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EVALUATION OF THE USE OF MAGNETIZATION TECHNOLOGY IN UNCONVENTIONAL IRRIGATION WATER ON THE QUALITY AND GROWTH OF THYME (*Thymus vulgaris*)

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ABSTRACT

Due to climatic changes, the world has suffered from water scarcity in the last decades, which led to the use of low-quality water for irrigation in the agriculture sector. This study was designed to evaluate the effect of the characteristic's magnetic field under saline condition on the growth characteristics and quality of Thyme. The experiment design was spilt-plot with two different water quality (magnetic water field and saltwater) and magnetic iron as a soil conditioner with three rates (i.e., 0, 100 and 150 mg/Kg). All experiments were performed in three replicates.

The results showed a positive effect of the Magnetic Water Field (MWF) interaction with magnetic iron (Fe_3O_4) at the rate of 150 mg/Kg on soil macronutrients, Ca^{+2} and K^+ content. This condition decreased the harmful effects of Na^+ and Cl^- ions, while there was no effect on the soil pH. The findings revealed that the interaction application of MWF+ magnetic iron (Fe_3O_4) at the rate of 150 mg/Kg gave a positive response on shoot fresh and dry weight. It was shown that the best high level of thyme essential oils was achieved using saltwater + magnetic iron (Fe_3O_4) at the rate of 100 and 150 mg/Kg.

Keywords: Magnetic Field, Saltwater, Magnetic Iron, Essential Oil, Thyme.

INTRODUCTION

Plants are exposed to a wide range of different environmental stresses due to unsteady environmental conditions. These stresses affect growth and crops production. Plant is a living organism, but it is not like an animal that can migrate or escape from non-ideal environmental conditions to an ideal environment in which it can thrive. The environmental stresses and the inability of the plants to move to enforce plants to develop adaptation mechanisms to survive in those environments. Plants are exposed to many environmental stresses that limit their productive potential. Biotic and abiotic stresses are the main two types of stresses that affect plants (Kumar *et al.*, 2014). Biotic stresses include fungal infections, bacteria, viruses, and insects. On the other hand, abiotic stress includes salinity, drought, temperature, or chemical stress (Najafian *et al.*, 2009). In recent years, scientists focused on studying these stresses and how to mitigate their effect on plant growth and production. Several techniques were developed to tackle these stresses and to help plants to survive the ever-changing environments.

One of the techniques developed to tackle abiotic stress is the exploitation of magnetic force to improve plant growth and production. The study of the magnetic field is of great importance because it has many applications. Plants irrigated by magnetized water acquire more nutrients from the soil. The magnetic field increases the yield parameters of crops such as Cereal, Sunflower, Sweet basil, Thyme, and Safflower (Amer *et al.*, 2014). The water of irrigation is passed on a permanent magnet or an electromagnet to get installed on the water pipeline to be magnetized. When water passes through a magnetic field, some physical but not chemical properties of water change, such as the surface tension, density, and viscosity (Mostafazadeh-Fard *et al.*, 2012). The magnetization of water enables the use of low-quality water for irrigation to produce many crops under severe water shortage conditions that are prevalent in many countries of the world. It also improves crop productivity and reduces the harmful impact of saline water on plants.

The magnetic field also reduces the bond angle between hydrogen and oxygen atoms inside the water molecule from 104.5 to 103 degrees, so it forms small clusters instead of large groups of the water molecule, and thus increases water absorption. As for the ionic assemblies, they decompose into fully dissolved ions of high energy and are more active under the influence of Lorentz forces (Leal & Tarsikka, 2017; Chang & Weng, 2006 and Zhao *et al.*, 2015).

There are two natural minerals with magnetic properties including pyrrhotite and magnetite. Magnetite is a natural raw mineral with a black or reddish-brown color that contains a high iron content of about 25 to30% and its hardness is 5 to 6 Mohs. (Soliman *et al.*, 2015)

Thyme *(Thymus vulgaris L.*) is an herbaceous perennial plant that belongs to the Lamiaceae family. Southern Italy and the western Mediterranean are the original home of thyme. There are more than 300 species of thyme planted all over the world. Thyme is a common medicinal plant in many traditional medicinal systems in the Mediterranean region. It is also a common spice and flavoring agent. Thymol and carvacrol, which are the principal constituents of thyme oil exhibited antioxidant, antimicrobial, antifungal activity especially against respiratory-related diseases (Sharafzadeh, 2011).

This study was carried out to determine whether the magnetic water field MWF could help mitigate the harmful effects of water salinity and the ability to use this water in the cultivation of thyme.

MATERIALS AND METHODS

To investigate the effect of the magnetic water treatment and magnetite on Thyme, the experiment was carried on sandy loamy soil at a private farm, 80-kilometer Cairo- Alexandria desert road- Egypt during the period from 2018 to 2019, to study the effects of two types of water (magnetized water and saltwater) and magnetic iron as a soil conditioner at different rates (i.e., 0, 100 and 150 mg/kg). All experiments were performed in three replicates and 18 treatments to study their effect on Thyme growth. Water samples and soil samples (0 to30cm. depth) were taken before cultivation to determine the main soil physical and chemical characteristics (Tables 1&2). The analyses were done according to previous reports (Estefan *et al*., 2013, Klute, 1986 and Page *et al*., (1982).

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Table (1): Chemical and physical characteristics of the initial soil sample before cultivation.

Soil Characteristics	Value
Particle Size Distribution (%):	
a) Sand	85.3
b) Clay	13.4
c) Silt	1.3
Texture	Sandy Loamy
Chemical Properties	
a) Organic matter (%)	0.54
b) E.C, in soil paste extract. (dSm^{-1})	17.94
c) pH (1:2.5)	7.30
Soluble Cations and Anions (meq/l)	
Ca^{+2}	37.7
Mg^{+2}	57.4
Na^{+}	97.3
K^{+}	0.83
CO_3^{-2}	0.00
HCO^{-}_3	2.83
Cl^{-}	142.0
SO_4^{-2}	45.1
Available Macronutrients (ppm)	
N	120.0
P	54.0
K	67.4

Table (2): The chemical analysis of irrigation water before and after magnetic treatment

WATER CHARACTERISTICS	SALTWATER	MAGNETIC WATER FIELD (MWF)
1- pH	6.98	6.80
2- EC in water (dSm^{-1})	7.29	7.12
3-Soluble Cations and Anions (meq/l) Ca^{+2} Mg^{+2} Na^{+} K^{+} CO_3^{-2} HCO^{3-} Cl^{-} SO_4^{-2}	 32.24 18.95 18.70 0.45 0.00 1.42 52.88 16.04	 31.05 19.42 18.26 0.43 0.00 1.42 51.95 15.80

Table (3): The chemical analysis of magnetite (magnetic iron) under this study

DETERMINATION	MAGNETITE
pH	**8.02**
K_2O%	**0.19**
Al_2O_3 (ppm)	**5.27**
FeO (ppm)	**66.70**

Figure (1): Magnetic Water Device

Laboratory analysis

Available nitrogen in the soil samples was extracted by KCl as described by Black (1982). Electrical conductivity (EC) in soil pastes extracts was determined as described by Ryan *et al.*, (1996). Soil reaction (pH value) was determined in the extract 1:2.5 as mentioned by Ryan *et al.*, (1996). Available phosphorus was determined using the ascorbic acid method according to the procedure outlined by Olsen & Sommers, (1982). Available potassium was extracted as described by Dewis and Freitas, (1970) with in N ammonium acetate at pH 7 and was determined using Janway Flame Photometry. Soluble cations and anions were determined using the method of USDA, (1954).

Gas chromatography-Mass Spectrometry of the essential oil: The essential oil of Thyme was extracted from the leaves of each treatment by distillation according to the method reported in the British Pharmacopoeia (1963) and the oil percentages were recorded.

The GC-MS analysis of the essential oil was carried out using gas chromatography-mass spectrometry instrument at the Department of Medicinal and Aromatic Plants Research, National Research Center.

Statistical Analysis: The results were statistically analysed using a Co-stat computer package to calculate the F ratio according to Sendecor and Cochran (1980). The Least Significant Differences method (L.S.D) was different the means at the 0.05 level of probability.

RESULTS AND DISCUSSION

Magnetic effects:

Vegetative growth characters: The results showed that high significant values of Thyme fresh shoot and dry shoot weight were obtained with magnetite at both rates100 and 150 mg/Kg compared with saltwater (SW) (Table 4). These values indicated the important role of Magnetic Water Field (MWF) to mitigate salt's effect on Thyme. The reduced salt effect improved the plant photosynthesis and plant uptake of nutrients which led to improved vegetative growth. While the use of (MWF) with magnetic iron (Fe_3O_4) changed the activity of the main enzymes involved in the metabolism of plants. The magnetic water reduced the harmful effect of the salt stress in addition. These results agreed with previous reports on vineyards (Ali *et al*., 2013), Fennel (*Foeniculum vulgare* Mill.) (Maie. Mohsen & Abeer. Kassem, 2016), Peanut (*Arachis hypogaea* L.) (Salem., 2017) and Cotton (*Gossypium hirsutum* L.) (Gao *et al.*, 2017).

The highest values of the essential oil were observed with MWF+ 150 mg/kg magnetic iron followed by MWF+ 100 mg/kg magnetic iron (Table 4). These results may be due to the role of the magnetic field to restructure the water molecules into small clusters by weakening the intra clusters hydrogen bonds, breaking the larger clusters and forming them into smaller stronger clusters made up of six symmetrically organized molecules. These tiny and uniform clusters possess hexagonal structures thus can easily enter the passageways across the plant cell membranes. Magnetite may also affect the phyto-hormone production leading to enhanced cell activity and plant growth (Faqenabi *et al*., 2009) as shown in safflower, (*Carthamus tinctorius*) (Fatemi & Aboutalebi, 2012)**,** (Elhindi *et al.*, 2016) and sweet basil *(Ocimum basilicum L.)* (Abdel Rahman & Shalaby, 2017).

Table (4): The effect of using Magnetic Water Field, saltwater and magnetite on Thyme growth parameters

Experiment Treatment			**Growth Parameters**		
Water Type	Applications	Concentration	Shoot F.W (g/ plant)	Shoot D.W (g/ plant)	Oil %
Magnetic Water Field (MWF)	Fe_3O_4 (mg/kg)	0.0	89.45	25.88	0.196
		100	154.19	38.15	0.196
		150	192.38	77.69	0.396
Saltwater (SW)	Fe_3O_4 (mg/kg)	0.0	77.64	23.87	0.183
		100	80.08	24.04	0.١٨٤
		150	87.65	29.29	0.19٠
LSD. at 0.05 Water Type× Applications × Concentration			LSD. at 0.05		
			5.64	7.84	5.94

The chemical composition of Thyme essential oil:

Thyme (*Thymus vulgaris* L.) is a valuable natural herb that is widely used in the pharmaceutical, cosmetic, and food industries. Thyme adapts easily to a variety of environmental conditions (Llorens-Molina & Vacas, 2016)**.** The GC-MS analysis of the volatile oil suggested the presence of 16 components in thyme essential oil including camphene, α-terpinene, *p*-cymene, 1,8-cineole, camphor, borneol, 3-cyclohexen-1-ol, α-terpinolene, hydroxymethyl, cyclocolorenone, 6-trimethyl-3-methylbuta-3-oxatricyclo octane, 4-bromo-1-naphthylamine, longiverbenone, caryophyllene oxide, germacrene-D, and caryophyllene (Table 5).

Most of the thyme essential oil components were obtained in maximum values under saltwater treatment. 1,8-cineole as the major compound in thyme essential oil was obtained in the highest value under saltwater + Fe_3O_4 with the rate 100mg/Kg followed by saltwater + Fe_3O_4 at a rate of 150mg/Kg. The results were in agreement with previous reports of Llorens-Molina & Vacas, (2016***).*** The highest values of camphene and camphor were 1.968 and 5.566%, respectively, which were obtained under saltwater + Fe_3O_4 at a rate of 100mg/Kg. Saltwater may affect the plant's morphological characters such as plant height and weight. It may also affect cell division, cell elongation and inhibits photosynthesis. Such changes may promote the production of secondary metabolites including volatile oils.(Ezz El-Din *et al.*, 2009)**.**

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Table (5): Effect of the magnetic field on the chemical composition of thyme essential oil

Magnetic Water Field (MWF)				SALTWATER (SW)			LSD. AT 0.05
Essential Oil Chemical Composition %	Magnetic Iron mg/Kg			Magnetic Iron mg/Kg			
	0.00	100	150	0.00	100	150	
Camphene	1.48	0.54	1.68	2.02	1.97	1.66	0.005
α-Terpinene	0.80	0.00	3.34	2.00	2.31	3.97	0.058
p-Cymene	3.31	0.00	4.04	3.09	3.67	3.91	0.011
1,8-Cineole	7.56	5.51	10.03	7.16	12.61	12.09	0.008
Camphor	4.01	1.51	4.48	4.82	5.57	4.55	0.007
Borneol	7.10	3.84	6.28	4.45	8.58	6.90	0.005
3-Cyclohexen-1-ol	1.12	0.00	1.45	1.04	1.45	1.16	0.027
α-TERPINOLENE	1.84	0.00	2.74	0.92	2.79	0.00	0.009
Hydroxymethyl	1.89	2.12	1.54	1.84	1.72	1.56	0.008
Cyclocolorenone	3.81	3.82	3.21	3.91	3.25	3.17	0.007
6-Trimethyl-3-methylbuta-3-oxatricyclo octane	3.51	4.69	3.11	3.69	3.04	3.40	0.009
4-bromo-Naphthalenamine	5.21	5.95	4.21	5.76	4.48	5.01	0.011
Longiverbenone	3.49	3.88	2.95	3.65	3.19	3.03	0.062
Caryophyllene oxide	1.33	0.53	1.11	1.30	1.09	0.99	0.008
GERMACRENE-D	0.61	0.61	0.68	0.69	0.56	0.60	0.009
Caryophyllene	1.00	0.94	1.59	1.98	1.45	1.98	0.011

Effects of magnetic and magnetite rates on soil available macronutrients content:

The maximum significant value of soil available macronutrients was obtained under MWF + Fe_3O_4 at the rate of 150 mg/kg followed by MWF + Fe_3O_4 at the rate of 100 mg/kg and then saltwater + Fe_3O_4 at a rate of 150 mg/kg (Table 6). These results can be attributed to the useful effects of

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magnetic field on the bond of NaCl which led to the dispersion of its atoms, and thus reducing the salinity harmful effects in soil as explained by Hafez & Soubeih, (2012)**.** Magnetic water affects the water hydrogen-bonded structure increasing the number of hydrogen bonds by approximately 0.34% when increasing magnetic field strength from 1 to 10T and higher values for mobile forms of nutrients were observed in the soil **(**Bagherifard & Ghasemnezhad, 2014)**.** Magnetic field can alter the physicochemical characteristics of the soil leading to augmented dissolvability of elements (Ali *et al.,* 2013)**.** Applied magnetics raised the amount of soil microbial content such as N-fixation bacteria and increased the activity of soil key enzymes. Such increases may enhance the availability of soil nutrients (Abd-Elrahman & Shalaby, 2017).

Table (6): Available macronutrients under magnetic water, saltwater and Magnetite application

Treatment			**Soil Analysis**		
water Type	Applications	Concentration	N (ppm)	P (ppm)	K (ppm)
Magnetic Water Field (MWF)	Fe_3O_4 (mg/kg)	0.0	63.00	20.19	99.70
		100	172.83	39.91	163.50
		150	244.52	40.33	158.37
Saltwater (SW)	Fe_3O_4 (mg/kg)	0.0	18.87	19.88	73.30
		100	65.03	32.35	75.95
		150	80.70	33.30	83.33
LSD. at 0.05 Water Type× Applications× Concentration			LSD. at 0.05		
			1.820	1.370	3.468

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Fig.(2) Thyme under saltwater treatment Thyme under magnetic field and magnetite

Chemical characteristics of the soil after Thyme harvesting irrigated by magnetic water and Magnetite:

A decrease in E.C and Na^{+} and Cl^{-} content was observed under MWF + magnetite at the rate of 150Kg/Fed followed by MWF + magnetite at the rate of 100 Kg/Fed. These results indicated that when the rate of magnetite increased it reduced pH, E.C and Na^{+} and Cl^{-} content but increased Ca^{+2} and K^{+} content in comparison with saltwater and magnetite.

Here again magnetic field restructures the water molecules into very small clusters, weakens hydrogen bonds, breaks the larger clusters into smaller ones, each is made up of six symmetrically organized molecules. These tiny and uniform clusters possess hexagonal structures thus they can easily enter the passageways in plant membranes, and toxic agents cannot enter. These features suggest that magnetic water is a bio-friendly compound for the plant it leaches salts from the soil and adsorbs H^{+} ions instead of other cations result in pH reduction (Abd-Elrahman & Shalaby, 2017). Magnetite

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can also weaken the bonds between ions and decreases the harmful toxic ions (Howaida & Mona, 2014).

Table (7): Some chemical characteristics of the soil after Thyme harvesting

Treatment			pH	E.C dSm^{-1}	SP	Cations meq/L				Anions meq/L			
Water Type Applications		Concentration				Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO^{-3}	HCO^{-}_{3}	Cl^{-}	SO^{-4}
Magnetic water field (MWF)	Fe_3O_4 (mg/kg)	0.0	7.60	17.65	24.76	65.36	26.58	97.24	1.18	0.00	2.30	129.74	41.24
		100	7.70	14.35	27.67	73.05	43.87	71.26	1.12	0.00	2.81	99.54	53.92
		150	7.60	14.35	30.67	72.48	32.01	73.60	1.03	0.00	2.40	99.60	44.36
Saltwater (SW)	Fe_3O_4 (mg/kg)	0.0	7.80	32.21	24.67	151.24	56.96	60.63	2.53	0.00	2.83	110.99	151.26
		100	7.80	26.09	25.67	156.65	90.38	41.66	4.03	0.00	2.82	90.78	228.39
		150	7.90	21.78	29.67	152.22	74.89	31.87	2.53	0.00	4.72	90.58	193.60
LSD. at 0.05 Water type× Applications× Concentration			LSD. at 0.05										
			7.16	0.15	0.499	0.78	0.50	14.82	0.28	0.00	0.31	0.38	0.67

CONCLUSION

Application of magnetic water field and magnetite at a rate of 150 mg/Kg produced the best values of the fresh and dry shoot weight of Thyme. This irrigation treatment decreased the harmful effects of Na^{+} and Cl^{-} on plants under saline conditions. The highest values of essential oils were obtained under saltwater treatment to face the stress exerted by the salts on the plants.

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تقييم استخدام تقنية المغنطة في مياه الري غير التقليدية على جودة ونمو نبات الزعتر (*Thymus vulgaris*)

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المستخلص

عانى العالم من ندرة المياه في السنوات الأخيرة بسبب التغيرات المناخية التي أدت إلى استخدام مياه منخفضة الجودة للري في قطاع الزراعة. تم تصميم هذه الدراسة لمعرفة تأثير المجال المغناطيسي على خصائص جودة نمو الزعتر. كان تصميم التجربة عبارة عن قطعة أرض مقسمة للمعاملة بنوعين مختلفين من المياه الأولى مياه معالجة بالمجال المغناطيسي ومياه مالحة. والثانية بالحديد المغناطيسي كمحسن للتربة بثلاث معدلات ٠–١٠٠–١٥٠ مجم / كجم. تم إجراء جميع التجارب في ثلاثة مكررات.

أظهرت النتائج تأثيراً إيجابياً لتفاعل مجال الماء المغناطيسي مع الحديد المغناطيسي (Fe_3O_4) بمعدل ١٥٠ مجم / كجم على محتوى التربة من المغذيات الكبرى ومحتوي الكالسيوم والبوتاسيوم وهذا بسبب انخفاض أيونات الصوديوم والكلوريد الضارة، بينما لم يكن هناك تأثير على درجة حموضة التربة. كما كشفت النتائج عن أن التطبيق الثنائي باستخدام المياه المعالجة بالمجال المغناطيسي (MWF) مع الحديد المغناطيسي (Fe3O4) بمعدل ١٥٠ مجم / كجم أعطى إستجابة إيجابية لوزن السيقان الطازج والجاف. كما تبين أن أفضل نسبة من زيوت الزعتر العطرية تم تحقيقها باستخدام الماء المالح مع الحديد المغناطيسي (Fe_3O_4) بمعدل ١٠٠ و ١٥٠ مجم / كجم.

الكلمات المفتاحية: المجال المغناطيسي، المياه المالحة، الحديد المغناطيسي، الزيت العطري، نبات الزعتر.