Response of *Rosmarinus Officinalis,L.* To Soil Matric Potential and Potassuim Fertilization in Newly Reclaimed Soils

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ABSTRACT

Two field experiments were conducted in Aly Moubark Experimental Farm at El-Bustan sandy soil through two successive seasons of 2003 and 2004. The present work aimed to study the effect of water stress (using tensiometers) with applied potassium fertilization on the growth, oil yield and its components of rosemary plants. Also to study the irrigation scheduling and water use efficiency under drip irrigation system.

The layout of the experiment was split plot. The main plots occupied by three irrigation treatments of soil matric potential (T1= 100 to 200 m bar, T2= 100 to 300 m bar and T3= 100 to 400 m bar). The sub plot contained four rates of potassium sulphate 48% K2O (K0, K1, K2 and K3 =0, 24, 48, 72 Kg K2O/fed, respectively).

The results revealed that, the irrigation treatment of T3 gave the highest values of rosemary growth and oil yield as well as the lowest amount of seasonal irrigation water (2566 and 2713 m3/fed. during 2003 and 2004 seasons respectively) compared with other irrigation treatments of T2 and T1. Also, this treatment (T3) saved about 27.9 % from irrigation water. Raising the potassium fertilization rate resulted in gradual increase in growth and yield parameters to reach the maximum values with the highest rate of K fertilization (K3=72 Kg K2O/fed).

The interaction effect between T3 (100-400 m bar) and K3 (72 Kg K2O/fed.) gave the best results in terms of plant height, number of main branches, fresh and dry weight per plant and per feddan, as well as the oil percentage and oil yield per plant and per feddan. In most cases, the essential oil components were significantly affected by the interaction between T3 and K3. Major components were camphor, borneol and verbenone produced their highest values with (T2×K0), (T3×K3) and (T3×K0) treatments, respectively. Also, the (T3×K3) treatment consumed the lowest amount of seasonal irrigation water (2420 and 2552 m3/fed. during 2003 and 2004 seasons respectively) and saved about 28.82% from irrigation water. On the other hand, (T3×K3) treatment gave an average water use efficiency values of 0.254 Kg dry weight/m3 and 3.418 ml oil/ m3.

INTRODUCTION

Rosemary (*Rosmarinus officinalis, L.*) is an important member of family Lamiaceae. Fresh or dried leaves of rosemary were used as a flavouring agent of some foods such as chicken, meats (especially Lamb), stews and vegetables. Medicinally, it is used as stimulant, carminative, diaphoretic and to strengthen the memory. Rosemary oil is clear up to 1% containing borneol, resin, bitter principle and tannin (Gamal 1967). The oil is used in cheap cosmetic and perfumes industry. Increasing the production of rosemary could be achieved through irrigation management and fertilization.

In arid and semi arid regions as Egypt where the irrigation is essential for crop production, determine the optimum water amount for plant production is very necessary. Instead of detailed information about amount of water, the "potential" method used only two easily acquired units of information. One is matric potential in the field at defined depth.

These data are simple and easy to obtain as reading on the dial of tensiometer. The other involves knowing what these reading would be when the crop is irrigated (Taylor 1965). Many researches reported in these respect for crops, but there were shortages of data dealing with the medicinal and aromatic plants, however, Sardans *et al* (2005) on *Rosmarinus officinalis* concluded that, the irrigation increased plant growth, but did not have significant effects on nutrient contents and flowering. Abdel-Latif *et al* (2001) on *Ammi visnaga* found that, the irrigation at 50% depletion of available soil moisture produced the highest yield and 30.4% was saved of water values consumptive use as comparing to 20% and 80% depletion of available soil moisture. Also, Kassem and Al-Moshileh (2005) mentioned that, the soil moisture depletion 45% increased the potato plant growth characters and water use efficiency compared with the other levels of soil moisture content (15, 30, 60 and 70 % of soil moisture depletion.

Accurate data for consumptive use are required in irrigation systems design for improving water use efficiency (El-Gindy et al 1991). Marvin et al (1976) defined consumptive use of plants as a sum of water loss by both evaporation and transpiration. Ghazy et al (1987) on potato pointed that, the best value of water use efficiency in clay soil was obtained at 70% depletion

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of the available water compared to 50% and 30% depletion of available water. Also, decreasing the amount of irrigation water increased water use efficiency of canola plants (El-Mowelhi *et al* 1999).

The role of potassium in the water economy of plants, including its effects upon transpiration coefficients, root pressure and osmotic pressure in plant sap in connection to transpiration and stomatal opening is discussed on the basis of the osmoregulating action of this element (Hofner, 1971).

In this respect, few numbers of researchers studied the interaction between irrigation and fertilization. Ibrahim (1985) and Abdel-Latif *et al* (2001) on Ammi visnaga ,L., Surendra *et al* (1994) on coriander and Sardans *et al* (2005) on Rosmarinus officinalis. So, this work aimed to study the effects of water stress with potassium fertilization on amount of applied water, water use efficiency, growth, oil yield and its active constituents in rosemary plants grown in newly reclaimed soil at South El-Tahrir region.

MATERIALS AND METHODS

Two field experiments were carried out at "Aly Moubark Experimental Researches station" in El-Bustan area, Nubaria region during 2003 and 2004 seasons. Before beginning the experimental work, soil samples were taken from the experimental field to determine some physical and chemical properties (Table 1) according to Page *et al* (1982).

Table 1. Some physical and chemical analysis of the soil at the experimental site

depth cm	PH 1-2.5	EC dS/m	Pb* mg/m³	Soil fractions, % Sand	Silt	Clay	Soil rexture
0-20	8.40	0.62	1.51	92.40	3.30	4.3	sandy
20-40	8.10	0.41	1.58	94.30	3.00	2.7	sandy
40-60	8.00	0.34	1.6	94.6	2.80	2.6	sandy

* Pb is soil bulk density.

In both seasons the experiment was set in split plot design with three replicates. The main plots were three irrigation treatments (soil matric potential). These were equivalent to irrigation level of 100-200, 100-300 and 100-400 m bar. The values were determined by tensiometer. Four rates of potassium fertilization were the sub plots. Potassium treatments were 0, 50, 100 and 150 Kg of potassium sulphate per feddan (48% K_2O). These were equivalent to 0, 24, 48, 72 Kg K_2O/fed. There were 12 different treatments. Every treatment contains of four laterals, each lateral is 50 m long. Spacing between laterals was 0.8m and spacing between inline was 0.5 m. the inline laterals were (GR) type with 4L/h discharge rate per emitter at inlet pressure one bar.

Water relation

Soil moisture content at different tensions (0.1, 0.2, 0.3, 0.4 and 15 bar) were determined (on volume basis) by pressure extractor apparatus in the laboratory according to Black 1965. Values are presented in Table 2.

Table2. Volumetric soil moisture content (θ_v) at different tensions and soil moisture depletion at the experimental site.

Soil Depth, cm	θ_v, cm³/cm³ Suction, bar 0.1 F.C.*	0.2	0.30	0.40	15 W.P.**	A.v ***
0-20	10.00	8.42	7.60	7.00	5.04	4.96
20-40	9.36	7.83	7.02	6.50	4.95	4.41
40-60	9.03	7.33	6.56	6.03	4.60	4.43
Mean	9.46	7.86	7.06	6.51	4.86	4.60
Soil moisture depletion from available water %	35 ˣ	52	64	100		

(*) Field capacity (F.C) = (θ_v at 0.1 bar).
(**) W.P. (wilting point = (θ_v at 15 bar).
(***) A.W. (available water = (θ_v at 0.1 bar- θ_v at 15 bar).
(x) 35% depletion = θ_v (0.1-0.2 bar) /Aw × 100.

Irrigation scheduling of rosemary was managed by soil matric potential using tensiometers. The tensiometers were placed paralle to plant rows 10 cm apart from plant at 40 cm depth.

Experimental treatments:

T_1 Irrigated at soil matric potential between 100 to 200 m bar. The soil moisture depletion from total volume between 100 to 200 m bar was 1.6% (θ_v).

The soil moisture depletion from available water was 35%.

The irrigated soil volume of water = Area (per plant) m²× soil depth =0.5×0.5×0.6 = 0.15 m³.

The quantity of applied water per plant= 0.15×1.6% (The soil moisture depletion from total volume= 0.0024 m³/ plant irrig.

The quantity of applied water per feddan = 0.0024×10000(plants number)

= 24 m³/fed irrig. According to Israelsen and Hansen (1962)

T_2The matric potential ranged between 100 to300 m bar, θ_v = 2.4% The quantity of applied water per fed. /irrg = 0.15× 2.4% × 10^4 = 36 m³/fed.irrig.

T_3The matric potential (h) ranged between 100 to 400 m bar θ_v= 2.95%. The quantity of applied water =0.15× 2.95% × 10^4 = 44 m³/fed.irrig.

Water use efficiency (E)

The water use efficiency is used to evaluate differentirrigation treatment in producing maximum yield per unit of water consumed.

Water use efficiency (E) =yield produced in Kg /water consumptive use m^3 or = Oil yield produced in ml/water consumptive use m^3.

Rosemary sowing

Terminal stems of *Rosmarinus officinalis* were obtained from the experimental Farm of Medical and Aromatic Plants, Dokki, H.R.I, A.R.C. Ministry of Agriculture. The terminal stems were sown in the nursery on October 10th 2002 and 2003 seasons. Seedlings were transplanted to the soil, beside the inline emitters on March 2nd and 5th in the first and second growing seasons respectively. The spacing between plants was 0.5 m. The plot area was (5×3.2 m) and contained 4 rows. There were 10 plants in every row (40 plants in each plot).

Every season, during the soil preparation, organic fertilizer (FYM) and calcium super phosphate (15.5% P_2O_5) were added to all treatments at rate of $15m^3$ /fed and 150 Kg /fed respectively. Potassium sulphate (48% K_2O) at rate of 0, 24, 48 and 72 Kg K_2O /fed were divided into three equal doses. The first dose was incorporated into soil during the soil preparation, while the second and third doses were added 45 and 75 days after transplanting respectively. The recommend dose of ammomuim sulphate (20.6 %N, 250 kg/fed.) was applied during the two growing seasons. Also, micro-nutrient i.e. iron, manganese and zinc were added as a foliar application inchelated forms. {(EDTA-Fe (6%), EDTA .Mn (15%) and EDTA. Zn (14%)}.

The micronutrients were sprayed in an aqueous solution (200 liter per feddan) at rate of 200 ppm of each element. The foliar applications were applied three times in each season for all treatments. The first and the second ones were applied after two and three months of transplanting respectively. The third foliar was applied after 3 months of the first harvest. The traditional agriculture practices have been done during the two experimental seasons.

The plants were harvested on September 26th and 30th in the first and second seasons, respectively. The following data were recorded: plant height (cm), branches per plant, fresh and dry weight per plant (gm) and per feddan (ton). Moreover, essential oil content and its components. The essential oil content was determined in the leaves according to British pharmacopoeia (1968). The essential oil components were determined by using gas Chromatography- Mass spectrum Technique.

Iformation	nConditions
Instrument	Gc 5890 Mass spectrophotometer 5989, Hewlett Packared (HP).
Column	HP/5 30m× 0.25 mm ×0.25 µm film thickness.
Stationary phase	Polyphenyle methyl silioxane.
Flow rate	0.6 ml Helium min^{-1}.
Column temp.	50-200 C°
Rate temp.	6 C min^{-1}.
Injection temp.	200C°.
Detector temp.	220 C°.
Recorder.	HP

The oil components percentages were estimated from the measured peak area of the chromatogram according to Gunther and Joseph (1978).

Data of the present study were statistically, analyzed using MSTAT-C software (Freed, 1988). The comparisons among means of the different treatments were carried out, using the Duncan's multiple range test as illustrated by Gomez and Gomez (1983).

RESULTS AND DISCUSSION

Growth and yield parameters:

The growth and yield characters of rosemary plants for each treatment during the two seasons of 2003 and 2004 are shown in Table (3). The data revealed that, increasing the levels of soil matric potential significantly increased the plant height, fresh and dry weight per plant and per feddan. While the number of main branches did not show any response to soil matric potential levels during the two growing seasons, except the difference between T_2 and T_3 in the second season. It was significant.

The highest mean values of growth and yield parameters were found with T_3 (100-400 m. bar = lowest amount of seasonal applied water) and the lowest mean values were found with T_1 (100 – 200 m. bar =highest amount of seasonal applied water). These results may be due to rosemary plant nature, as its leaves are narrow and needle like (similar to pin needles) so it is drought resistant, Menlo (1974). Similar results were obtained by Talha and Osman (1978) on flax, Awad *et al* (1982) on *Phaseolus vulgaris L.*, Kassem and Moshileh (2005) on potato and El-Shakweer and El-Samanody (1985) on Faba bean. They found that the greatest values of grain yield and maximum water use efficiency were occurred with the plants irrigated at 70% depletion of available water as comparing to other irrigation treatments at 25, 40, 55 and 80% depletion of soil available water.

Also, data in Table (3) clearly indicated that, application of different rates of potassium fertilization caused gradual significant increases in all parameters of vegetative growth and yield of rosemary plants. The application of 72 Kg K_2O/fed. (K_3) stands favorably and responsible for the statistically increment for the studied vegetative parameters over the other potassium fertilization rates, in the both seasons. The lowest mean values of vegetative growth parameters were found with control treatments. These results might be attributed to the vital role of potassium and its effects on rosemary plants growth. Potassium regulates photosynthesis, plant respiration rate, carbohydrate supplies, and helps the plant to use water more efficiency by promoting turgidity to maintain internal pressure in the plant (Marschner 1994). Many researches studied the effect of potassium fertilization on the growth of several medicinal and aromatic plants , such as Sidky and Khalied (1998) on peppermint , Bishr *et al* (1998) on

Nigella staviaL., Harridy *et al* (2001) on roselle, Abdel-Latif *et al* (2001) on *Ammi visnaga,L.*, and Hegazi *et al* (2002) on garlic. All of them proved that, there was a positive trend between the potassium fertilization and growth and yield of plants.

As regard, the interaction effect between the irrigation treatments of different levels of soil matric potential and potassium fertilization rates, data in Table (3) showed that, the effect was significant in most treatments of studied vegetative growth and yield parameters. The recorded data clearly indicated that, the highest values of vegetative growth characters during the two seasons owing to a synergetic effect between the irrigation treatment at soil matric potential level of (100-400 m bar, T_3) and the highest rate of potassium fertilization (72 Kg K_2O/fed, K_3). The increments observed in fresh and dry weight could be related to the increases in plant height and stimulation of branches. These results may be due to the effect of potassium on plant growth and consequently to the efficiency of the root in absorbing various nutrients and defy the defection of the irrigation. Surendra *et al* (1994) on coriander and Abdel-Latif *et al* (2001) on *Ammi visnaga, L.* reported similar results.

2- Chemical composition of rosemary plants

a- Essential oil percentage and yield

Data in Table (4) pointed out that, the different irrigation treatments had significant effects on the essential oil percentages, oil yield per plant (ml) and per feddan (L). The maximum values were produced with irrigation treatment (T_3, soil matric potential= 100-400 m bar), followed by T_2 then T_1. These results may be explained through the findings of Penka (1978), who mentioned that, the essential oils are the product of the respiratory catabolic processes, which increase under the dry conditions of the growing site of the plants.

It was evident from data in Table (3) that, application of different rates of potassium fertilization resulted in gradual significant increases in oil percentages and yield per plant and per feddan. The best results were obtained with (K_3) (The highest rate of potassium fertilization), and the lowest values were produced with control treatments. These results are in line with those reported by Bishr *et al* (1998) on *Niggla stavia,L.*,, Sidky and Khalied (1998) on *Mentha piperta ,L.* and Hegazi *et al* (2002) on *Allium sativum,L.* plants.

As for, the interaction between the irrigation treatments and different rates of potassium fertilization, data in the same Table (4) illustrated that, in most cases the interaction had a significant effect on oil percentage and yields per plant and per feddan. The treatments of ($T_3 \times K_3$) gave the highest mean values of oil percentages and oil yield per plant and per feddan in both seasons

b-Essential oil components

The gas Chromatography mass spectrum technique (Gc-Ms) determinations of distillated oil obtained from rosemary leaves were shown in Figures (1a and 1b) and Table (5). Data showed that, no definite trend was observed among the components percentages as affected by different levels of matric soil potential. The matric soil potential (T_3, 100-400 m. bar) gave the highest mean values of some components such as Beta-pinene, alpha terpineol, bornyl acetate, beta-citronellol, camphene, piperitenone and franesene. While components as: linalool, camphor, isopinocamphone, isobornyl acetate, Eugenol and beta-caryophyllene gave their maximum mean values with the soil matric potential at level (100-200 m bar) Borneol and verbenone were insignificant affected by different irrigation treatments.

Regarding, the main effect of potassium fertilization on oil components, it was found the response of different components to different rates of potassium fertilization differ from component to another, but most of components gave the best results with the highest rate of potassium (K_3). These results may be due to the effects of potassium since, it has a role in enzyme activation and it is considered as a necessary cofactor for many of the enzyme catalyzed steps in metabolic pathways, Ibrahim (1985). The response of different components of *Mentha piperita, L.* to potassium fertilization was reported by Sidky and Khalied (1998). He found that, both 1.8 cineol and menthone percentages were decreased by the application of potassium treatments, while, a-pinine increased.

Also, from data in Table (3), it was noticed that, there were significant difference between treatments in the most components as a result to the interaction effect between the two factors under study.

Major essential components of rosemary leaves were identified as camphor, broneol and verbenone. The highest value of camphor was (19.92%) and obtained at ($T_2 \times K_0$) treatment. While, the maximum result of borneol was (24.54%) and found with ($T_3 \times K_3$) treatment. The highest percentage of verbenone was (19.51) and produced at ($T_3 \times K_0$) treatment.

Table 3. Plant height (cm), No of main branches, fresh and dry weight per plant (gm) and feddan (ton) of rosemary plants as affected by soil matric potential and potassium fertilization during 2003 and 2004 seasons.

Irrigation treatments	Potassium fertilization rates	2003						2004					
		Plant height(cm)	No. of main branches	Fresh weight / plant(gm)	Fresh weight/ fed.(ton)	Dry weight/ plant(gm)	Dry weight/ fed. (ton)	Plant height(cm)	No. of main branches	Fresh weight / plant(gm)	Fresh weight/ fed.(ton)	Dry weight/ plant(gm)	Dry weight/ fed. (ton)
T_1		37.308 C	3.000A	52.173C	0.5480C	20.080C	0.2109C	39.458C	3.583AB	62.670C	0.6582C	27.963C	0.2937C
T_2		43.150 B	3.250A	82.237B	0.8636B	33.733B	0.3541B	45.042B	3.333B	88.712B	0.9333B	38.398B	0.4031B
T_3		48.975 A	3.583A	126.358A	1.3268A	46.235A	0.4856A	47.667A	3.917A	122.388A	1.2851A	43.263A	0.4543A
	K_0	39.2111C	2.556C	58.907B	0.6188D	25.120D	0.2637D	37.233C	2.444C	49.080D	0.5153D	22.180C	0.2331C
	K_1	41.711 B	2.889BC	77.319C	0.8120C	31.050C	0.3260C	45.033B	3.556B	48.999C	0.8948C	36.400B	0.3822B
	K_2	42.300 B	3.667AB	90.297B	0.9481B	34.113B	0.3581B	45.622B	3.667B	102.577B	1.077B	38.563B	0.4048B
	K_3	49.356 A	4.000A	121.167A	1.2723A	43.113A	0.4530A	48.333A	4.778A	128.370A	1.348A	49.020A	0.5147A
	K_0	32.23 h	3.00c	36.26j	0.381j	17.15g	0.180g	33.66h	2.33e	43.30i	0.455i	20.26j	0.213i
	K_1	39.13fg	2.33d	41.13i	0.432i	18.00g	0.189g	40.30f	4.00bc	55.14g	0.579g	27.61h	0.290g
	K_2	37.90 g	3.33bc	62.954g	0.661g	20.53f	0.216f	39.86f	3.33cd	71.00f	0.746f	29.47h	0.309g
T_1	K_3	39.97ef	3.33bc	68.35f	0.718f	24.64e	0.259e	44.00e	4.66b	81.24e	0.853e	34.51g	0.362f
	K_0	40.30ef	2.00d	54.58h	0.573h	22.03f	0.231f	38.43g	2.33e	49.82h	0.523h	23.20i	0.244h
	K_1	40.70ef	3.33bc	71.58 e	0.752e	30.95d	0.324d	46.80d	3.00d	79.02e	0.873e	38.35f	0.403e
	K_2	41.50 e	3.66b	84.58d	0.888d	36.55c	0.384c	47.10cd	3.66c	104.73d	1.100d	40.44e	0.424e
T_2	K_3	50.10 b	4.00ab	118.20c	1.241c	45.40b	0.477b	47.83c	4.33b	121.27c	1.274c	51.60b	0.542b
	K_0	45.10d	2.66cd	85.88d	0.902d	36.18c	0.380c	39.60fg	2.66de	54.12g	0.568g	23.08i	0.243h
T_3	K_1	45.30d	3.00c	119.24c	1.252c	44.20b	0.464b	48.00c	3.66c	120.83c	1.269c	43.24d	0.454d
	K_2	47.50c	4.00ab	123.36b	1.295b	45.26b	0.475b	49.90b	4.00bc	132.00b	1.386b	45.78c	0.481c
	K_3	58.00a	4.66a	176.95a	1.858a	59.30a	0.623a	53.16a	5.33a	182.60a	1.917a	60.95a	0.640a

Values marked with the same letter(s) are statistically similar using Duncan's multiple range test at p=0.05. Uppercase letter(s) indicate differences between main effects, and lowercase letter (s) indicate differences within interaction of each character.

T_1, T_2 and T_3 = soil matric potential at levels (100-200,100-300 and 100-400 m bar, respectively.).

K_0, K_1, K_2 and K_3= 0, 24, 48 and 72 Kg K_2O/fed., respectively.

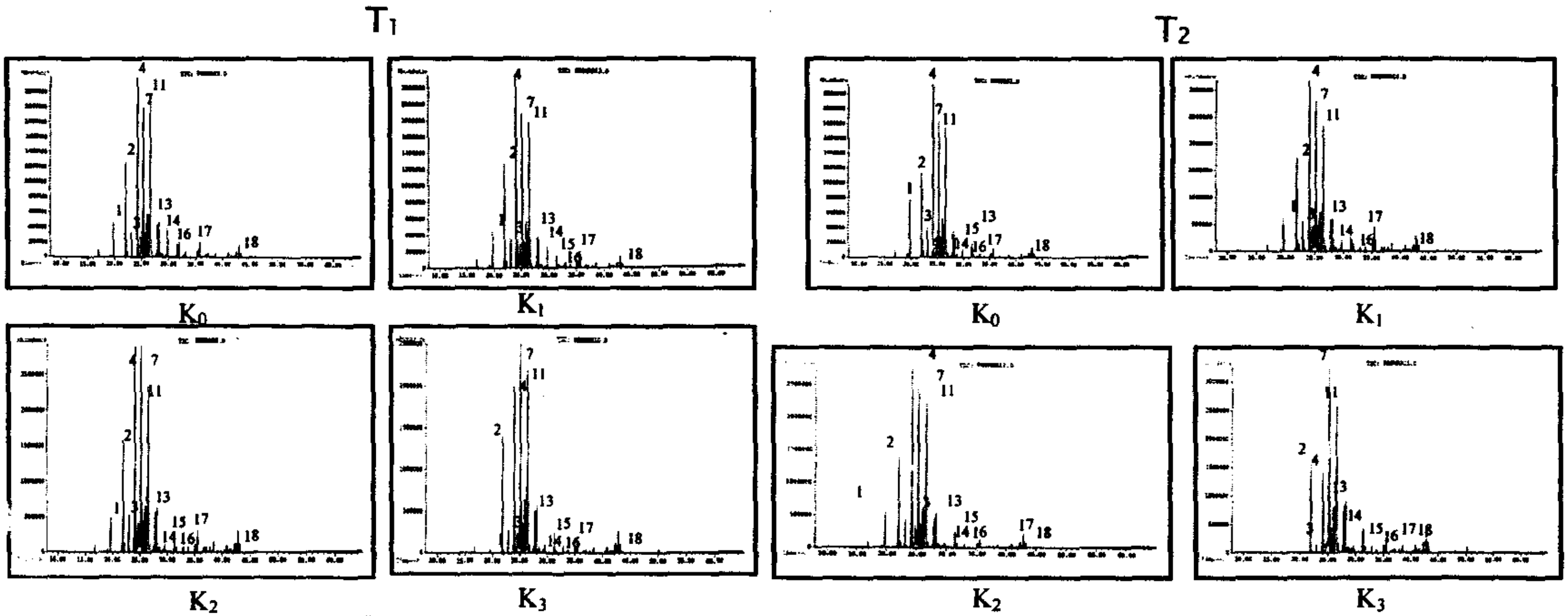
Table 4. Oil percentages, oil yield per plant (ml) and per feddan (L) of rosemary plants as affected by soil matric potential and potassium fertilization during 2003 and 2004 seasons.

Irrigation treatments	Potassium fertilization rates	2003			2004		
		Oil %	Oil / plant (ml)	Oil / fed. (L)	Oil %	Oil / plant (ml)	Oil / fed. (L)
T_1		0.8675C	0.1676C	1.847C	0.9550C	0.3072C	3.225C
T_2		0.9875B	0.3498B	3.682B	1.065B	0.3727B	3.913B
T_3		1.060A	0.5051A	5.304A	1.185A	0.5253A	5.515A
	K_0	0.8033D	0.2062D	2.177D	0.8967C	0.2000D	2.100D
	K_1	0.8900C	0.2787C	2.926C	0.9933B	0.3684C	3:869C
	K_2	0.9933B	0.3474B	3.648B	1.183A	0.4604B	4.835B
	K_3	1.200A	0.5310A	5.692A	1.200A	0.5779A	6.068A
	K_0	0.770i	0.1327k	1.393h	0.830g	0.1687g	1.771g
	K_1	0.910ef	0.1640j	1.722g	0.870fg	0.2403f	2.523f
	K_2	0.840gh	0.1727i	1.813g	1.26ab	0.3717e	3.903e
T_1	K_3	0.950e	0.2010h	2.461f	1.30a	0.4480d	4.704d
	K_0	0.760i	0.1673i	1.791g	0.790g	0.1830g	1.922g
	K_1	0.80hi	0.2470g	2.594f	0.980e	0.3763e	3.952e
T_2	K_2	1.10c	0.3997e	4.197d	1.130d	0.4563cd	4.792cd
	K_3	1.29b	0.5853b	6.146b	0.920ef	0.4750cd	4.988cd
	K0	0.880fg	0.3187f	3.346c	1.070d	0.2483f	2.608f
T3	K1	0.960e	0.4250d	4.463d	1.130cd	0.4887c	5.131c
	K2	1.04d	0.4700c	4.935c	1.210bc	0.5533b	5.810b
	K3	1.360a	0.8067a	8.470a	1.330a	0.8107a	8.512a

Values marked with the same letter(s) are statistically similar using Duncan's multiple range test at $p=0.05$. Uppercase letter(s) indicate differences between main effects, and lowercase letter(s) indicate differences within interaction of each character.

T_1, T_2 and T_3 = soil matric potential at levels (100-200,100-300 and 100-400 m.bar, respectively.).

K_0, K_1, K_2 and K_3= 0, 24, 48 and 72 Kg K_2O/fed., respectively.



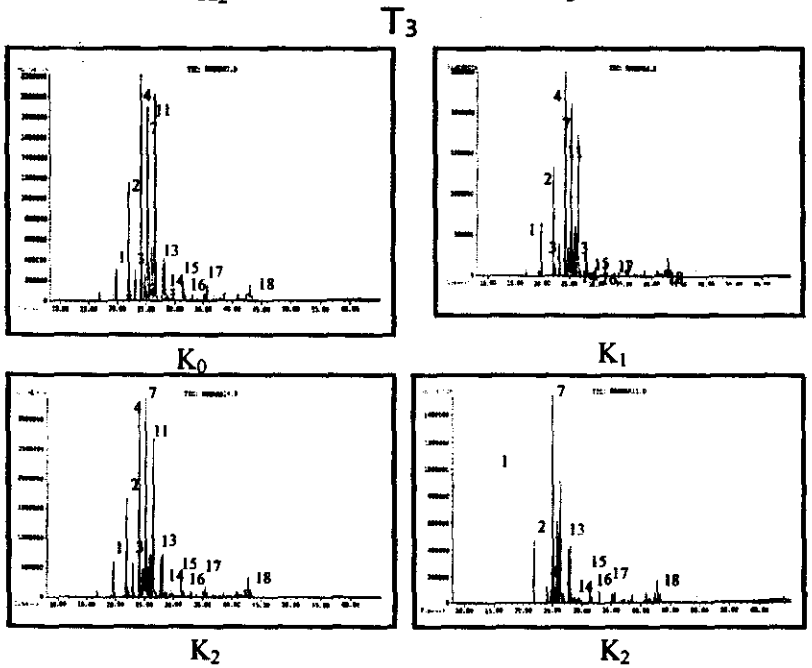


Fig. 1. Chromatogram of rosemary essential oil components as affected by soil matrix potential and potassium fertilization in the second season (2004) T_1, T_2 and T_3 = soil matric potential at levels (100-200, 100-300 and 100-400 m.bar) respectively.

K_0, K_1, K_2 and K_3 = 0, 24, 48 and 72 kg k_2O/fed. Respectively.

(1) 1, 8-cineok.	(2) Linalool.
(3) P-Ethylphenol.	(4) Camphor.
(5) Isopincamphone.	(6) Beta-pinene
(7) Borneol.	(8) 4-terpineol.
(9) Alpha-terpineol.	(10) Bronyl acetate.
(11) Verbenone.	(12) Beta-Citronellol
(13) Camphene.	(14) Isobronylacetate.
(15) Piperitenone.	(16)Eugenol.
(17) Beta-caryophyllene.	(18) Farnesene.

Table5: Essential oil components of rosemary plants as affected by matric potential and Potassium fertilization during second season (2004).

Irrigation treatments	Potassium fertilization rates	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
T_1		1.763B	7.714A	1.888A	16.883A	2.065A	0.993B	18.733A	1.943A	5.065B	3.705C	16.970A	2.553B	2.998B	1.183A	1.220C	0.530A	1.290A	1.258C
T_2		2.388A	7.293AB	1.905B	16.010B	1.863B	1.028B	19.063A	1.940A	5.155B	3.935B	16.285A	2.670B	3.118B	0.608B	1.393B	0.428B	1.133B	1.589B
T_3		1.815B	6.910B	0.768C	14.380C	1.975AB	1.103A	20.067A	1.858B	5.753A	4.583A	15.750A	3.188A	3.678A	0.360C	1.455A	0.408B	0.975C	1.795A
	K_0	3.010A	7.420B	1.597B	18.677A	2.123B	1.107B	17.6878B	1.907B	4.850B	3.410C	17.910A	2.387C	2.837B	1.233A	1.150C	0.637A	1.077B	1.186C
	K_1	2.780A	8.007A	2.213A	18.960A	2.370A	0.823C	17.743B	1.850C	4.817B	3.430C	14.767C	2.353C	21.643C	0.850B	1.017D	0.367C	1.010C	1.170C
	K_2	2.097B	7.206B	1.580B	18.00B	2.193B	0.780C	19.086B	1.927AB	4.867B	3.783B	16.253B	2.490B	2.973B	0.400C	1.423B	0.367C	0.923D	1.480B
	K_3	0.067C	6.590C	0.690C	7.394C	1.183C	1.453A	22.633A	1.970A	6.763A	5.673A	16.410B	3.983A	4.603A	0.383C	1.833A	0.450B	1.520A	2.353A
	K_0	2.380cd	7.380cd	1.710d	17.77e	2.040d	1.340C	16.92ef	1.870e	4.890d	3.54e	17.870be	2.47ef	2.910d	2.130a	1.11g	1.260a	1.270d	1.240h
	K_1	2.630c	8.260a	2.160bc	19.29bc	2.260b	0.630f	17.88e	1.960bc	4.970d	3.380fg	16.120de	2.340g	2.640e	1.630b	0.980h	0.260h	1:40c	0.470j
T_1	K_2	1.840e	7.357cd	2.220bc	17.29f	2.240b	0.450h	19.10c	1.890de	4.730d	3.710d	15.29ef	2.480de	2.940d	0.4600d	1.340e	0.360e	1.500b	1.50ef
	K_3	0.200f	7.860ab	1.460e	13.18g	1.720e	1.55b	21.03bc	2.050a	5.670c	4.190c	18.60ab	2.920c	3.450c	0.510d	1.450d	0.240h	0.990f	1.820c
	K_0	4.870a	7.360cd	2.600a	19.92a	2.290b	0.600fg	17.85e	1.910cde	4.690d	3.240g	16.35de	2.31g	2.660e	0.820c	1.240f	0.300fg	0.910g	1.070i
T_2	K_1	2.160de	7.800abc	2.130c	18.25d	2.270b	1.270d	16.82ef	1.950bcd	4.770d	3.550e	14.27fg	2.36fg	2.590e	0.800c	1.040h	0.560bc	1.98f	1.450f
	K_2	2.520cd	7.220de	2.280bc	18.98c	2.160bc	0.550g	19.25c	1.970bc	4.920d	3.470ef	17.47bc	2.41efg	2.960d	0.370f	1.330e	0.330ef	0.610h	1.380g
	K_3	0.00f	6.790e	0.610f	6.890h	0.730g	1.690a	22.33b	1.930cd	6.240b	5.480b	17.05cd	3.600b	4.260b	0.44de	1.960b	0.520c	1.98f	2.460b
	K_0	1.780e	7.520bcd	0.480f	18.34d	2.040cd	1.380c	18.29de	1.940cd	4.970d	3.450ef	19.51a	2.380efg	2.940d	0.750c	1.100g	0.350e	1.05f	1.25h
T_3	K_1	3.550b	7.960ab	2.350b	19.34b	2.580a	0.570g	18.53d	2.00ab	4.710d	3.360fg	13.91fg	2.360fg	2.650e	0.120h	1.030h	0.280gh	1.018e	1.59d
	K_2	1.930e	7.040de	0.240g	17.73e	2.180b	1.340c	18.90cd	1.920cde	4.950d	4.170c	16.00de	2.580d	3.020d	0.370ef	1.600c	0.410d	0.660h	1.56de
	K_3	0.00f	5.120f	0.00h	2.110i	1.100f	1.120e	24.54a	1.570f	8.380a	7.350a	13.58g	5.430a	6.100a	0.200g	2.090a	0.590b	1.010f	2.78a

Values marked with the same letter(s) are statistically similar using Duncan's multiple range test at p=0.05. Uppercase letter(s) indicate differences between main effects, and lowercase letter (s) indicate differences within interaction of each character.

T_1, T_2 and T_3 = soil matric potential at levels (100-200,100-300 and 100-400 m.bar, respectively.).

K_0, K_1, K_2 and K_3= 0, 24, 48 and 72 Kg K_2O/fed., respectively.

(1) 1, 8-cineole. (2) Linalool. (3) P-Ethylphenol (4) Camphor . (5) Isopinocamphone. (6) Beta-pinene.
(7) Borneol. (8) 4 –terpineol. (9) Alpha – terpineol (10)Bronyl acetate. (11)Verbenone. (12) Beta-Citronellol.
(13) Camphene. (14) Isobronylacetate.(15) Piperitenone (16) Eugenol (17) Beta – caryophyllene. (18) Farnesene.

Table 6. irrigation numbers and irrigation water quantities (m3/fed) for Rosemary plants during 2003 and 2004 seasons.

T*	F.K.#	Season 2003														Total m^3/fed	Season 2004														Total m^3/fed
		March		April		May		June		July		August		Sept.			March		April		May		June		July		August		Sept.		
		A[x]	B[xx]	A	B	A	B	A	B	A	B	A	B	A	B		A	B	A	B	A	B	A	B	A	B	A	B	A	B	
	K_1	16	384	20	480	22	528	25	600	26	624	26	624	16	384	3624	17	408	20	480	22	528	25	600	27	648	27	648	19	456	3768
	K_2	16	384	20	480	21	504	24	576	25	600	25	600	15	360	3504	17	408	20	480	21	504	24	576	26	624	26	624	18	432	3648
T_1	K_3	16	384	20	480	21	504	23	552	24	576	24	576	14	336	3408	17	408	20	480	21	504	23	552	25	600	25	600	18	432	3576
Mean m^3/fed			384		480		512		576		600		600		360	3512		408		480		512		576		624		624		440	3664
	K_1	10	360	12	432	13	468	14	504	15	540	15	540	8	288	3132	10	360	13	468	14	504	15	540	16	576	16	576	9	324	3348
	K_2	10	360	12	432	12	432	14	504	14	504	14	504	8	288	3024	10	360	12	432	13	468	14	504	15	540	15	540	9	324	3168
T_2	K_3	10	360	12	432	11	396	13	468	13	468	13	468	8	288	2880	10	360	12	432	12	432	13	468	14	504	14	504	9	324	3024
Mean m^3/fed			360		432		432		492		504		504		288	3012		360		444		468		504		540		540		324	3180
	K_1	7	308	8	352	9	396	10	440	11	484	11	484	5	220	2684	7	308	8	352	9	396	11	484	12	528	12	528	6	264	2860
	K_2	7	308	8	352	9	396	10	440	10	440	10	440	5	220	2596	7	308	8	352	9	396	10	440	11	484	11	484	6	264	2728
T_3	K_3	7	308	8	352	8	352	9	396	9	396	9	396	5	220	2420	7	308	8	352	8	352	9	396	10	440	10	440	6	264	2552
Mean m^3/fed			308		352		381		425		440		440		220	2566		308		352		381		440		484		484		264	2713

(*) Irrigation Treatment (#)Potassium fertilizer rate (x) irrigation numbers (xx) Irrigation water quantities

Irrigation scheduling:

The monthly and seasonal applied water by rosemary plants under the three treatments are presented in Table (6).

Data show that the monthly and seasonal applied water increased by decreasing soil moisture depletion from available water from 64% to 35% as soil moisture stress from (0.1to 0.4 bar) to (0.1 to 0.2 bar).

The seasonal data show that T_1 used 3512 and 3664 m^3/feddan of irrigation water in 2003 and 2004 seasons, respectively, T_2 used 3012 and 3180 m^3/feddan and T_3 used 2566 and 2713 m^3/feddan in 2003 and 2004 seasons, respectively.

The reduction in applied water from T_1 to T_3 is due to reduce the irrigation frequencies (controlled by soil matric potential, which made long irrigation interval).

These results were in agreement with those obtained by El-Gindy *et al* (1991) on Cucumber and squach, they found that increasing soil stress caused decreasing of water consumptive use. Kassem and Al-Mosheileh (2005) they found that, the soil moisture depletion at 45% from available water increased plant growth and yield compared with other soil moisture depletion.

The monthly values were low at beginning of growing season (March) but the maximum values of monthly occurred during July and August Table (6) for all treatments, when the plants were maximum growth, beside air temperature was relatively high. Data in Table (6) showed that the monthly values ranged between 440-600 m^3/feddan during July and August in the first season and 484 and 624 m^3/feddan in the second season. These results were in agreement with obtained by Abdel-Messeih and El-Gindy (2004) on Apricot trees.

Concerning the interaction effect of both soil stress and potassium fertilization, data in Table (7) show that the effect of the two parameters on both dry weight and oil yield per feddan of rosemary. By using 72 Kg K_2O per feddan (K_3) and irrigated at tension (100 to 200 m. bar) T_3 {65% depletion from available water}

The values of water irrigation T_3 with highest level of potassium fertilization (K_3) were 2566 and 2713 m^3/feddan in 2003 and 2004 seasons respectively. The results were in agreement with those obtained by Awad *et al* (1982) on Kideny bean. They found that, the optimum level of soil moisture depletion (60% of available water) in combination with high doses of super phosphate gave the best quantity as well as quality of kideny bean seeds.

Water use efficiency:

Data in Table (7) revealed that water use efficiency increased by increasing dry weight (Kg) and oil yield (ml) and decreasing the amount of applied water (m^3).

The water use efficiency values were higher in the second season compared with the first season. It is mainly due to higher yield production in the second season. The values of T_3 gave the higher values of water use efficiency because of increasing the production.

On the contrary T_1 gave the lower values of water use efficiency. It is due to decrease the yield production. These results are in agreement with El-Mowelhie *et al* (1999).

Concerning the interaction effect of both irrigation treatments (T_1, T_2 and T_3) and potassium fertilization (K_1, K_2 and K_3) on water use efficiency of rosemary plants. The highest values of water efficiency on dry weight (Kg) and oil yield (ml) were found in the treatment T_3K_3.

Decreasing amount of applied water from T_1 to T_3 and increasing potassium doses from K_1 to K_3 increasing water use efficiency from 0.052 and 0.077 Kg /m^3 on dry weight in the treatment T_1K_1 to 0.257 and 0.251 Kg /m^3 on dry weight in the treatment T_3K_3 during 2003 and 2004 seasons respectively.

The oil yield ranged between 0.475 and 0.670 ml/m^3 in the treatment T3K3 during 2003 and 2004 seasons, respectively.

The results are in agreement with El-Shakweer and El-Samanody (1985) on faba bean and Kassem and El-Mosheilah (2005) on potato.

CONCLUSION

From the above results, it can be concluded that, the interaction effect between T_3 (soil matric potential at level 100-400 m bar= lowest amount of seasonal applied water) and K_3 (highest rate of potassium fertilization = 72 Kg K_2O/fed) significantly improved the growth, yield, essential oil percentages and yield of rosemary plants. The response of the essential oil components to the interaction between the soil matric potential and potassium fertilization differ from component to another according to the different treatments.

Table 7. Irrigation quantities, yield production and water use efficiency for dry weight kg/m³and oil yield ml/m³for study area.

T*	F.K.**	Irrigation Quantities m³/fed		Dry weight Kg/fed		Oil ml/fed		E. for dry weight		E. for oil	
		2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
T_1		3512	3664	210.9	293.7	1847	3225	0.06	0.08	0.526	0.880
T_2		3012	3180	354.1	403.1	3682	3913	0.118	0.127	1.222	1.231
T_3		2566	2713	485.6	454.3	5304	5515	0.189	0.168	2.067	2.033
	K_1	3624	3768	189	290	1722	2523	0.052	0.077	0.475	0.67
T_1	K_2	3504	3648	216	309	1813	3903	0.062	0.085	0.517	1.07
	K_3	3408	3576	259	362	2461	4704	0.076	0.101	0.722	1.315
	K_1	3132	3348	324	403	2594	3952	0.104	0.120	0.828	1.180
T_2	K_2	3024	3168	384	424	4197	4792	0.127	0.134	1.388	1.513
	K_3	2880	3024	477	542	6146	4988	0.166	0.179	2.164	1.65
	K_1	2684	2860	464	454	4463	5131	0.173	0.159	1.663	1.794
T_3	K_2	2596	2728	475	481	4935	5810	0.183	0.176	1.901	2.130
	K_3	2420	2552	623	640	8470	8512	0.257	0.251	3.2	3.335

* Irrigation Treatment.
** Fertilizer rate (Potassium)

Also, the interaction between T_3 and K_3 gave the lowest amount of seasonal irrigation water (2420 and 2552 m³/fed. during 2003 and 2004 seasons respectively) and saved about 28.82% from irrigation water. In addition, $T_3 \times K_3$ treatment produced an average water use efficiency values of 0.254 Kg dry weight/m³ and 3.418 ml oil/ m³.

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الملخص العربي

استجابة نبات حصى البان لجهد الشد والتسميد البوتاسي في الأراضي المستصلحة حديثا

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أجريت تجربتان حقليتان في المزرعة البحثية بقرية علي مبارك بالبستان بالأراضي الرملية خلال موسمين متتاليين ٢٠٠٣ و ٢٠٠٤ ، ويهدف البحث إلي دراسة تأثير الإجهاد المائي (بإستخدام التنشومترات) مع التسميد البوتاسي على النمو و إنتاج الزيت ومكوناته لنباتات حصى البان، هذا بالإضافة إلي دراسة جدولة الرى وكفاءة استخدام المياه تحت نظام الرى بالتنقيط.

واستخدم لهذه التجربة التصميم الإحصائي بنظام القطع المنشقة و شغلت القطع الرئيسية بثلاث معاملات ري (جهد الماتريك) تمثل ٣ مستويات (T_1 من ١٠٠ إلي ٢٠٠ مل بار، T_2 من ١٠٠ الى ٣٠٠ مل بار و T_3 من ١٠٠ الى ٤٠٠ مل بار) و القطع تحت الرئيسية تكونت من ٤ معدلات سلفات بوتاسيوم ٤٨% (صفر،٢٤،٤٨،٧٢ كجم بو٢أ/فدان٠)

وأشارت النتائج إلي أن معاملة الري (T_3) أعطت أعلى القيم في قياسات النمو و إنتاج الزيت كما أعطت أقل كمية مياه ري موسمية (٢٥٦٦ و ٢٧١٣ م٣ /فدان خلال موسمي ٢٠٠٣ و ٢٠٠٤ على التوالي) أيضا وفرت هذه المعاملة (T_3) ٢٧,٩% من مياه الري.

ارتفاع معدلات التسميد البوتاسي ادت الى زيادة تدريجية في قياسات النمو والإنتاج حتى وصلت إلى أعلى القيم مع المستوى العالي من التسميد (K_3 = ٧٢ كجم بو٢أ/فدان) التأثير المتبادل بين T_3 (١٠٠ إلى ٤٠٠ مللي بار) و K_3 (أعلى معدل تسميد بوتاسي) أعطى أفضل النتائج في طول النبات و عدد الفروع الرئيسية للنبات والوزن الطازج والجاف للنبات والفدان. و في معظم الحالات تأثرت مكونات الزيت الطيار معنويا بمعاملة التداخل بين T_3 و K_3. المكونات الأساسية في الزيت الطيار وهي الكامفور والبرينول والفربينون أعطت أعلي القيم مع ($K_0 \times T_2$)، ($K_3 \times T_3$) و ($K_0 \times T_3$) علي التوالي. أيضا المعاملة ($K_3 \times T_3$) استهلكت أقل كمية مياه رى موسمية (٢٤٢٠ و ٢٥٥٢ م٣ /فدان خلال موسمي ٢٠٠٣ و ٢٠٠٤ على التوالي). و وفرت هذه المعاملة ٢٨,٨٢% من مياه الري. ومن وجهة نظر أخرى فقد كان متوسط كفاءة استخدام وحدة المياه للمعاملة ($K_3 \times T_3$) بالنسبة للمادة الجافة (٠,٢٥٤ كجم / م٣ مياه). و بالنسبة لمحصول الزيت الطيار (٣,٤١٨ مللي زيت / م٣ مياه).