88)	4.59 (0.68)	13.42 (0.14)	11.62 (1.25)	5.50 (1.46)	17.12 (0.15)
	H + B10	9.64 (1.50)	4.24 (0.30)	13.88 (0.64)	12.84 (1.60)	4.51 (0.47)	17.35 (0.80)
Surface irrigation		9.13 (0.97)	4.20 (0.60)	13.33 (0.26)	12.08 (1.28)	4.55 (0.92)	16.63 (0.33)
Sub-surface	C	9.69 (1.58)	4.93 (0.33)	14.62 (0.88)	12.60 (1.84)	6.23 (0.32)	18.83 (1.07)
	H	10.31 (1.27)	6.89 (0.88)	17.20 (0.28)	13.60 (1.61)	10.21 (0.68)	23.81 (0.66)
	BIO	9.83 (0.92)	8.49 (1.09)	18.32 (0.12)	13.42 (1.03)	14.20 (0.86)	27.62 (0.12)
	H + B10	10.58 (0.85)	6.65 (0.83)	17.23 (0.01)	13.38 (1.66)	11.63 (1.24)	25.01 (0.30)
Sub-surface		10.10 (1.15)	6.74 (0.78)	16.84 (0.26)	13.25 (1.54)	10.57 (0.77)	23.82 (0.54)
Soil conditioners	C	9.33 (1.21)	4.05 (0.45)	13.38 (0.54)	12.17 (1.42)	4.88 (0.43)	17.05 (0.69)
	H	9.70 (0.97)	5.85 (0.73)	15.54 (0.17)	12.86 (1.45)	7.44 (0.94)	20.30 (0.36)
	BIO	9.34 (0.90)	6.54 (0.88)	15.87 (0.01)	12.52 (1.14)	9.85 (1.16)	22.37 (0.14)
	H + B10	10.11 (1.18)	5.45 (0.71)	15.56 (0.33)	13.11 (1.63)	8.07 (0.86)	21.18 (0.55)
LSD 5 % irrigation		ns	**1.26**	**1.25**	ns	**1.26**	**1.41**
LSD 5 % soil conditioners		ns	ns	**1.77**	ns	**1.79**	**1.99**
LSD 5 % Interaction		ns	ns	ns	ns	**1.60**	**2.82**

C = control, H = Hundez soil, BIO. = bentonite, H + B10 = Hundez soil + bentonite, Δ = standard deviation, LSD = Least Significant Differences, ns = not significant.

Table 5. Fresh yield of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Treatment		Fresh yield (kg/Fad.) First Season 1st cut Mean (±Δ)	2nd cut Mean (±Δ)	Total Mean (±Δ)	Second season 1st cut Mean (±Δ)	2nd cut Mean (±Δ)	Total Mean (±Δ)
Surface	C	825.5 (37.8)	160.6 (18.3)	986.1 (13.8)	1079.4 (55.8)	222.5 (18.5)	1301.9 (26.3)
	H	835.7 (61.3)	232.8 (40.4)	1068.5 (14.8)	1115.0 (32.4)	276.3 (15.4)	1391.3 (12.0)
	BIO	820.4 (46.0)	216.2 (24.3)	1036.6 (15.3)	1068.5 (68.6)	323.0 (39.0)	1391.3 (20.9)

	H + B10	886.7 (46.8)	198.1 (13.2)	1084.9 (23.8)	1181.9 (32.8)	233.5 (22.4)	1415.5 (7.3)
Surface irrigation		842.1 (48.0)	201.9 (24.0)	1044.0 (16.9)	1111.2 (47.4)	263.8 (23.8)	1375.0 (16.7)
Sub-surface	C	891.9 (39.4)	241.9 (19.3)	1133.8 (14.2)	1159.4 (77.0)	305.6 (29.0)	1465.0 (33.9)
	H	948.1 (34.6)	297.9 (29.9)	1246.1 (3.3)	1251.2 (71.8)	402.3 (26.1)	1653.6 (32.3)
	BIO	904.7 (53.7)	366.0 (40.2)	1270.7 (9.5)	1234.2 (69.3)	446.4 (31.8)	1680.7 (26.5)
	H + B10	973.7 (42.7)	272.3 (39.5)	1245.9 (2.3)	1230.8 (84.2)	408.5 (32.7)	1639.3 (36.4)
Sub-surface		929.6 (42.6)	294.5 (32.2)	1224.1 (7.3)	1218.9 (75.6)	390.7 (29.9)	1609.6 (32.3)
Soil conditioners	C	858.7 (38.6)	201.3 (18.8)	1060.0 (14.0)	1119.4 (66.4)	264.0 (23.8)	1383.5 (30.1)
	H	891.9 (47.9)	265.4 (35.2)	1157.3 (9.0)	1183.1 (52.1)	339.3 (20.6)	1522.4 (22.2)
	BIO	862.5 (49.8)	291.1 (32.2)	1153.7 (12.4)	1151.3 (68.9)	384.7 (35.4)	1536.0 (23.7)
	H + B10	930.2 (44.8)	235.2 (26.4)	1165.4 (13.0)	1206.4 (58.5)	321.0 (27.6)	1527.4 (21.9)
LSD 5 % irrigation		ns	**39.0**	**47.8**	ns	**65.1**	**56.7**
LSD 5 % soil conditioners		ns	**55.1**	**67. 7**	ns	ns	**80.2**
LSD 5 % Interaction		ns	ns	ns	ns	ns	ns

C = control, H = Hundez soil, BIO. = bentonite, H + B10 = Hundez soil + bentonite, *Δ* = standard deviation, LSD = Least Significant Differences, ns = not significant.

Table 6. Dry yield of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Treatment		Dry yield (kg/Fad.)					
		First Season			Second season		
		1st cut Mean (±*Δ*)	2nd cut Mean (±*Δ*)	total Mean (±*Δ*)	1st cut Mean (±*Δ*)	2nd cut Mean (±*Δ*)	total Mean (±*Δ*)
Surface	C	206.4 (19.4)	72.7 (13.0)	279.1 (4.5)	269.9 (22.9)	81.09 (12.6)	350.98(7.2)
	H	208.9 (15.3)	110.6 (13.2)	319.5 (1.5)	278.7 (29.6)	107.44 (27.4)	386.2 (1.5)
	BIO	203.2 (20.2)	105.5 (15.6)	308.7 (3.2)	267.2 (28.6)	126.60 (33.5)	393.8 (3.4)
	H + B10	221.6 (34.6)	97.6 (13.7)	319.2 (14.7)	295.4 (36.8)	103.70 (10.8)	399.1 (18.4)
Surface irrigation		210.0 (22.4)	96.6 (13.9)	306.7 (6.0)	277.8 (29.5)	104.71 (21.1)	382.5 (5.9)
Sub surface	C	222.9 (36.3)	113.3 (7.6)	336.3 (20.3)	289.83 (42.2)	143.4 (7.3)	433.2 (24.7)
	H	237.0 (29.3)	158.4 (20.3)	395.5 (6.3)	312.84 (37.1)	234.8 (15.6)	547.7 (15.2)
	BIO	226.2 (21.0)	195.3 (25.0)	421.4 (2.8)	308.57 (23.8)	326.7 (19.7)	635.2 (2.9)

	H + B10	243.4 (19.5)	15.9 (19.1)	396.3 (0.2)	307.70 (38.2)	267.6 (28.6)	575.3 (6.8)
Sub-surface		232.4 (26.5)	155.0 (18.0)	387.4 (6.0)	304.73 (35.3)	243.1 (17.8)	547.8 (12.4)
Soil conditioners	C	214.7 (27.8)	93.0 (10.3)	307.7 (12.4)	279.9 (32.6)	112.2 (10.0)	392.1 (16.0)
	H	223.0 (22.3)	134.5 (16.7)	357.5 (3.9)	295.8 (33.3)	171.1 (21.5)	466.9 (8.4)
	BIO	214.7 (20.6)	150.4 (20.3)	365.1 (0.2)	287.9 (26.2)	226.6 (26.6)	514.5 (0.3)
	H + B10	232.5 (27.0)	125.2 (16.4)	357.8 (7.5)	301.6 (37.5)	185.6 (19.7)	487.2 (12.6)
LSD 5% irrigation		ns	**29.07**	**28.8**	ns	**29.2**	**32.5**
LSD 5% soil conditioners		ns	ns	**40.8**	ns	**41.3**	**46.0**
LSD 5% Interaction		ns	ns	ns	ns	**37.0**	**65.0**

C = control, H = Hundez soil, BIO. = bentonite, H + B10 = Hundez soil + bentonite, *Δ* = standard deviation, LSD = Least Significant Differences, ns = not significant.

Data presented in tables (3, 4, 5 and 6) indicate that fresh and dry herb (g / plant and Kg/Fad.) was insignificantly affected by drip irrigation systems in the 1st cut during both seasons, while these treatments had a pronounced effect during 2nd cut as well as sum of two cuts during both seasons. Generally, subsurface system gave the highest values of fresh and dry herb weights. Different sources of soil amendments treatments had no significant effect on fresh herb and dry weights of herb (g/plant and Kg/acre) during 1st cuts of both seasons. On the other hand, these treatments had a pronounced effect during the 2nd cut and sum of the 2 cuts of both seasons. During the 1st cut of both seasons, HUNDZ soil + bentonite gave the highest values of these characters. Moreover, during the 2nd cut herb fresh and dry weights (g/plant and Kg/acre) reached their maximum values as a result of bentonite treatment for both seasons. Regarding the effect of soil amendments on total fresh and dry weights (sum of three cuts), the data reported in Tables 3, 4, 5 and 6 show that HUNDZ soil + bentonite and bentonite are advised for 1st and 2nd seasons, respectively. Concerning the combined drip irrigation systems with different sources of soil amendments had no significant effect on herb fresh and dry weights during both seasons except for the herb dry weight for the 2nd cut of the 2nd season.

2.3. EO content (%) and yield (ml/plant)

During the first part of the study, was possible to implement a water-saving irrigation system without affect the growth of the plants in terms of plant/branches number and yield. In order to verify if the reduced amount of water and the specific soil conditioner employed affect the less evident chemical composition of the plants, the corresponding Essential Oil (EO) was extracted and analyzed.

The procedures of extraction and analysis are described in the experimental at the end of the document. The results obtained were expressed in terms of percentages (EO%), EO ml, and amount of EO per cultivated on a determined cultivated area has been assessed as shown in tables 7-9.

Table 7. EO percentage of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Treatment	EO %					
	First Season			Second season		
	1st cut Mean (±*Δ*)	2nd cut Mean (±*Δ*)	total Mean (±*Δ*)	1st cut Mean (±*Δ*)	2nd cut Mean (±*Δ*)	total Mean (±*Δ*)

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 31 July 2020 doi:10.20944/preprints202007.0748.v1

Surface	C	3.63 (0.06)	3.75 (0.13)	7.38 (0.05)	3.63 (0.03)	3.73 (0.09)	7.36 (0.04)
	H	3.75 (0.13)	3.85 (0.03)	7.60 (0.07)	3.72 (0.11)	3.81 (0.02)	7.53 (0.06)
	BIO	3.92 (0.03)	3.94 (0.01)	7.86 (0.01)	3.90 (0.03)	3.93 (0.04)	7.83 (0.01)
	H + B10	3.70 (0.04)	3.83 (0.10)	7.53 (0.22)	3.75 (0.24)	3.87 (0.10)	7.62 (0.10)
Surface irrigation		3.75 (0.15)	3.84 (0.07)	7.59 (0.06)	3.75 (0.10)	3.83 (0.06)	7.59 (0.03)
Sub surface	C	3.80 (0.10)	3.89 (0.03)	7.69 (0.05)	3.83 (0.04)	3.82 (0.03)	7.65 (0.01)
	H	4.23 (0.06)	4.42 (0.07)	8.66 (0.01)	4.18 (0.06)	4.26 (0.04)	8.44 (0.02)
	BIO	4.10 (0.10)	4.32 (0.03)	8.42 (0.05)	4.21 (0.02)	4.30 (0.03)	8.51 (0.01)
	H + B10	4.03 (0.15)	4.23 (0.10)	8.26 (0.04)	4.04 (0.21)	4.21 (0.04)	8.25 (0.13)
Sub-surface		4.04 (0.10)	4.22 (0.06)	8.26 (0.03)	4.06 (0.08)	4.15 (0.03)	8.21 (0.04)
Soil conditioners	C	3.72 (0.08)	3.82 (0.08)	7.54 (0.00)	3.73 (0.03)	3.78 (0.06)	7.50 (0.02)
	H	3.99 (0.10)	4.14 (0.05)	8.13 (0.03)	3.95 (0.09)	4.03 (0.03)	7.98 (0.04)
	BIO	4.01 (0.06)	4.13 (0.02)	8.14 (0.03)	4.06 (0.02)	4.12 (0.03)	8.17 (0.01)
	H + B10	3.87 (0.28)	4.03 (0.10)	7.90 (0.13)	3.89 (0.23)	4.04 (0.07)	7.94 (0.11)
LSD 5% irrigation		**0.14**	**0.06**	**0.19**	**0.11**	**0.05**	**0.13**
LSD 5% soil conditioners		**0.20**	**0.09**	**0.26**	**0.15**	**0.07**	**0.18**
LSD 5% Interaction		ns	0.29	ns	ns	**0.09**	**0.25**

C = control, H = Hundez soil, BIO. = bentonite, H + B10 = Hundez soil + bentonite, Δ = standard deviation, LSD = Least Significant Differences, ns = not significant.

Table 8. EO content of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Treatment		EO (ml/plant)					
		First Season			Second season		
		1st cut Mean (±Δ)	2nd cut Mean (±Δ)	Total Mean (±Δ)	1st cut Mean (±Δ)	2nd cut Mean (±Δ)	Total Mean (±Δ)
Surface	C	0.33 (0.03)	0.12 (0.03)	0.44 (0.00)	0.43 (0.03)	0.13 (0.02)	0.56 (0.01)
	H	0.34 (0.03)	0.19 (0.02)	0.53 (0.01)	0.45 (0.05)	0.18 (0.05)	0.63 (0.01)
	BIO	0.35 (0.08)	0.18 (0.03)	0.53 (0.03)	0.45 (0.09)	0.22 (0.06)	0.67 (0.02)
	H + B10	0.36 (0.09)	0.16 (0.03)	0.52 (0.05)	0.48 (0.09)	0.17 (0.02)	0.66 (0.05)
Surface irrigation		0.34 (0.06)	0.16 (0.03)	0.51 (0.02)	0.45 (0.07)	0.18 (0.04)	0.63 (0.02)

Sub-surface	C	0.37 (0.06)	0.19 (0.01)	0.56 (0.04)	0.48 (0.09)	0.24 (0.01)	0.72 (0.06)
	H	0.44 (0.12)	0.30 (0.04)	0.74 (0.06)	0.57 (0.14)	0.43 (0.10)	1.00 (0.03)
	BIO	0.40 (0.10)	0.37 (0.05)	0.77 (0.03)	0.57 (0.13)	0.61 (0.04)	1.18 (0.06)
	H + B10	0.43 (0.04)	0.28 (0.03)	0.71 (0.01)	0.54 (0.09)	0.49 (0.11)	1.03 (0.01)
Sub-surface		0.41 (0.08)	0.29 (0.03)	0.69 (0.03)	0.54 (0.11)	0.44 (0.06)	0.98 (0.03)
Soil conditioners	C	0.35 (0.04)	0.16 (0.02)	0.50 (0.02)	0.45 (0.06)	0.19 (0.02)	0.64 (0.03)
	H	0.39 (0.07)	0.24 (0.03)	0.63 (0.03)	0.51 (0.10)	0.31 (0.07)	0.82 (0.02)
	BIO	0.37 (0.09)	0.27 (0.04)	0.65 (0.03)	0.51 (0.11)	0.41 (0.05)	0.92 (0.04)
	H + B10	0.39 (0.07)	0.22 (0.03)	0.62 (0.03)	0.51 (0.09)	0.33 (0.07)	0.85 (0.02)
LSD 5% irrigation		ns	**0.05**	**0.07**	**0.08**	**0.05**	**0.09**
LSD 5% soil conditioners		ns	**0.07**	**0.1**	ns	**0.07**	**0.12**
LSD 5% Interaction		ns	ns	ns	ns	**0.10**	ns

C = control, H = Hundez soil, BIO. = bentonite, H + B10 = Hundez soil + bentonite, Δ = standard deviation, LSD = Least Significant Differences, ns = not significant.

Table 9. EO yield of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Treatment		EO (L/Fad.)					
		First Season			Second season		
		1st cut Mean (±Δ)	2nd cut Mean (±Δ)	total Mean (±Δ)	1st cut Mean (±Δ)	2nd cut Mean (±Δ)	total Mean (±Δ)
Surface	C	7.5 (0.6)	2.7 (0.6)	10.2 (0.1)	9.8 (0.8)	3.0 (0.5)	12.8 (0.2)
	H	7.8 (0.7)	4.3 (0.5)	12.1 (0.1)	10.4 (1.2)	4.1 (1.0)	14.5 (0.1)
	BIO	8.0 (1.7)	4.2 (0.6)	12.1 (0.8)	10.4 (2.0)	5.0 (1.3)	15.4 (0.4)
	H + B10	8.3 (2.2)	3.7 (0.6)	12.0 (1.1)	11.1 (2.1)	4.0 (0.5)	15.2 (1.1)
Surface irrigation		7.9 (1.3)	3.7 (0.6)	11.6 (0.5)	10.4 (1.5)	4.0 (0.9)	14.5 (0.5)
Sub surface	C	8.4 (1.5)	4.4 (0.3)	12.8 (0.8)	11.1 (2.2)	5.5 (0.3)	16.6 (1.3)
	H	10.0 (2.7)	7.0 (0.9)	17.0 (1.3)	13.0 (3.2)	10.0 (2.2)	23.1 (0.7)
	BIO	9.2 (2.2)	8.4 (1.1)	17.7 (0.7)	13.0 (3.0)	14.1 (0.9)	27.1 (1.4)
	H + B10	9.8 (0.9)	6.5 (0.7)	16.3 (0.1)	12.5 (2.0)	11.3 (2.5)	23.7 (0.3)
Sub-surface		9.4 (1.8)	6.6 (0.7)	16.0 (0.7)	12.4 (2.6)	10.2 (1.5)	22.6 (0.9)

Soil conditioners	C	8.0 (1.0)	3.6 (0.4)	11.5 (0.4)	10.4 (1.5)	4.3 (0.4)	14.7 (0.7)
	H	8.9 (1.7)	5.6 (0.7)	14.6 (0.7)	11.7 (2.2)	7.0 (1.6)	18.8 (0.4)
	BIO	8.6 (2.0)	6.3 (0.9)	14.9 (0.8)	11.7 (2.5)	9.5 (1.1)	21.2 (0.9)
	H + B10	9.1 (1.5)	5.1 (0.7)	14.2 (0.6)	11.8 (2.1)	7.6 (1.5)	19.4 (0.4)
LSD 5% irrigation		ns	**1.2**	**1.6**	**1.9**	**1.2**	**2.0**
LSD 5% soil conditioners		ns	**1.7**	**2.3**	ns	**1.7**	**2.8**
LSD 5% Interaction		ns	ns	ns	ns	**2.4**	ns

C = control, H = Hundez soil, BIO. = bentonite, H + B10 = Hundez soil + bentonite, *Δ* = standard deviation, LSD = Least Significant Differences, ns = not significant.

The data obtained revealed that the EO content (%) and yield (ml/plant and Kg/Fad.) are affected by the drip irrigation systems, the different sources of soil amendment and by the combined effect of both factors (Tables, 7, 8 and 9). Mean comparison between both drip irrigation systems showed that the highest EO content (%) and yield (ml/plant or L/acre) were obtained from plants grown under sub surface irrigation system. This observation is in agreement with the previous reported data relative to growth parameters and confirms the possibility to grow a good quality *Rosmarinus officinalis* with a minimum amount of water.

Concerning the effect of different sources of soil amendment, data presented in the same tables indicate that HUNDZ soil and HUNDZ soil + bentonite gave the highest mean value of EO content (%) for the 1st cut of 1st season while bentonite alone gave the maximum value of EO percentage for the 2nd cut and total (sum of both cuts) of both seasons. The combination between drip irrigation systems and soil amendments had no significant effect on EO's percentage except during the 2nd cut of 2nd season. Generally, plants grown on bentonite under sub surface irrigation system gave the maximum mean value of EO percentage during both seasons except during the 1st cut of 1st season.

Concerning the effect of drip irrigation systems, different sources of soil amendments on EO yield (ml/plant and L/Fad.), data tabulated in Tables 8 and 9 indicate that the effect of these treatments gave a trend similar to the one observed in the case of EO percentage.

2.4. Composition of EO

The EO extracted from plants subjected to different treatments revealed the presence of twenty-four compounds, which account for more than 95% of the overall chemical composition detected by GC-MS (Table 10).

Table 10. Main constituents of EO of *Rosmarinus officinalis* plant grown under different drip irrigation systems and different sources of soil conditioners.

Name	KI	surface				subsurface			
		C	HZ	BENT	HZ + BENT	C	HZ	BENT	HZ + BENT
Tricyclene	900	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.1
α-Pinene	909	19.3	16.7	16.8	21.1	14.5	18.8	20.6	15.4
Camphene	927	4.8	4.7	4.6	4.8	4.4	4.8	4.7	4.2
thuja 2,4-Diene	930	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.4
β-Pinene	956	0.5	0.4	0.4	0.6	0.4	0.4	0.5	0.3
β-Myrcene	957	0.7	0.5	0.5	0.8	0.5	0.5	0.6	0.4
Phellandrene	984	0.3	0.2	0.2	0.3	0.2	0.2	0.3	0.2
δ-2-Carene	1005	0.7	0.6	0.6	0.7	0.6	0.6	0. 7	0.5
ϱ-cymene	1026	1.1	0.9	0.9	1.2	1.0	0.9	1.0	0.8
Eucalyptol	1036	14.5	14.5	14.4	15.5	14.4	14.1	13.7	13.1

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 31 July 2020 doi:10.20944/preprints202007.0748.v1

γ-Terpinene	1062	1.0	0.8	0.74	1.0	0.8	0.7	0.9	0.5
Terpinolene	1065	1.4	1.1	1.0	1.3	1.1	1.0	1.2	0.9
Linalool	1102	1.0	1.0	1.0	1.1	1.0	0.9	1.1	0.9
α-campholenal	1106	0.5	0.4	0..5	0.5	0.5	0.4	0.4	0.3
Camphor	1145	40.0	44.1	44.3	40.7	44.0	41.9	38.6	44.8
Pinocarvone	1161	0.2	0.1	0.1	0.3	0.3	0.3	0.3	0.1
terpinen-4-ol	1163	0.9	0.9	0.9	0.7	1.0	0.9	0.9	2.3
Thymol	1165	0.1	0.1	0.2	0.9	0.8	0.8	0.9	0.1
α-Terpineol	1180	2.5	2.2	2.3	2.1	2.5	2.2	2.4	3.3
Verbenone	1223	7.8	6.9	7.1	5.2	9.1	7.7	7.9	6.3
bornyl acetate	1261	0.4	0.4	0.3	0.1	0.3	0.4	0.4	0.2
Caryophyllene	1400	0.2	0.2	0.3	-	0.3	0.2	0.2	0.2
α-Humulene	1406	0.4	0.3	0.4	-	0.4	0.4	0.4	0.1
Bisabolene, trans-	1479	0.1	0.2	0.0	-	0.1	0.1	-	0.1
Monoterpene hydrocarbons		30.4	26.7	26.4	32.3	24.1	28.6	31.2	23.7
Oxygenated hydrocarbons		68.0	70.8	71.0	67.2	74.0	69.6	66.6	71.5
Sesquiterpene hydrocarbons		0.7	0.8	0.7	0.0	0.8	0.7	0.7	0.3
Total of identified compounds		99.1	98.2	98.2	99.5	98.9	98.9	98.4	95.6
Unidentified compounds		0.9	1.8	1.8	0.4	1.1	1.1	1.6	4.4

The unidentified compounds ranged from 0.9% to 4.4% from the separated compounds. The major constituents of EO samples were camphor (38.6%-44.8%), α-pinene (14.5%-21.1%) and then eucalyptol (13.1%-15.5%).

Recently Melito et al. [26] studied the chemical composition of *Rosmarinus officinalis* EOs extracted from Sardinian plants. The authors evidenced a great variability in composition according to meteorological and environmental condition and several chemo types were identified. The chemical analysis highlighted the presence of seven major compounds among which α-pinene ranged between 26 and 28%, champhene from 5-8%, 1,8-cineole 15 and 25%, borneol from 5 and 11%, camphor from 3-12%, verbenone 6 and 15% and bornyl acetate from 4 and 7%. According to these results the different chemical composition between Sardinian and Egypt EOs could be related to the different geographical area of cultivation as well as the different environmental contest.

Regarding the comparison between growth different conditions, no considerable differences between the relative distribution of these major constituents and the specific treatment were observed. This specific result is of particular importance in the context of water harvesting in arid fields. In fact, the data obtained demonstrate for the first time that is possible to cultivate *Rosmarinus officinalis* L. employing less water as usual without altering its chemical composition.

Subsurface drip irrigation had a pronouncing effect on growth characters with respect to surface irrigation. In this regard, subsurface drip is a low-pressure, highly efficient irrigation method which uses buried drip tubes or drip tape to meet crop water needs. Subsurface irrigation saves water and improves yields by eliminating surface water evaporation and reducing the incidence of disease and weeds. A subsurface drip system may require higher initial investment and cost will vary due to water source, quality, and filtration need, choice of material, soil characteristics and degree of automation desired. This technology has been a part of irrigated agriculture since 1960, and advanced rapidly in the last two decades. A subsurface drip irrigation system is flexible and can provide frequent light irrigations. This is especially suitable for arid, semi-arid, hot, and windy areas with limited water supply. Farm operations also become free of impediments that normally exist above ground with any other pressurized irrigation system.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 31 July 2020 doi:10.20944/preprints202007.0748.v1

The effect of the soil amendment is related to the providing a better environment for roots and plant growth: this includes the improvement of the soil structure and water holding capacity, the availability of nutrients, and the living conditions for soil organisms, which are important for the plants to grow. Furthermore, a better soil texture and better root growth avoids soil degradation during heavy rains or in windy regions. It also supports the nutrient cycle when organic amendments are used (e.g. manure). Beside soil amendment, there are several methods to provide soil moisture conservation such as soil cover and reforestation (living plants), mulching or several tillage techniques. It is also very important the adaptability of a certain planted crop to the specific climate. Basically, any organic or inorganic material that is added to the soil and improves its quality can be considered as soil amendment. The type of amendment chosen depends entirely on how the soil needs to be changed. By using soil amendment, almost every type of soil can be made fertile. Bentonite, historically employed for clarification procedures [40], is a volcanic ash rock consisting predominantly of montmorillonite, a clay mineral of Mg and Al, which determine the peculiar structural properties of the material [41]. It has also been recognized as a very good material for the improvement of coarse textured soils in different parts of the world [42].

3. Materials and Methods

3.1 Location of the experiments

Field trial was carried out at the Agricultural Research Station (Al-Adlya farm), SEKEM Company, Sharkiya Governorate, Egypt (80 km to the East of Cairo), during the two seasons of 2012/2013–2013/2014. The determination of some physical and chemical properties of soil samples and the analyses of the irrigation water systems were conducted according to standard procedures already described and represented in Table 1. Also, some meteorological data and evapotranspiration during the growing season are presented in Table 1.

3.2. Experimental design

The field experiment was carried out as a split plot design. The experiment included eight treatments which represented the interaction between two irrigation systems combined with three soil amendments treatments and control with three replicates. The irrigation systems (surface and subsurface irrigation) were represented in the main plot while the soil conditioners treatments (control (0), HUNDZ soil (3%), bentonite (3%) and HUNDZ soil + bentonite) were placed in the sub-plot. The HUNDZ soil and bentonite conditioners were added to the soil preparation in a concentration of 3%. Plants row spacing was 0.75 m and the distance between each plant was 0.25 m in plots with area of 15 m^2 (3X5 m).

3.3 Irrigation setup

The drip irrigation lines were twin-wall drip tapes (GR), with outlets spaced every 0.5 m. Standard drippers of 4 L/h discharge at 1.5 bar working pressure were used. Drip irrigation lines were laid above and under ridges of plant rows, and the installation depth of the subsurface drip lines was 0.20 m.

3.4 Plant materials

Rosmarinus officinalis L., variety Spanish rosemary cuttings (at age 2 years) were imported from Bionorica Company, Germany.

3.5 Cultivation

The cuttings were cultivated in the nursery in foam trays filled with a mixture of sand:compost:petmos (1:1:1 volume) in the first week of October. Cuttings were covered with 100-micron white plastic mulch after cultivation and then irrigated every 3-5 days by dripping irrigation. After 45 days, the plastic mulch cover was removed, and after the cuttings showed white roots (2-5 cm) which were ready for transferring in the permanent soil in the open field. Irrigation was performed as needed until the plants generated the first two true leaves stage, where the irrigation treatments were applied. The experimental soils were supplied with 20 m^3/Fad. (Fad. = 4200 m^2) of mature compost. Routine agricultural practices were carried out as usually practiced in rosemary cultivation. Data for growth characters, yield, EO and its chemical constituents for all treatments were obtained during two harvests in June and in August in the two seasons. The data measurements included plant height (cm), number of branches/plants, fresh and dry weights of herb (g/plant).

3.6 EO production

EO percentage of each replicate at the two harvests was determined in the air-dried herb according to Guenther (1995) and expressed as ml/100g, while EO yield was expressed as ml /plant and L / m^2.

The extraction procedure for the essential oil as carried out according to a previous literature data [43], A sample weighing 300 g of plant aerial part was subjected to hydro-distillation using a Clevenger type apparatus for 2h. The extraction was repeated twice, the obtained EO was collected separately, dried over anhydrous sodium sulfate (Na_2SO_4) and then stored at 4º C in amber glass vials until analysis.

3.7 Qualitative and quantitative analyses of EOs

Rosemary EO samples were analyzed through GC-MS with a Hewlett Packard 5890 GC equipped with a Hewlett Packard 5971 MS system operating in the EI mode at 70 eV. EO separation was performed on an HP-5 capillary column (30 m × 0.25 mm, film thickness 0.17 µm). The following temperature program was used: 60ºC hold for 3 min, then increased 4ºC/min till reach 210ºC, then held at 210ºC for 15 min, then increased 10ºC/min to 300ºC, and finally held at 300ºC for 15 min. Helium was used as the carrier gas at a constant flow of 1 mL/min for both columns. The data was analyzed using Agilent Chemstation software and the identification of the individual components performed by comparison with the co-injected pure compounds and by matching the MS fragmentation patterns and retention indices with the data reported in libraries or literature data (NIST/EPA/NIH 2008; HP1607 purchased from Agilent Technologies and Adams, 2011). The relative proportion percentages of the EO constituents were obtained by peak area normalization [44].

3.8 Statistical analysis

Data of each season were statistically analyzed separately according to Cochran and Cox. The differences between the means of the treatments were considered significant when they were more than Least Significant Differences (LSD) at 5%. The data were subjected to ANOVA test (MS DOS/ Costat Exe Program).

4. Conclusions

Aromatic plants cultivation in arid and semiarid regions can be achieved in a sustainable and effective way, with a special care on water consumption and quality of growth parameters. In the specific case of *Rosmarinus officinalis* L. was possible to determine improved cultivar conditions by selecting a combination of subsurface irrigation system and HUNDZ-bentonite soil conditioner. In particular, by switching from surface to subsurface irrigation system and by employing as soil conditioner a combination of HUNDZ conditioner and bentonite, was possible to reach the same plant quality as usual but saving a consistent amount of weather. This notable result was assessed both in terms of plant growth parameters, as well as in terms of chemical composition, determined by extracting the essential oil and subjecting it to GC-MS analysis. The approach herein presented, based on the study of the correlation between growth parameters and chemical composition, and growth procedure, can be further extended to other cultivations.

Author Contributions: Conceptualization, E.O.; methodology S.H; formal analysis, G.L.P..; investigation, A.N.G. El G.; resources, E. Omer; data curation, A.M.; writing—original draft preparation, E.O. and S.H.; writing—review and editing, A.M.; supervision, G.P.; project administration, E.O.; funding acquisition, E.O. and G.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: This work was supported from the National Research Centre, Egypt (Project No. 10120106).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Falkenmark, M.; Lindh, G. Water For a Starving World, Routledge; 1 edition (June 17, 2019). ISBN-13: 978-0367213183.
2. Fahmy, S.; Ezzat, M.; Shalby, A.; Kandil, H.; Sharkawy, M.; Allam, M.; Assiouty, I.; Tczap A. Water Policy Review and Integration Study. Report No. 65, 2002. Ministry of Water Resources and Irrigation, Egypt.
3. Kang, S.Z.; Shi, P.; Pan, Y.H.; Liang, Z.S.; Hu, X.T.; Zhang J. Soil water distribution, uniformity and water-use efficiency under alternate furrow irrigation in arid areas. *Agricultural Water Management*, **2000**, *19(4)*, 181-190.
4. Molden, D.J.; El-Kady, M.; Zhu, Z. Use and productivity of Egypt's Nile water. In: J. Burns I., Anderson S.S., eds. Contemporary Challenges for Irrigation and Drainage: Proceedings from the USCID 14th Technical Conference on Irrigation, Drainage and Flood Control. Phoenix, Arizona, June 3–6, 1998, pp. 99–116. USCID, Denver, CO.
5. Petretto, G.L.; Urgeghe, P.P.; Massa, D.; Melito, S. Effect of salinity (NaCl) on plant growth, nutrient content, and glucosinolate hydrolysis products trends in rocket genotypes. *Plant Physiol. Biochem.* **2019**, *141*, 30-39.
6. Ashour, A.; El Attar, S.T.; Rafaat, Y.M.; Mohamed, M.N. Water Resources Management. *Egypt Journal of Engineering Sciences, Assiut University*, **2009**, *37(2)*, 269-279.
7. http://www.fao.org/3/t7202e/t7202e08.htm, accessed on 28/04/2020.
8. Phene, C.J.; Davis, K.R.; Hutmacher, R.B.; Yosef, B.; Meek, D.W. Effect of high frequency surface and subsurface drip irrigation on root distribution of sweet corn. *Irr. Sci.* **1991**, *12*, 135-140.
9. Al-Jamal, M.S.; Ball, S.; Sammis, T.W. Comparison of sprinkler, trickle and furrow irrigation efficiencies for onion production. *Agricultural Water Management*, **2001**, *46(3)*, 253-266.
10. Zhao, R.H.; He, W.-Q.; Lou, Z.-K.; Nie, W.-B.; Ma, X.-Y. Synchronization Optimization of Pipeline Layout and Pipe Diameter Selection in a Self-Pressurized Drip Irrigation Network System Based on the Genetic Algorithm. *Water*, **2019**, *11(3)*, 489.
11. Kumar, R.R.; Sriram, K.; Narayanan, I.S. Self Optimizing Drip Irrigation System Using Data Acquisition and Virtual Instrumentation to Enhance the Usage of Irrigation Water. In: Auer M., Ram B. K. (eds) Cyber-physical Systems and Digital Twins. REV2019 2019. Lecture Notes in Networks and Systems, vol 80. Springer, Cham.
12. Hanson, B.; May, D.; Effect of subsurface drip irrigation on processing tomato yield, water table depth, soil salinity, and profitability. *Agricultural Water Management*, **2004**, *68*, 1-17.
13. Suganya, S.; Sivasamy, R. Moisture retention and cation exchange capacity of sandy soil as influenced by soil additives. *J. Appl. Sci. Res.* **2006**, *2*, 949-951.
14. Mansour, H.A.; Gaballah, M.S.; Abd El-Hady, M.; Ebtisam, I. Influence of different localized irrigation systems and treated agricultural wastewater on distribution uniformities, potato growth, tuber yield and water use efficiency. *The Journal of Agricultural Science*, **2014**, *2(2)*, 143-150.
15. Mansour, H.A.-G.; Tayel, M.Y.; Abd El-Hady, M.A.; Lightfoot, D.A.; El-Gindy, A.M. Modification of water application uniformity among closed circuit trickle irrigation systems. *Agricultural Science*, **2010**, *1(1)*, 1-9.
16. Ahmed, E.M.; Barakat, M.M.A.; Ragheb, H.M.; Rushdi, M.K. Impact of Surface and Subsurface Drip Irrigation Systems and Fertigation Managements on Yield and Water Use Efficiencies of Two Squash Varieties. *Assiut J. Agric. Sci.* **2017**, *48*, 1-1.
17. Oron, G.; DeMalach, Y.; Gillerman, L.; David, I.; Rao, V.P. Improved saline - water use under subsurface drip irrigation. *Agricultural Water Management*, **1998**, *39*, 19-33.
18. Oliveira, M.R.G.; Calado, A.M.; Portas, C.A.M. Tomato root distribution under drip irrigation. *J. Am. Soc. Hort. Sci.* **1996**, *121(4)*, 644-648.
19. Grabow, G.L.; Huffman, R.L.; Edmisten, K. Automated control of subsurface drip irrigation using rainfall and soil water data. ASAE Paper No. 042190, 2004. St. Joseph, Mich.: ASAE.
20. Gengoglan, C.; Altunbey, H.; Gengoglan, S. Response of green bean (phaseolus vulgaris L.) to subsurface drip irrigation and partial rootzone drying irrigation. *Agricultural Water Management*, **2006**, *84*, 274-280.
21. El-Shawadfy, M. Influence of different irrigation systems and treatments on productivity and fruit quality of some bean varieties. M. Sc. thesis, Fac. of agric., 2008, Ain Shams Univ.
22. Camp C.R. Subsurface drip irrigation: A review. *Trans. ASAE*, **1998**, *41(5)*, 1353-1367.
23. Singh, D.K.; Rajput, T.B.S. Response of lateral placement depths of subsurface drip irrigation on okra (Abelmoschus esculentus). *International Journal of Plant Production*, **2007**, *1(1)*, 73–84.

24. Lamm, F.R.; Manges, H.L.; Stone, L.R.; Khan, A.H.; Rogers, D.H. Water requirement of subsurface drip-irrigated corn in northwest Kansas. *Transactions of the ASAE*, **1995**, *38(2)*, 441-448. ASAE, St. Joseph, Michigan 49085.
25. Maldini, M.; Montoro, P.; Addis, R.; Toniolo, C.; Petretto, G.L.; Foddai, M.; Nicoletti, M.; Pintore G. A new approach to discriminate Rosmarinus officinalis L. plants with antioxidant activity, based on HPTLC fingerprint and targeted phenolic analysis combined with PCA. *Ind. Crop Prod.* **2016**, *94*, 665-672.
26. Melito, S.; Petretto, G.L.; Chahine, S.; Pintore, G.; Chessa, M. Seasonal Variation of Essential Oil in Rosmarinus officinalis Leaves in Sardinia. *Nat. Prod. Com.* **2019**, *14*, 7.
27. Khorshidi, J.; Mohammadi, R.; Fakhr, M.T.; Nourbakhsh, H. Influence of Drying Methods, Extraction Time, and Organ Type on Essential Oil Content of Rosemary (Rosmarinus officinalis L.). *Nature and Science*, **2009**, *7(11)*, 42-44.
28. Moreno, S.; Scheyer, T.; Romano, C.S.; Vojnov, A. Antioxidant and antimicrobial activities of rosemary extracts linked to their polyphenol composition. *Free Radic Res.* **2006**, *40*, 223-231.
29. Wang, W.; Wu, N.; Zu, Y.; Fu, Y. Antioxidative activity of Rosmarinus officinalis L. essential oil compared to its main components. *Food Chem.* **2008**, *108*, 1019-1022.
30. Rozman, T.; Jersek, B. Antimicrobial activity of rosemary extracts (Rosmarinus officinalis L.) against different species of Listeria. *Acta agriculturae Slovenica*, **2004**, *93(1)*, 51-58.
31. Moghtader, M.; Afzali, D. Study of the antibacterial properties of the essential oil of Rosemary. *American-Eurasian J. Agric. Environ Sci.* **2009**, *5(3)*, 393-397.
32. Papachristos, D.P.; Stampoulos, D.C. Fumigant toxicity of three essential oils on the eggs of Acanthoscelide sobtectus (Say) (Coleoptera: Bruchidae). *J. Stored Prod Res.* **2004**, *40*, 517–525.
33. Cuman, R.K. Anti-Inflammatory and Antinociceptive Effects of Rosmarinus officinalis L. Essential Oil in Experimental Animal Models. *J. Med. Food.* **2008**, *11(4)*, 741–746.
34. Takaki, I.; Bersani-Amado, L.E.; Vendruscolo, A.; Sartoretto, S.M.; Diniz, S.P.; Bersani-Amado, C.A.; Tunc, I.; Berger, B.M.; Erler, F.; Dagli, F. Ovicidal activity of essential oils from plants against two stored-product insects. *J. Stored Prod. Res.* **2000**, *36*, 161-168.
35. Ozcan, M.M.; Chalchat, J. Chemical composition and antifungal activity of rosemary (Rosmarinus officinalis L) oil from Turkey. *International Journal of Food Sciences and Nutrition*, **2008**, *59(7-8)*, 691-698.
36. Pozzatti, P.; Alves Scheid, L.; Borba Spader, T.; Linde Atayde, M.; Morais Santurio, J.; Hartz Alves S. In vitro activity of essential oils extracted from plants used as spices against fluconazole-resistant and fluconazole-susceptible Candida spp. *Can. J. Microbiol.* **2008**, *54(11)*, 950–956.
37. Isman, M.B. Plant essential oils for pest and disease management. *Crop Protection*, **2000**, *19*, 603-608.
38. Phene, C.J.; De Tar, W.R.; Clark, D.A. Real time irrigation scheduling of cotton with an automated pan evaporation system. *Applied Engineering in Agriculture*, **1992**, *8*, 787-793.
39. Bidondo, D.; Andreau, R.; Martinez, S.; Garbi, M.; Chale, W.; Cremaschi, G. Comparison of the effect of surface and subsurface drip irrigation on water use growth and production of a greenhouse tomato crop. ISHS Acta Hortic. 927, XXVIII. International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on Greenhouse 2010 and Soilless Cultivation.
40. Mannu, A.; Vlahopoulou, G.; Sireus, V.; Petretto, G.L.; Mulas, G.; Garroni, S. Bentonite as a Refining Agent in Waste Cooking Oils Recycling: Flash Point, Density and Color Evaluation. *Nat. Prod. Commun.* **2018**, *13(5)*, 613-616.
41. Varma, R.S. Clay and clay-supported reagents in inorganic synthesis. *Tetrahedron*, **2002**, *58*, 1235-1255.
42. Satje, A., Nelson, P. Bentonite treatments can improve the nutrient and water holding capacity of sugarcane soils in the wet tropics. *Proceedings of the Australian Society of Sugarcane Technologists*, **2009**, *31*, 166-176.
43. Petretto, G.L.; Fancello, F.; Zara, S.; Foddai M., Mangia, N.P.; Sanna, M.L.;Omer; E.A., Menghini, L.; Chessa, M.; Pintore, G. Antimicrobial Activity against Beneficial Microorganisms and Chemical Composition of Essential Oil of Mentha suaveolens ssp. insularis Grown in Sardinia. *J. Food Sci.* **2014**, 79, M369-377.
44. Mannu, A.; Melito, S.; Petretto, G.L.; Manconi, P.; Pintore, G.M.; Chessa, M. Geographical variation of the chemical composition in essential oils extracted from Sardinian Salvia verbenaca. *Nat. Prod. Res.* **2020**, doi: 10.1080/14786419.2020.1788021.