Effect of antitranspirants application on growth and productivity of sunflower under soil moisture stress

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Abstract: The experiment was conducted for two successive summer seasons 2016 and 2017 at Sakha Agricultural Research Station, Kafr El-Sheikh, Egypt to evaluate the effect of foliar spray with antitranspiranrs under three levels of soil moisture stress on growth, yield, yield components and water productivity of sunflower (*Helianthus annuus* L.) cultivar Sakha 53**.** The experiment was laid out in a split plot design with four replicates. The main plots were occupied by soil moisture levels namely wet (35-45%), medium (45-55%) and dry (55-65%) of maximum allowable depletion of available soil moisture (MAD of ASW). While subplots contained three treatments of antitraspirants i. e. without spray (control), spray with kaolin at 6% and spray with Magnesium Carbonate at 6%. Obtained results proved that, increasing soil moisture stress up to (55-65% MAD of ASW) caused significant reduction in all growth parameters, photosynthetic pigments (chlorophyll a, chlorophyll b), relative water content (RWC %) and seed oil %. Also, yield parameters (stem diameter, head diameter, 100- seed weight and seed yield) show significant reduction at dry treatment. On the other hand, increasing soil moisture stress caused significant increase in proline content and seed protein % at both growing seasons. Foliar application with antitraspirants positively affected all the growth and physiological criteria of the tested plants compared with control treatment and also cause marked reduction in transpiration rate. Generally, under irrigation water shortage, application of antitranspirants effectively reduced water consumption use and enhanced water productivity. Additionally, most of the growth and yield parameters and seed quality were improved significantly as influenced by spraying antitranspirants which were responsible for reducing water consumptive use.

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Key words: sunflower, water stress, antitraspirants, physiological criteria, yield, water productivity.

1. Introduction

Sunflower (*Helianthus annuus* L.) occupies a prominent place among oilseed crops as it contributes about 12% of the world edible oil production. The name Helianthus, being derived from helios (the sun) and anthos (a flower), has the same meaning as the English name sunflower, which has been given these flowers from a supposition that they follow the sun by day, always turning towards its direct rays. The sunflower that most people refer to is H. annuus, an annual sunflower **(Luqueño et al. 2014)**. The average fatty acid composition of oil from temperate sunflower crops is 55-75% linoleic acid and 15-25% oleic acid. Protein content is 15-20% **(Aznar-Moreno et al., 2013; Ali and Ullah, 2012).**

Sunflowers are grown in warm to moderate semi-arid climatic regions of the world from Argentina to Canada and from Central Africa to the Commonwealth of Independent States **(Esmaeli et al. 2012; Onemli, 2012)**. Plants are drought-resistant, but yield and oil content are reduced if they are exposed to drought stress during the main growing and flowering periods. Sunflowers will produce moderate yields with as little as 300 mm of rain per year, while 500-750 mm are required for better yields **(Gholamhoseini et al., 2013; Ghaffari et al., 2012)**. Sunflowers adapt to a wide variety of soil, but perform best on good soils suitable for maize or wheat production **(Radanielson et al., 2012)**.

Water stress is one of the severe conditions that affect crop growth, gene expression, distribution, yield and quality **Yang et al. (2004).** To avoid a global water crisis, farmers will have to strive to increase productivity to meet growing demands for food, while industry and cities find ways to use water more efficiently **(Chartres and Varma, 2010).**

Ramamoorthy et al. (2009) reported that irrigation sunflower at 25% available soil moisture (ASM) significantly decreased seed yield and its components. **Soriano et al. (2004**) found that seasonal evapotranspiration (ET_C) of sunflower and water use efficiency WUE decreased by increasing available soil moisture depletion (ASMD) percentage.

Kazemeini et al. (2009) concluded that seed yield and oil content of sunflower were the major sensitive parameters to water deficit during the flowering and reproduction formation stages. Also, **Kaya and Kolsarici (2011)** stated that all the yield components were affected by the number of irrigations. Moreover, they found that seed yield increased with increasing number of irrigations. **Nezami et al.** (2008) indicated that plant height, plant dry matter, stem diameter, head size, seed number head^{-1}, weight of 1000 seeds and seed weight head^{-1} under dry and semi-dried condition declined.

Antitranspirants are the materials or chemicals which decrease the water loss from plant leaves by reducing the size and number of stomata. Nearly 99 % of the water absorbed by the plant is lost in transpiration. Antitranspirants were grouped into three kinds, namely film-forming types (which coat leaf surface with films that are impervious to water vapor), reflecting materials (which reflect back a portion of the incident radiation falling on the upper surface of the leaves) and stomatal closing types (which affect the metabolic processes in leaf tissues **(Prakash and Ramachandran 2000).**

Kaolin is a non-abrasive, non-toxic alumino-silicate ($Al_4Si_4O_{10}$ $(OH)_8$) clay mineral that has been formulated as a wet table powder for application with conventional spray equipment **(Cantore et al. 2009)**. A reflective Kaolin spray was found to decrease leaf temperature by increasing leaf reflectance and to reduce transpiration rate more than photosynthesis in many plant species grown at high solar radiation levels **(Nakano and Uehara 1996).**

Magnesium Carbonate ($MgCo_3$) is considered to be an antitraspirants that close stomata and thus affect metabolic processes in leaf tissues **(Kalil et al. 2012)**. Water stress are substantially impacts yield. Hence, the application of antitranspirant immediately prior to booting stage may conserve water and improve grain set which could outweigh the photosynthetic limitations **(Kettlewell et al. 2010).**

The present study was proposed to achieve better plant production and supporting sunflower plant to tolerate water stress using antitranspirants spraying.

2. Materials and Methods

Experimental site

Two field experiments were conducted during two successive seasons 2016 and 2017 at the Experimental Farm of Sakha Agricultural Research Station, (31° 07\\N Latitude and 30° 57\\Longitude) Kafr El-Sheikh, ARC Egypt, to study the effect of foliar spray with anti-transpirants under three levels of soil moisture expressed as depletion available soil moisture on growth, yield components and water productivity of sunflower (*Helianthus annuus* L.) cultivar Sakha 53. The daily meteorological data for Kafr El-Sheikh area during the two growing seasons (2016/2017) were presented in Table (1)**.** Soil samples were randomly taken from the experimental site at depth of 0 to 30 cm from soil surface and were analyzed for both physical and chemical characteristics according to **Klute (1986) and Page et al. (1982)** as presented in Table (2).

Table (1): Means of some meteorological data for Kafr El-Sheikh area during the two growing seasons (2016 and 2017).

Month	Maximum temperature (ºC))	Minimum temperature (ºC)	Relative humidity (%)	Wind speed (km/day)	ET_0 (mm/day)
2016					
June	33.6	26.3	61.15	112.6	6.74
July	33.7	26.1	69.75	105.5	6.71
August	33.6	26	70.3	92.8	6.10
September	32.6	24.3	66.45	95.1	5.02
2017					
June	32.5	28.1	65.75	102.6	6.61
July	34.7	29.4	70.37	81.97	6.91
August	33.73	28.47	70.6	70.17	6.19
September	32.26	25.9	68.28	83.03	5.02

Source: Meteorological station at Sakha Agricultural Research Station (31° 07\\N Latitude and 30° 57\\Longitude) with an elevation of about 6 meters above sea level.

Experimental Details

A split- plot design with four replicates were used in this work, where

I- Main Plots (irrigation treatments):

- Irrigation when (35-45%) of MAD of ASW (wet treatment).
- Irrigation when (45-55%). of MAD of ASW (medium treatment)**.**
- Irrigation when (55-65%) of MAD of ASW (dry treatment).

II- Sub plots (antitraspirants spray)

- without spray (control)
- spray with Kaolin ($Al_4Si_4O_{10}$ $(OH)_8$) at 6%
- spray with Magnesium Carbonate at 6% were sprayed twice at 35 and 50 days after sowing.

Cultivation and fertilization

The seeds were sown on 15th and 11st of June in the first and second season, respectively**.** The plot area was 12 m^2 (3 m width and 4 m length), each plot contains 5 rows and seeds were sown by hand and the distance between hills were 20 cm. Two rows were used for growth analysis data and anther three rows were left for determining seed yield and its components. The plants were thinned to one plant per hill after 21 days from sowing. Other cultural practices for growing sunflower were conducted as recommended. According to soil analysis and sunflower fertilizer requirements, Nitrogen was applied at the rate of 30 kg N/fed of ammonium sulfate (20.5% N) and Phosphorus was applied at a rate of 100 kg P/fed. using Calcium Super Phosphate (15.5% P_2O_5). Sunflower harvest occurred on 14 and 17 September in first and second season, respectively when the back of the capitula was yellow and the bract was brownish.

Table (2): Means of some physical and chemical properties of the experimental site during the two growing seasons (2016 and 2017).

Physical properties										
Particle size distribution (%)				Soil moisture constants						
Sand	Silt	Clay	Texture	F.C	P.W.P	A.W	B.D ($gm.cm^{-3}$)	N Mgl^{-1}	P Mgl^{-1}	K Mgl^{-1}
25.85	24.65	49.5	Clayey	37.57	20.42	17.15	1.21	18.72	6.52	272.36
Chemical analysis										
$EcdSm^{-1}$	pH (1:2.5) extract	Cations meq/L				Anions meq/L				
		Ca++	Mg++	Na+	K+	Cl^-	HCO_3^-	CO_3^{--}	SO_4^{--}	O.M.
2.2	8.04	5.2	2.23	9.37	0.63	4.65	7.65	0	5	1.82

Studied characteristics:

Representative plant samples were taken randomly from each plot to estimate the following traits:

***1.* Photosynthetic pigment content in leaves**: The total chlorophyll pigments were determined by reading the absorbance on spectrophotometer at 664 and 647 nm and concentration of photosynthetic pigments were calculated according to the equation mentioned by **Moran (1982).**

Chl. a= 12.7(O.D)664-2.79(O.D)647= mg L^{-1}

Chl. b =20.7(O.D)647-4.62(O.D)664= mg L^{-1}

***2.* Measurement of relative water content (RWC %):**

In measuring relative water content, the method of **Weatherly (1950)** and its modification by **Barrs and Weatherly (1962)** was adopted, following the considerations given by **El-Sharkawy and Salama (1973)**. Leaf discs, were punched from the center of the leaf. Fresh weight was taken (FW) and floated for 4 hours in distilled water and weighted again to obtain turgid weight (TW). For dry weight (DW) determination, the discs were oven dried at 85ºC for a constant weight. Relative water content was calculated according to the following equation:

RWC (%) = (FW-DW) / (TW-DW) x 100

***3.* Proline Assay**

Proline content of leaves was determined according to a modification of the method of **Bates et al. (1973).** Its absorbance was measured at 520 nm in a spectrophotometer. The content of proline was calculated from a standard curve in $mg.g^{-1}$ FW.

Porometer measurements:

After 60 days from sowing, a portable Steady Porometer (LI-COR Model LI 1600) was used to determine stomatal resistance S/cm (Sr.) and transpiration rate (Tr.) μ $H_2O/cm^{-2}/S$.

Yield and its components:

At maturity five guarded plants were taken randomly and characters were recorded i.e. Plant height (cm), stem diameter (cm), head diameter (cm) and 100-seed weight (g).

- Seed yield kg fed^{-1}: heads of bagged plants from inner ridges of each plot were harvested and left two weeks until fully air dried and seed weight was used to estimate seed yield kg fed^{-1}.
- Seed oil percentage (%): was determined according to **A.O.A.C. (1995)** using soxhlet apparatus using petroleum ether as a solvent.
- Seed protein %: was determined according to **A.O.A.C. (1995)** and calculated by multiplying the N by the converting factor 6.25 **(Hymowitz et al. 1972).**

Crop water relations

Irrigation Measurements

The irrigation water applied was measured with a flow meter installed in the water delivery unit of the irrigation pump.

Soil moisture monitoring

Soil water storage was measured periodically in each plot gravimetrically. Irrigation was applied identically for all irrigation treatments from the day after sowing (DAS) until the complete establishment of sunflower plants (after 8 leaves had formed; **(Chimenti and Hall, 1993).** After this stage, the plots were irrigated according to the aforementioned irrigation regimes. Each irrigation treatment was based on a predefined level of MAD, which was a fixed percentage of the total ASW. Irrigation water was applied whenever the threshold value of MAD for the particular irrigation treatment was attained for estimating soil water storage, the effective root zone of a sunflower crop was considered as 0–1.00 m **(Ataei, 2004).**

- **Crop Evapotranspiration**
- **Calculation of reference evapotranspiration (ETo)**

ETo is estimated by using the Penman-Monteith equation **(Allen,1998)** and it is worthy mentioned that "CROPWAT v.8.0" program was used to compute the mean values for the reference evapotranspiration (ETo).

- **Actual evapotranspiration (ETa)**

Soil moisture was determined a day before each irrigation for the depth 30, 60 and 90 cm on weight basis, and then was converted to volumetric water content by multiplication with the soil bulk density, using the following formula:

$$CU = [(\theta_2 - \theta_1)/ 100] \times B.d. \times D \times A$$

CU = water consumptive use. θ_1 = initial moisture content. θ_2 = final moisture content (after irrigation). B.d = bulk density. D = soil depth (cm) A=area

- **Water Productivity (WP), Irrigation Water Productivity (IWP)**

Water productivity (WP) and irrigation water productivity (IWP) were calculated as seed yield divided by seasonal ET and total seasonal irrigation water applied **(Sezen et al. 2011).**

Statistical Analysis

The obtained data of the different treated groups were statistically analyzed and comparison among means was performed by computer programming methods (statgraphic- vers-4-2- Display ANOVA), as described by **Snedecor and Cochran (1982).** Treatment means were compared by Duncan's multiple range test **(Duncan's,1955).**

3. Results and Discussion

Effect on Photosynthetic Pigments:

The results given in Table (3) showed the effect of irrigation levels on chlorophyll content during the two seasons 2016 and 2017. It is cleared from the tabulated data that, chlorophyll content (chl. a & chl. b and total chl.) at flowering stage were significantly increased when sunflower plants were watered with wet treatment (35-45 %MAD of ASW). On the other hand, dry treatment (55-65% MAD of ASW) recorded the lowest values of such pigments in the two growing seasons. The reduction in chlorophyll content in most stressed plants may be due to the disorganisation of thylakoid membranes, with more degradation than synthesis of chlorophyll via the formation of proteolytic enzymes, such as chlorophyllase, which is responsible for degrading chlorophyll, as well as damaging the photosynthetic apparatus **(Ronghua et al., 2006)**. In this regard, **(Ripley et al., 2007)** found that, water stress may reduce photosynthetic assimilation by both stomatal and metabolic limitations.

Table (3): Chlorophyll content (mg/dm^2) as affected by soil moisture stress and antitranspirants in 2016 and 2017 seasons.

Treatment	Chl.a (mg/dm^2)		Chl.b (mg/dm^2)		Total Chl. (mg/dm^2)	
	2016	2017	2016	2017	2016	2017
Irrigation levels						
Wet	2.551 a	2.640 a	1.581 a	1.724 a	4.133 a	4.364 a
Medium	2.283 b	2.403 b	1.375 b	1.487 b	3.659 b	3.891 b
Dry	2.121 c	2.167 c	1.258 c	1.329 c	3.379 c	3.497 c
F-test	**	**	**	**	**	**
LSD at 5%	0.029	0.058	0.0392	0.045	0.0463	0.085
Antitranspirants treatments						
Control	2.268 c	2.346 c	1.268 c	1.382 c	3.536 c	3.728 c
Kaolin	2.384 a	2.506 a	1.538 a	1.637 a	3.922 a	4.143 a
$MgCo_3$	2.304 b	2.358 b	1.407 b	1.521 b	3.711 b	3.880 b
F-test	**	*	**	**	**	**
LSD at 5%	0.079	0.067	0.0448	0.077	0.121	0.122

*,** significant at 5% and 1% level of probability, respectively. Mean values designed by the same letter in each column are not significant according to Duncan's Multiple Range Test.

According to the results of this study, chlorophyll content increased with the two antitranspirants in comparison to the control. The highest values were recorded by using kaolin (6%) during the two seasons.

In this respect, **Adolfo (2007)** found that, kaolin application improve plant physiological activities, especially under hot weather and water stress. The beneficial effect of applied antitranspirants might be due to the stimulative effects on photosynthetic capacity by overcoming stomata limitations, enhancing biosynthesis of photosynthetic pigments, or protecting photosynthetic pigments from water stress-induced degradation.

Effect on Relative Water Content (RWC)% and Proline content:

Perusal of the data in Table (4) revealed that, as compared to the control values relative water content (RWC%) was declined under soil moisture stress condition. The highest RWC% were recorded with the wet treatment (35-45%) followed by the medium one i.e. irrigation at (45-55% MAD of ASW). However, the lowest RWC% was obtained from irrigation at dry treatment (55-65% MAD of ASW) during the two studied seasons. Our results demonstrated that, plant water relations play a key role in maintaining the physiological advantages of sunflower plants. **Monroy et al. (2015)** stated that, Plants subjected to adequate irrigation had higher RWC% than water-stressed plants, mainly due to the fact that the amount of water supplied was enough to maintain the turgidity of the leaf tissue. Also, **Unyayar et al. (2004)** stated that RWC % of the sunflower leaves decreased under drought stress. Additionally, **El Mantawy et al. (2017)** found that in sunflowers plants water stress caused significant decrease in relative water content % but caused significant increase in proline content.

Table (4): Relative water content (RWC%) and proline content as affected by soil moisture stress and antitranspirants in 2016 and 2017 seasons.

Treatments	RWC (%)		Proline (mg g^{-1} fresh weight)	
	2016	2017	2016	2017
Irrigation levels				
Wet	65.70 a	67.28 a	0.0140 c	0.0146 c
Medium	61.34 b	62.84 b	0.0226 b	0.0230 b
Dry	56.99 c	60.26 c	0.0318 c	0.0320 c
F-test	**	*	**	**
LSD at 5%	3.560	3.186	6.172	8.386
Antitranspirants treatments				
Control	55.36 c	56.64 c	0.0225 b	0.0232 b
kaolin at 6 %	66.41 a	69.59 a	0.0231 a	0.0241 a
$MgCo_3$ at 6%	62.27 b	64.14 b	0.0228 ab	0.0237 ab
F-test	**	**	**	**
LSD at 5%	2.808	4.050	4.362	6.664

*,** significant at 5% and 1% level of probability, respectively. Mean values designed by the same letter in each column are not significant according to Duncan's Multiple Range Test.

It is obvious from the results that, spraying sunflower plants with kaolin at 6 % significantly increased RWC% (66.41% in the first season and 69.59% in the second season) as compared with untreated plants (55.36% in the first season and 56.64 % in the second season), respectively. According to **Abdel-Fattah (2013),** antitranspirants which form a film on the surface of the plants, increase the relative water content in leaves. Proline has been considered as a carbon and nitrogen source for rapid recovery from stress and acting as stabilizer for membranes and some macromolecules and also as a free radical scavenger. The data in Table (4) clearly showed that, leaf proline content increased with sunflower plants exposed to water stress (dry treatment) compared with wet and medium treatment. These results are in agreement with those obtained by **Manivannan et al. (2007).** Also**, (Alia et al. 2001)** stated that The accumulation of proline in plant tissues in response to different a biotic stresses may play an important role against oxidative damages caused by reactive oxygen spices (ROS) due to its action as a single oxygen quencher.

Effect on transpiration rate and stomata resistance

It is evident from Table (5) that soil moisture stress up to (55-65%) caused marked reduction in transpiration rate while, stomatal resistance values were significantly increased by increasing soil moisture stress from 25-35% up to 55-65%. This results may be due to when land plants absorb less water from the environment through their roots than is transpired (evaporated) from their leaves, water stress develops. Stomatal pores in the leaf surface progressively close decreasing the conductance to water vapour and thus slowing transpiration rate at which water deficits develop **Tezara et al**. (1996).

Antitranspirants can be used to reduce water stress and enhance water status of plants. Foliar application of kaolin or $MgCo_3$ decreased the transpiration rate and stomata resistance compared to the control plants (Table 5). This may be due to the fact that antitraspirants reduce the transpiration rate by smaller stomata opening ($MgCo_3$) or by reflection of sunlight (kaolin). In this respect, **Ibrahim and selim (2010)** found that kaolin spray decreased leaf temperature by increase leaf reflectance and reduce transpiration rate more than photosynthesis in plants. Similar observations regarding the effect of kaolin on reducing transpiration rates have been reported by various authors as **Moftah and Al- Humaid (2005).**

Table (5): Transpiration rate and Stomata resistance as affected by soil moisture stress and antitranspirants in 2016 and 2017 seasons.

Treatment	Transpiration rate (mg H_2O Cm^2/s)		Stomatal resistance (S/Cm)	
	2016	2017	2016	2017
Irrigation levels				
Wet	5.452 a	5.380 a	2.497c	2.388 c
Medium	4.336 b	4.283 b	3.190 b	3.145 b
Dry	3.526 c	3.476 c	4.471a	4.400 a
F-test	*	*	**	**
LSD at 5%	0.0703	0.0859	0.115	0.1701
Antitranspirants treatments				
Control	4.547 a	4.503 a	3.564 a	3.441 a
kaolin at 6 %	4.307 c	4.245 c	3.126 c	3.166 c
MgCo3 at 6%	4.460 b	4.391 b	3.377 b	3.326 b
F-test	**	**	**	**
LSD at 5%	0.0834	0.103	0.1227	0.1182

*,** significant at 5% and 1% level of probability, respectively. Mean values designed by the same letter in each column are not significant according to Duncan's Multiple Range Test

Effect on yield component

The effect of soil moisture stress and antitranspirants on yield parameters (plant height, stem and head diameters of sunflower) were presented in Table (6). It is obvious from the obtained data that, water stress caused significant decrease on all growth parameters during the two growing seasons. Water stress causes deceleration of cell enlargement and thus reduces stem length by inhibiting inter nodal elongation and also checks the tillering capacity of plants. In this respect, **Buriro et al. (2015)** found that growth and yield attributes like, plant height, head diameter, number of seeds per head, 1000-seed weight and seed yield per hectare were significantly affected by irrigation frequencies i.e. 0, 2, 4, 6 and 8 irrigation, six irrigations were found optimum for obtaining good yield of sunflower.

Table (6): Plant height, stem and head diameters as affected by soil moisture stress and antitranspirants in 2016 and 2017 seasons.

Treatment	Plant height (Cm)		Stem diameter (Cm)		Head diameter (Cm)	
	2016	2017	2016	2017	2016	2017
Irrigation levels						
Wet	173.11 a	175.22 a	2.65 a	2.71 a	18.4 a	19.25 a
Medium	168.66 b	171.02 b	2.43 b	2.53 b	16.61 b	17.68 b
Dry	162.77 c	165.55 c	2.31 c	2.42 b	15.63 c	16.61 c
F-test	**	**	**	*	**	**
LSD at 5%	2.355	1.628	0.056	0.131	0.610	0.737
Antitranspirants treatments						
Control	166.22 b	168.52 b	2.38 b	2.45 b	15.91 b	16.73 c
Kaolin	170.33 a	172.72 a	2.58 a	2.66 a	17.65 a	18.75 a
$MgCo_3$	168.0 ab	170.55 b	2.43 ab	2.56 a	17.08 a	18.07 b
F-test	*	*	*	*	**	**
LSD at 5%	3.125	2.064	0.057	0.095	0.577	0.668

*,** significant at 5% and 1% level of probability, respectively. Mean values designed by the same letter in each column are not significant according to Duncan's Multiple Range Test.

Concerning, spraying sunflower plants with kaolin and $MgCo_3$, antitranspirants significantly stimulated all growth characters in relative to the untreated plants. The highest values were recorded by using kaolin at the rate of 6 %. The positive effect of these compounds on vegetative growth parameters could be explained on the light of their effect on making powder film on the surface of leaves which can protect the plants from heat damage of reflected sunrays and at the same time enhancing cell division and the biosynthesis of organic foods **Gaballah et al. (2014).**

Effect on 100-seed weight and seed yield

The effect of soil moisture stress and antitranspirants on 100-seed weight and seed yield of sunflower was presented in Table (7). The obtained data showed that, increasing soil moisture stress up to (45-55%) cause marked reduction in seed yield during the two growing seasons. In this regard, **Buriro, et al. (2015)** found that**,** A substantial reduction in yield and yield components was noted by withdrawing irrigation number. Also, **Erdem et al. (2006)** demonstrated the effect of water stress on 58% yield reduction of sunflower. Similar results were obtained by **Taherabadi et al**. **(2013)** whom showed that, longer irrigation regimes and drought stress during growth stages of sunflower decreased significantly yield and yield components.

Table (7): 100 seed weight and seed yield as affected by soil moisture stress and antitranspirants in 2016 and 2017 seasons.

Treatment	**100 seed weight (g)**		**Seed yield (kg/fed.)**	
	2016	2017	2016	2017
Irrigation levels				
Wet	7.31 a	7.61 a	1610.14 a	1651.99 a
Medium	6.51 b	6.80 b	1552.42 a	1579.81 b
Dry	5.72 c	5.92 c	1481.75 b	1510.01 c
F-test	**	**	*	**
LSD at 5 %	0.275	0.0433	41.359	64.886
Antitranspirants treatments				
Control	6.07 b	6.32 c	1462.54 b	1485.56 c
Kaolin	6.87 a	7.17 a	1608.48a	1653.84 a
MgCo$_3$	6.60 a	6.84 b	1573.29 a	1602.40 b
F-test	**	**	**	**
LSD at 5%	0.4918	0.2602	59.962	47.273

*,** significant at 5% and 1% level of probability, respectively. Mean values designed by the same letter in each column are not significant according to Duncan's Multiple Range Test.

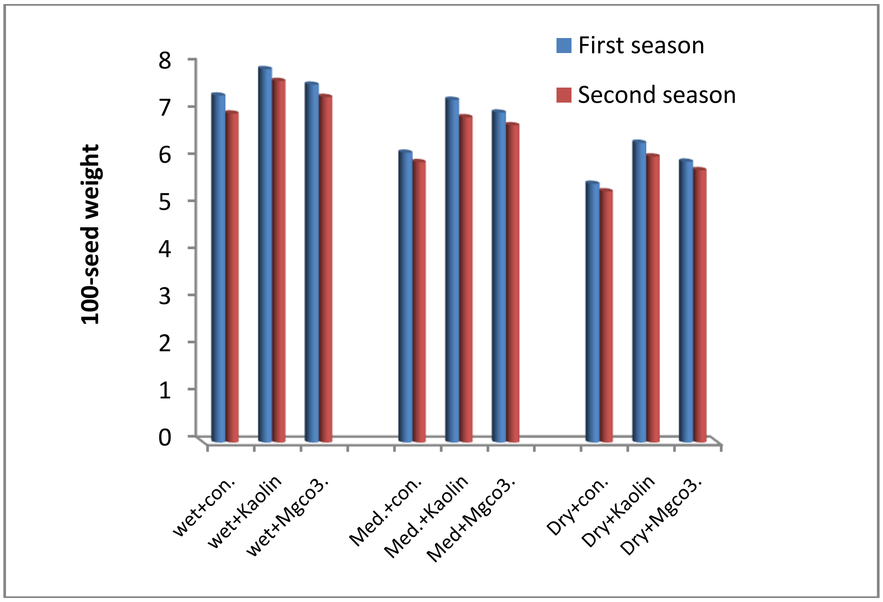

Fig. (1): 100- seed weight as affected by interaction between antitraspirants and soil moisture stress during the two seasons 2016 and 2017.

It was evident from the table that, in comparison to the control, foliar spraying of antitraspirants especially with kaolin at the rate of 6% caused significant increase in seed yield during the two growing seasons. These results are in harmony with those obtained by **Gaballah et al. (2014)** whose study the influence of antitranspirants and organic compost on sunflower yield and yield quality under sandy soil condition and found that, KCl was the best antitranspirant compared the other used and its efficiency increase by using organic compost under the sandy soil conditions. Similar results were obtained by **Peter (2008).**

In regard to the interaction between soil moisture stress and antitraspirants spray on 100- seed yield and seed yield, Fig. (1 & 2) clearly showed that the highest values were obtained at wet treatment with spraying with antitraspirants (kaolin or $MgCo_3$) during the two growing seasons.

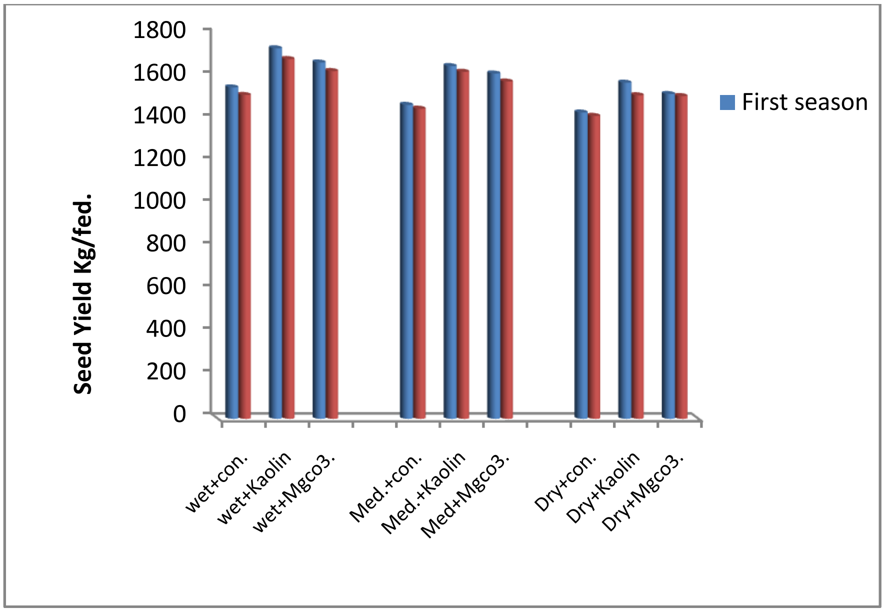

Fig. (2): Seed yield as affected by interaction between antitraspirants and soil moisture stress during the two seasons 2016 and 2017.

Effects on seed oil and seed protein %

It is clear from data in Table (8) that, water stress negatively affected the seed oil % during the two growing seasons. Maximum percentage of oil was obtained with plants irrigated at (35-45% of MAD of ASW). Seed oil percentage under severe water limitation (55-65% MAD of ASW) was considerably lower than that under other irrigation treatments. These results are in harmony with **Poudineh et al. (2015)** whom showed that the highest values of seed oil were obtained with optimum irrigation and there was no significant difference between the mild stress (70%) and severe stress (50%) treatments**.** Similar trend was obtained by **(Sullu and Dagdelen, 2015).**

Table (8): Seed oil and seed Protein % as affected by soil moisture stress and antitranspirants in 2016 and 2017 seasons.

Treatment	**Seed oil (%)**		**Seed protein (%)**	
	2016	2017	2016	2017
Irrigation levels				
Wet	47.00 a	47.90 a	15.27 c	15.12 c
Medium	46.01 b	47.00 b	16.04 b	15.91 b
Dry	45.26 c	45.90 c	16.69 a	16.56 a
F-test	*	*	**	**
LSD at 5%	0.120	0.163	0.109	0.068
Anti-transpirants treatments				
Control	45.50 b	46.39 c	15.61 c	15.42 c
kaolin at 6 %	46.65 a	47.46 a	16.31 a	16.20 a
$MgCo_3$ at 6%	46.12 a	46.97 b	16.08 b	15.96 b
F-test	*	*	**	**
LSD at 5%	0.205	0.259	0.055	0.125

*,** significant at 5% and 1% level of probability, respectively. Mean values designed by the same letter in each column are not significant according to Duncan's Multiple Range Test.

Comparing between the two types of antitranspirants and the control on seed oil and seed protein % were presented in Table (8) where Kaolin followed by Magnesium Carbonate were effective in increasing significantly both seed oil and seed protein %. In this regard**, Gaballah, et al. (2014)** stated that spraying sunflower plants with the KCl as an antitranspirant at rates of 5 and 10 g/L significantly increased seeds yield and oil yield by 52.7 and 61.7% and 91.6 and 111.2% than that of untreated, respectively.

Concerning the effect of interaction between soil moisture stress and antitranspirants spray on seed protein and oil %, Fig. (5 & 6) showed that the highest values of seed oil % were obtained at wet treatment with spraying by antitranspirants (kaolin or $MgCo_3$) during the two growing seasons. On the other hand, plants exposed to dry treatment with foliar application by antitraspirants recorded the highest values of protein % during the two seasons.

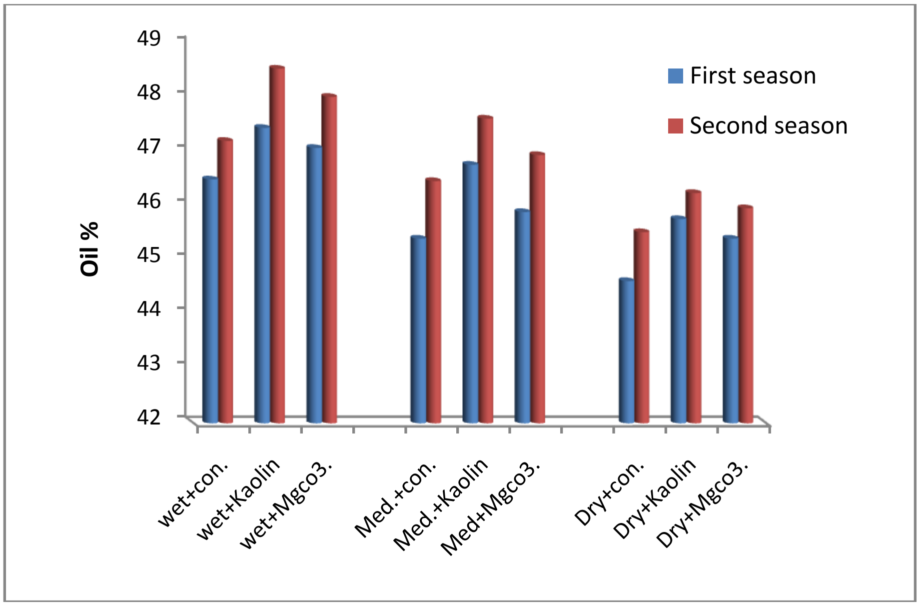

Fig. (3): Seed oil (%) as affected by interaction between antitraspirants and soil moisture stress during the two seasons 2016 and 2017.

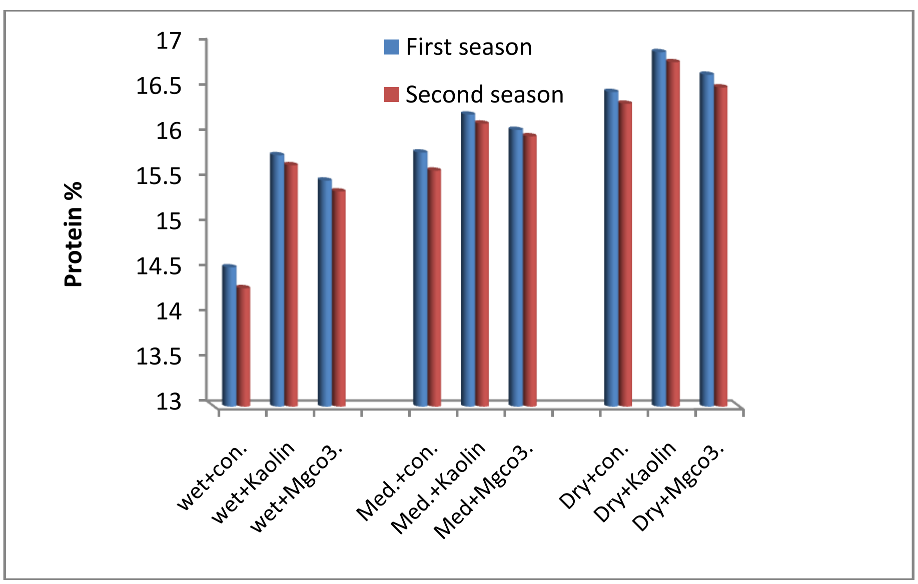

Fig. (4): Seed protein (%) as affected by interaction between antitraspirants and soil moisture stress during the two seasons 2016 and 2017.

Crop water relations:

Water saving and reduction in productivity

Its obvious from (Table 9 & Fig.5) that, average of water applied to sunflower crop for the wet (35-45% of MAD of ASW) treatment was about 2668.51 $m^3 fed.^{-1}$. The amount of water savings in the medium and the dry treatments were 320.08 m^3 $fed.^{-1}$ (11.99 %) and 652.97 $m^3 fed.^{-1}$ (24.47 %), respectively. It was clear that, the average yield reduction percentage at the medium and dry treatments were 4.08% and 9.37%, respectively. The data clearly showed that, the maximum yield reduction (7.03 %) was occurred with dry treatment without antitraspirants spray. In general we can concluded that spraying kaolin (6%) caused an increment by about 10.55% (155.54 kg) and 7.72 % (113.78 kg) in case of spraying with $MgCo_3$.

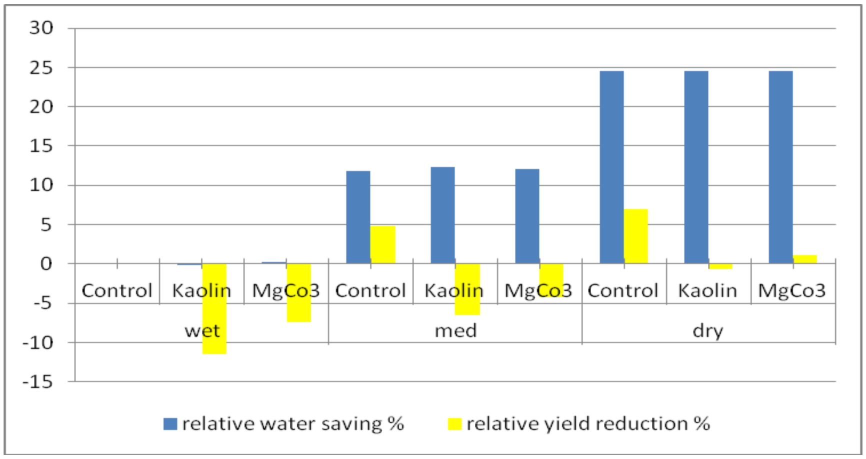

Fig (5): average (WA) and (RYD) % as affected by soil moisture levels and antitranspirants as a mean of two seasons 2016 and 2017.

Table (9). Average water applied (WA), relative water saving RWS (%) and relative yield reduction RYD (%) as affected by soil moisture treatments and antitranspirants spraying.

Moisture levels	Antitranspirants	WA (m^3/fed.)	RWS (%)	Seed yield (kg/fed.)	RYD %
Wet	**Control**	2670.08	-	1534.36	-
	Kaolin	2670.76	-0.03	1710.15	-11.46
	$MgCo_3$	2664.68	0.20	1648.64	-7.45
Medium	**Control**	2355.44	11.78	1461.28	4.76
	Kaolin	2340.93	12.33	1633.86	-6.48
	$MgCo_3$	2348.9	12.03	1598.5	-4.18
Dry	**Control**	2015.38	24.52	1426.52	7.03
	Kaolin	2015.46	24.52	1544.78	-0.68
	$MgCo_3$	2015.78	24.50	1516.35	1.17

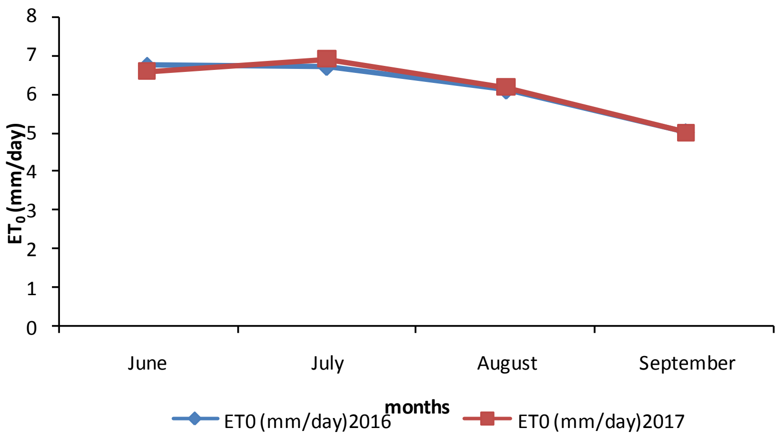

Fig. (6): Values of reference crop evapotranspiration through the growth stages of sunflower as a mean of two seasons.

Reference evapotranspiration (ETo)

The values of reference crop evapotranspiration through the growth stages of two sunflower seasons, weather parameter values of temperature, relative humidity, sunshine hour and evaporation within the year 2016 and 2017 were followed the similar trend. The values of ETo through two growth seasons indicated that it was high at the beginning of season and decreased gradually till harvesting time. This is may be due to the changes in the climatologically norms for the area, as the cultivation starts with both relatively high temperature and solar radiation and ended by a decrease than it was. The total ETo value during the two growth seasons of 2016 and 2017 of sunflower were 24.57 and 24.73 mm, respectively as shown in Fig (6).

Actual evapotranspiration (ETa)

The mean values of actual evapotranspiration or water consumptive use (WCU) for the sunflower crop as a function of soil moisture levels were presented in Fig (7). Results clarify that consumptive use of water declined with the decreasing moisture supply under various levels. Maximum (388.9 mm) and minimum (340.58 mm) values were recorded under moisture levels wet and dry, respectively. consumptive use in drier conditions declined, as expected, due to sub-optimal evaporation rates under water stress condition. The results are in conformity with the findings of **(Mishra and Padmakar, 2010).** Worth mentioning is that, spraying with kaolin and magnesium carbonates produced almost similar WCU (387.95 and 388.90 mm), respectively. Also we can say that spraying with kaolin and magnesium carbonates reduced WCU by about 5.22 % and 4.99 % from the control treatment (without spraying) as shown in Fig (8). This result is in agreement with that obtained by (**Makus, 1997 and Singh et al., 1999).** In the regard of interaction between treatments we can noticed that data showed its highest values in wet treatment (501.45mm), while the least WCU (292.27) was recorded in dry ($MgCo_3$) treatment, as shown in Fig (9).

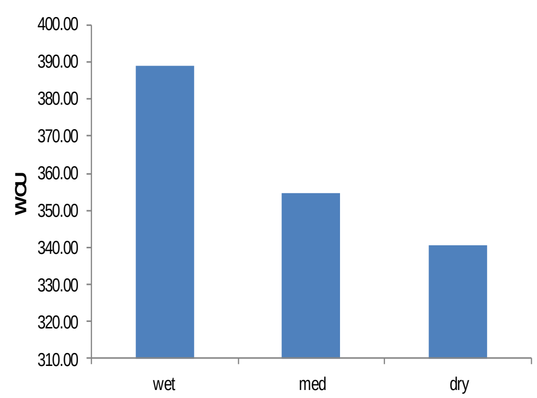

Fig. (7): Effect of moisture levels on water consumptive use

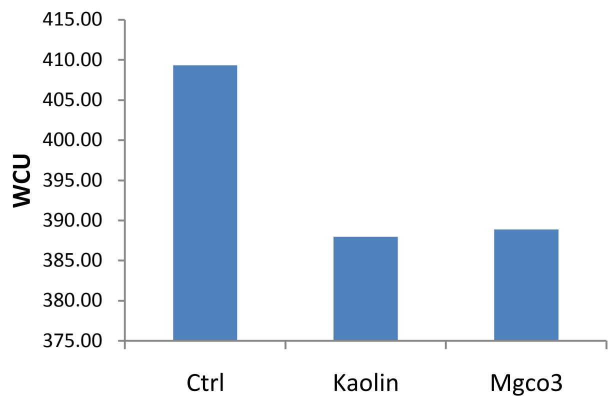

Fig. (8): Effect of antitranspirants on water consumptive use

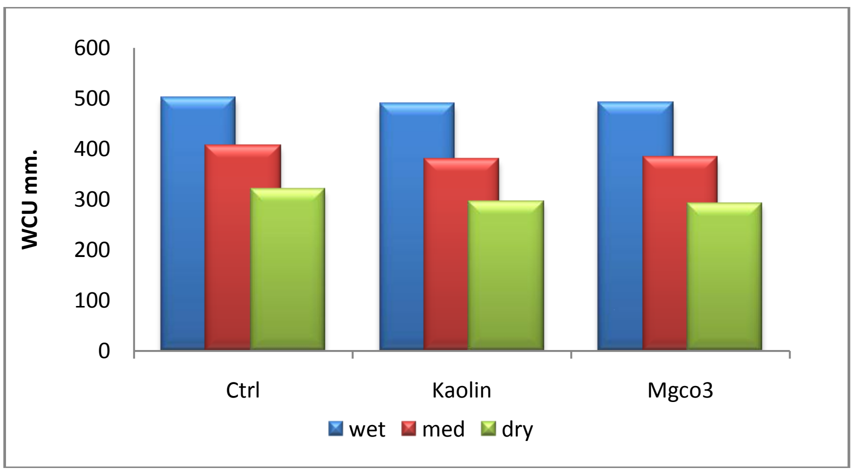

Fig (9): Actual evapotranspiration values for the sunflower crop as a function of soil moisture levels and antitranspirants as a mean of two seasons 2016 and 2017.

Water Productivity (WP), irrigation Water Productivity (IWP)

water productivity is defined as the product amount or value per amount of water (m^3) used for irrigation in production **(Shideed et al., 2005).** Fig (10) indicated that plants have significant change on seed yield and eventually on the crop water productivity (WP). The treatments irrigation at 45-55% of MAD of ASW (medium) with using magnesium carbonates as spraying had a better crop water productivity (WP, 1.24 kg m^{-3}). This indicates that the efficiency of individual crop in these treatments is to convert water transpired (or used) to seed. This increased water use efficiency due to decreased water consumptive use of the crop. The data also indicated that the lowest WP (0.73 kg m^{-3}) was recorded with wet (35-45 %of MAD of ASW) treatment without any sprayings. Regarding the effect of soil moisture levels Fig (11) the greatest WP was observed in dry treatment (1.18 kg m^{-3}), followed by medium treatment (0.96 kg m^{-3}), and wet treatment (0.79 kg m^{-3}). The increase in WP in dry than in wet could be due to a greater loss of water by evapotranspiration than the corresponding increase in seed yield. On another side the effect of antitranspirants, we can noticed that using both kaolin or magnesium carbonate had similar values of WP (1.03 & 1.01 kg m^{-3}), respectively. Where we found that the ctrl (without spraying) had the lowest value (0.88 kg m^{-3}) as shown in Fig (12). These results are in agreement with (**Makus, 1997 and Singh et al., 1999)** who found that, under subtropical conditions like Egypt, using antitranspiration may reduce transpiration rate from the plant, consequently, the amount of used water and improved the water use efficiency.

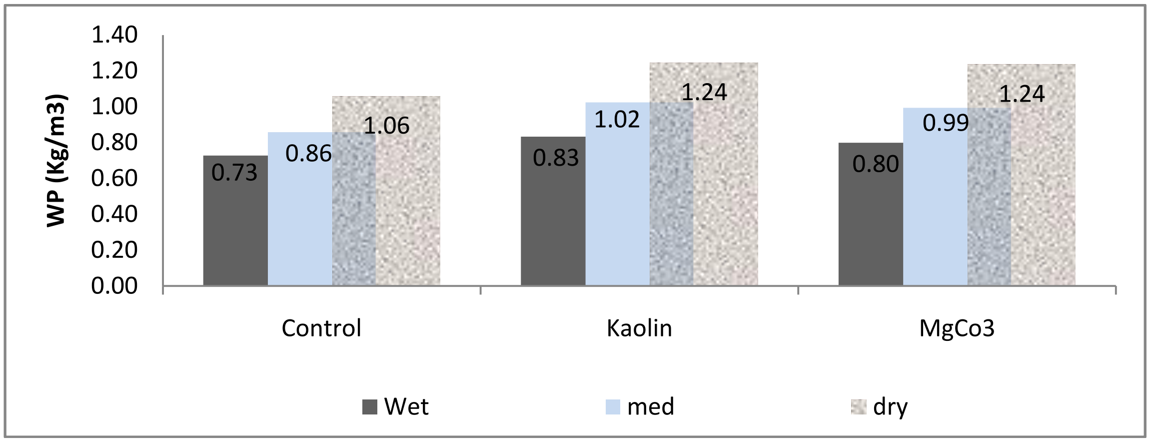

Fig. (10): Effects of soil moisture levels and spraying with antitranspirants on average values water productivity.

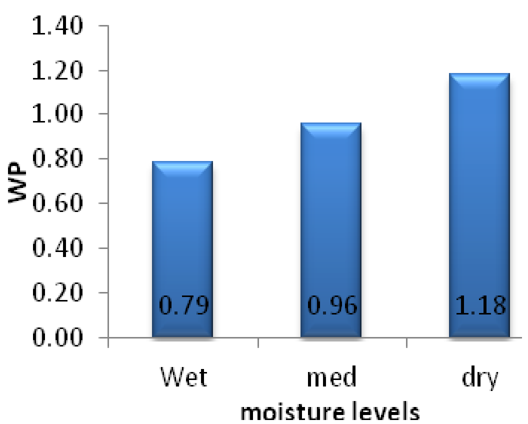

Fig. (11): effect of soil moisture levels on water productivity.

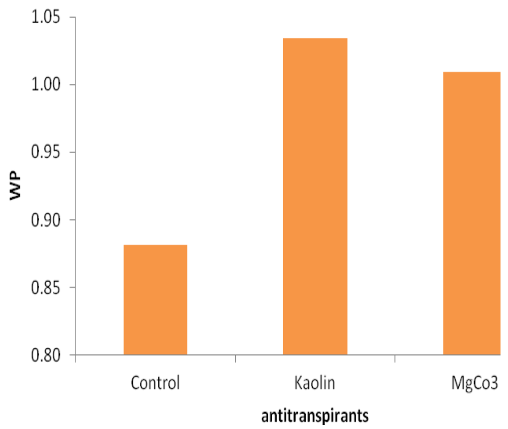

Fig. (12): effect of antitranspirants on water productivity.

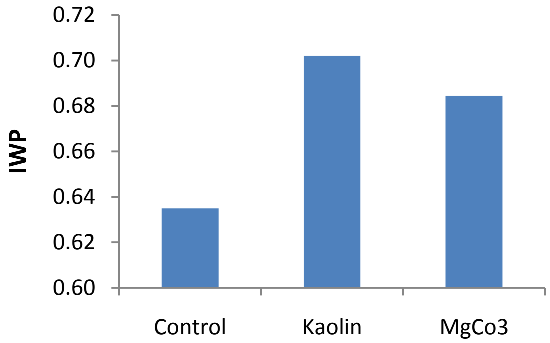

Fig. (13): Effect of antitranspirants on irrigation water productivity.

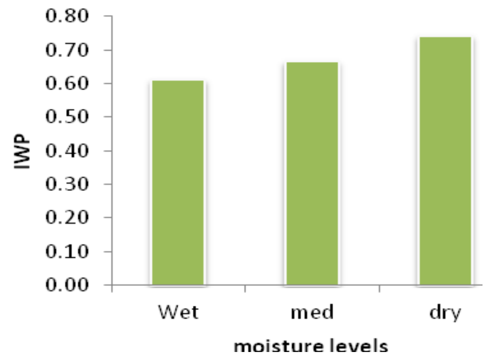

Fig. (14): effect of moisture levels on irrigation water productivity.

Irrigation Water Productivity (IWP)

Irrigation water productivity (IWP) values varied from 0.57 to 0.77 kg m^{-3}. The dry treatment resulted in the highest IWP value. The data in Fig. (13) showed that, increasing level of soil moisture progressively decreased irrigation water productivity. The values of IWP were 0.61, 0.67 and 0.74 kg m^{-3} for wet, medium and dry respectively. As shown in Fig. (14) the IWP as a function of using antitranspirants. indicated that irrigation water increasing with using both kaolin or magnesium carbonates. The effect of antitranspirants on IWP could be arranged as follows, kaolin (0.70 kg m^{-3}), $MgCO_3$ (0.68 kg m^{-3}) and then control treatment (without spraying, 0.63 kg m^{-3}), with the same tendencies observed in WP. Generally, The more stress treatments (55-65% mad of ASW) resulted in higher IWP values. **Sezen et al. (2011)** reported that, IWP values varied from 0.39 to 0.97 kg m^{-3} in different treatments and experimental seasons. **Akcay and Dagdelen (2016)** stated that, the WUE and IWUE values decreased with the increasing irrigation interval. The higher WUE and IWUE were obtained at the lowest irrigation level of each irrigation interval.

Conclusions

In the light of the present study, water stress had a negative impact on growth parameters, yield and yield components and oil percentage of sunflower plants at dry and medium stress in comparison to the optimum irrigation. These results suggest that the use of kaolin may be a helpful tool to mitigate the negative effects of water stress and to improve the water use efficiency in sunflower plants under water deficit conditions. The results of this study indicated that the application of antitranspirants to sunflower in advance of drought can conserve soil moisture and improve water productivity.

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