Plant Stress ©2012 Global Science Books

Roles of Antitranspirants in Improving Growth and Water Relations of *Jatropha curcas* L. Grown under Water Stress Conditions

Soha E. Khalil[1*] • Mohamed M. Hussein[1] • Jaime A. Teixeira da Silva[2]

[1] Department of Water Relation and Field Irrigation, National Research Centre, Dokki, Cairo, Egypt
[2] Faculty of Agriculture and Graduate School of Agriculture, Kagawa University, Miki cho, Kita gun, Ikenobe, 761-0795, Japan

Corresponding author: * soha_khalil2001@yahoo.com

ABSTRACT

In recent years, deficit irrigation has been widely investigated as a valuable and sustainable production strategy in Egypt. Also, in response to rising oil prices and the quest for alternative economically viable and environmentally sustainable forms of energy, certain plant species with bio-energy potential have been proposed for large-scale planting and bio-fuel production. Hence, the present investigation was conducted in a greenhouse during the two consecutive summer seasons to investigate the effects of three soil moisture levels (85, 55, and 25% depletion of the available soil water), and four antitranspirant treatments (control, 6% kaolin, 6% $MgCO_3$, and 6% kaolin + $MgCO_3$) which were sprayed twice during the plant's life (the first after 60 days from planting and the second 4 weeks later) and their interactions on growth attributes, percentage relative water content (RWC%), osmotic pressure, Pro content and percentage carbohydrates of *Jatropha curcas* L. Results indicated that increasing water stress significantly retarded growth attributes and RWC%. On the contrary, increasing severity of drought caused a significant increase in osmotic pressure, Pro content and percentage carbohydrates. A spray with antitranspirants markedly increase all growth attributes and RWC% while osmotic pressure, Pro content and percentage carbohydrates decreased markedly compared with control plants. The interaction effect between soil moisture levels and antitranspirant treatments was significant for all the studied parameters in both seasons. Highest values were observed in plants watered with the highest soil moisture level (25% depletion of the available soil water) and which received 3% kaolin + 3% $MgCO_3$ which had a greater effect.

Keywords: antitranspirants, available soil moisture, carbohydrates, growth, jatropha, Pro, RWC%
Abbreviations: $MgCO_3$, magnesium carbonate; **RWC**, relative water content

INTRODUCTION

In response to increasing oil prices and the quest for alternative economically viable and environmentally sustainable forms of energy, certain plant species with bio-energy potential have been proposed for large-scale planting and bio-fuel production, aided by breeding strategies (Islam *et al.* 2011). International interest in *Jatropha curcas* L. (Euphorbiaceae) as a drought-tolerant, fast-growing, and renewable bio-energy crop has grown significantly in recent years (Gush 2008). *J. curcas* is promising as a sustainable biofuel option since its seeds contain up to 35% oil which is easily convertible into biodiesel, kerosene and other fuels; moreover, it has potential to reclaim wastelands with positive effects on ecology and socio-economic development (Francis *et al.* 2005) and with its reputation of being a drought-resistant and easily establishing species, this small tree is now planted worldwide on wastelands in the semi-arid tropics (Fairless 2007; Achten *et al.* 2008; Maes *et al.* 2009). Its probable centre of origin is Mexico and Central America; it is now naturalized and widespread throughout the tropics. Plants are succulent; its oil is an environmentally safe and cost-effective renewable source of non-conventional energy. This plant is also a source of poisons and medicines (Ashish *et al.* 2010). In South and North Africa, governments have received numerous requests for permission to plant this species, but apart from certain trial plantings, a moratorium on commercial plantings has been imposed. This is due to, among other considerations, the extremely limited data available on its potential environmental impacts (specifically water-use). This knowledge gap is of particular concern in a dry area such as sub-Saharan Africa, where evaporation and evapotranspiration from vegetation is the component of the water balance that accounts for the greatest loss of water from catchments. Accurate estimates of water-use are therefore fundamental to gaining a good understanding of the hydrological impacts of a specific plant species or vegetation type (Gush 2008). Improving the tolerance of crop plants using antitranspirants has been an important but largely unfulfilled aim of modern agriculture.

Antitranspirants are chemical compounds whose role is to train plants by gradually hardening them to stress as a method of reducing the impact of drought. There are different types of antitranspirants: film-forming which stops almost all transpiration; stomatic, which only affects the stomata; reflecting materials (Nasraui 1993). Reducing transpiration can play a useful role in this respect by preventing the excessive loss of water to the atmosphere via stomata (Khalil 2006). Antitranspirant are substances involved in increasing drought resistance by tending to cause xeromorphy and/or stabilizing cell structure (Ouda *et al.* 2007). Kaolin is a non-toxic aluminosilicate ($Al_4Si_4O_{10}(OH)_8$) clay mineral; kaolin spray decreased leaf temperature by increasing leaf reflectance and reduced transpiration rate more than photosynthesis in plants (Ibrahim and Selim 2010). Magnesium carbonate ($MgCO_3$) is considered to be an antitranspirant that closes stomata and thus affects metabolic processes in leaf tissues (Nermeen and Emad 2011). The present investigation was carried out to observe what adaptive features *J. curcas* has evolved that may allow it to grow and survive in dry habitats.

Received: 22 August, 2011. Accepted: 8 November, 2011.

Original Research Paper

Table 1 Mechanical and chemical analyses of the tested soil over the two growing seasons (2009 and 2010).

Seasons	Sandy %	Silt %	Clay %	Soil texture	pH	EC ds/m	O.M %	N ppm	P ppm	K ppm
1st season	68.75	11.39	15	Sandy	7.9	1.9	0.72	151	199	114
2nd season	66.25	10.5	13	Sandy	7.9	1.3	0.60	123	186	105

MATERIALS AND METHODS

Water treatments

The following three water treatments were applied throughout the entire growth period of the crop:

W1 = water stress was maintained at about 85% depletion of the available soil water and the soil water was maintained at field capacity when this depletion level was reached;

W2 = water stress was maintained at about 55% depletion of the available soil water and the soil water was maintained at field capacity when this depletion level was reached;

W3 = water level was maintained at about 25% depletion of the available soil water and the soil water was maintained at field capacity when this depletion level was reached.

These soil moisture levels were applied 45 days after planting.

Antitranspirant treatments

The following antitranspirant treatments (all values in w/v) were used during the experiment:

A0 = without antitranspirant (control treatment);
A1 = 6% kaolin (reflecting antitranspirant);
A2 = 6% $MgCO_3$ (stomatic antitranspirant);
A3 = 3% kaolin + 3% $MgCO_3$.

Planting and watering

Two pot experiments were established at the greenhouse of the National Research Center, Dokki, Egypt, during two successive summer seasons of 2009 and 2010 to evaluate the effect of different soil moisture levels and different antitranspirant treatments on growth, water relations and some chemical composition of *J. curcas*. Seeds were obtained from the Agriculture Research Center, Giza, Cairo, and directly sown on the 15th of April (5 seeds/pot) in earthenware pots of 30 cm diameter filled with 10 kg of sandy soil. The mechanical and chemical analyses of the soil were determined according to a standard method described by Klute (1986) and results are shown in **Table 1**. Plants were thinned to one/pot. All pots received a recommended dose of NPK fertilizers, namely 2 g calcium super phosphate (15.5% P_2O_5), which was added immediately after sowing, 1.68 g potassium sulphate (48% K_2O), which was added immediately after thinning, and 0.61 g ammonium nitrate (33.5% N), which was divided into three equal portions: the first immediately after sowing, the second after thinning and the third 2 weeks after the second. Seeds were regularly irrigated with tap water for 45 days; each pot was maintained to 25% water field capacity one day before applying the treatments, so that the soil moisture amount in each pot was uniform. The different soil moisture levels were then established by weighing each pot every 1 to 3 days and calculating the amount of water added. The pots were then irrigated to restore the soil to the appropriate moisture regime by adding a calculated amount of water. The general principal stated by Boutraa and Sanders (2001) was used for the water treatment application. The three antitranspirant treatments and all possible combinations between both antitranspirants were tested. Each of these treatments was sprayed twice during the plant's life: first after 60 days from sowing and the second time 4 weeks later. Foliar sprays were applied, always early in the morning. Antitranspirants were purchased from Scientific East Group, Begam-Shoubra, Egypt.

Experimental design

This experiment included 9 treatments which included all combinations between three soil moisture levels (W1, W2, W3) and four antitranspirant treatments (A0, A1, A2, A3). Treatments were arranged in a split plot design with five replicates each, and different soil moisture levels were assigned at random in the main plots, while sub-plots were devoted to the different antitranspirant treatments.

Data collection

After 120 days the plants were sampled at random to estimate the following characters: plant height (cm), number of leaves/plant, main root length (cm), leaf area (cm^2), fresh weight (FW; g) of the whole plant, and dry weight (DW; g) of the whole plant. The percentage relative water content (RWC%) of fresh leaves was also measured according to Weatherly (1962). The determination of total soluble solids (TSS) concentration in the cell sap of fresh plant was also estimated by using a refractometer; the corresponding osmotic pressure (Atm) values were then obtained from tables, as given by Gusev (1960). Samples were collected and dried for 48 h at 70°C to determine Pro (Pro) content (μmole/g DW) on dry leaves according to Troll (1995). Total soluble carbohydrates were also determined on dry leaves according to Dubois *et al.* (1956).

Statistical analyses

The collected data were subjected to statistical analysis of variance using the normal (*F*) test and mean separation were possible by using Least Significant Difference (LSD) test at the 5% level according to Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Growth parameters

Increasing water stress significantly retarded stem and root elongation (**Table 2A**). There was a negative relation between shoot height and root length with increasing water stress. Leaf area and leaf number were also significantly reduced by increasing water stress. Furthermore, a negative relation was observed between FW and DW of the whole plant and increasing water stress. The most significant increases in all growth parameters were evident under the highest soil moisture level, i.e., W3. The reduction in these growth parameters under the lowest soil moisture level (i.e., W1) may be attributed to losses of tissue water which inhibited cell division and enlargement, or possibly to a decrease in the activity of meristematic tissues responsible for elongation (Siddique *et al.* 1999). Soil drying also decreased leaf growth, thereby reducing leaf water status in addition to accumulating organic solutes, hence enabling osmotic adjustment and inhibiting the incorporation of small substrate molecules into the polymers needed in the growth of new cells (Ali *et al.* 1999). In addition, decreasing leaf area under drought stress may be caused by decreasing cell division and expansion (Liberman and Wang 1982). Moreover, total FW and DW decreased due to exposure to injurious levels of drought which might have resulted from a reduction in chlorophyll content and consequently, photosynthetic efficiency (Khalil *et al.* 2010). These results correspond with the findings of Farrag and El-Nagar (2005), who indicated that increasing water stress caused a significant decrease in the growth of cucumber (*Cucumis sativus*) plants. In addition, Ibrahim and Selim (2007) found that inadequate irrigation strongly negatively affected the growth of early summer squash (*Cucurbita pepo*) plants. Bafeel and Moftah (2008) showed that decreasing water stress significantly increased the FW and DW of eggplant (*Solanum melongena*).

When comparing the effectiveness of different types of antitranspirants used in this study, the use of kaolin + $MgCO_3$ resulted in the highest significant increase in all

Table 2A Effect of soil moisture levels on growth parameters of *Jatropha curcas* L. (combined analysis of 2009 and 2010 seasons).

Treatments	Plant height (cm)	No. of leaves /plant	Root length (cm)	Leaf area (cm^2)	Fresh weight (g)	Dry weight (g)
W1	89.29	25.25	24.29	83.663	102.32	23.92
W2	110.71	33.00	29.25	121.987	136.58	47.94
W3	144.33	36.00	33.42	133.758	252.94	68.52
$LSD_{0.05}$	1.03	1.60	1.58	0.91	1.86	5.53

Table 2B Effect of antitranspirants treatments on growth parameters of *Jatropha curcas* L. (combined analysis of 2009 and 2010 seasons).

Treatments	Plant height (cm)	No. of leaves /plant	Root length (cm)	Leaf area (cm^2)	Fresh weight (g)	Dry weight (g)
A0	94.33	25.33	21.28	93.039	110.81	34.80
A1	102.78	29.33	27.00	106.227	148.33	43.20
A2	115.22	32.67	30.33	118.977	171.51	48.37
A3	146.78	38.33	37.33	134.302	225.13	60.80
$LSD_{0.05}$	0.90	1.17	0.98	1.04	1.00	3.29

Table 2C Effect of interactions on growth parameters of *Jatropha curcas* L. (combined analysis of 2009 and 2010 seasons).

Treatments		Plant height (cm)	No. of leaves /plant	Root length (cm)	Leaf area (cm^2)	Fresh weight (g)	Dry weight (g)
W1	A0	66.00	20	16.17	66.576	46.33	17.80
	A1	85.67	23	24	78.104	96.09	21.10
	A2	86.67	26	26	88.133	99.59	22.83
	A3	118.83	32	31	101.839	167.25	33.95
W2	A0	86.50	25	21	90.445	85.29	23.85
	A1	89.83	31	25	117.284	111.29	43.75
	A2	110.50	35	28	135.870	139.48	59.55
	A3	156.00	41	38	144.347	210.30	64.60
W3	A0	130.50	31	26.67	122.094	200.82	62.75
	A1	132.83	34	32	123.292	237.60	64.74
	A2	148.50	37	37	132.927	275.50	62.73
	A3	165.50	42	43	156.719	297.85	83.85
$LSD_{0.05}$		1.55	2.02	1.70	1.80	1.74	5.70

W1 = 85% depletion of the available soil water; W2 = 55% depletion of the available soil water; W3 = 25% depletion of the available soil water; A0 = without antitranspirants; A1 = kaolin (6%); A2 = $MgCO_3$ (6%); A3 = kaolin (3%) + $MgCO_3$ (3%).

growth parameters compared with the control followed by $MgCO_3$; the lowest values were obtained for kaolin-only spray. In addition, kaolin + $MgCO_3$ increased plant height, leaf number/plant, root length, leaf area, plant FW and DW by 55.60, 51.32, 75.42, 44.35, 103.16, and 74.71%, respectively (**Table 2B**). These increases in growth parameters as a result of antitranspirant treatments may be due to the reduction in transpiration rate as result of stomata closure (Pennazio and Roggero 1984). Also, antitranspirants increased plant growth, possibly by increasing photosynthesis as a result of the improvement of the water status of the plant (Samir 1988). Ouda *et al.* (2007) noted that reflecting antitranspirants helped to reduce the heat load on leaves and increased the penetration of solar radiation into the canopy, increasing photosynthesis. The same finding was made by Gaballah and Moursy (2004) and El-Kholy *et al.* (2005b). Ibrahim and Selim (2010) suggested that a foliar spray with kaolin reduced the transpiration rate, which in turn maintained a higher water content in plant tissues, possibly favoring plant metabolism, physiological processes, photosynthetic rate, carbohydrate metabolism and many other important functions that directly affect plant growth. Jain and Srivastava (1981) also reported that low concentrations of antitranspirant stimulated the growth of maize (*Zea mays*) seedlings. Furthermore, Metwally *et al.* (2002) concluded that the application of antitranspirants significantly increased plant height, number of branches, and number of leaves/ plant as well as FW and DW of roselle (*Hibiscus sabdariffa*) plants. Khalil (2006) reported that all antitranspirants (film-forming, stomata and reflecting) significantly increased all growth parameters of sesame (*Sesamum indicum*) plants compared with the control treatment. Bafeel and Moftah (2008) suggested that a foliar spray with kaolin could lead to a reduction in the transpiration rate, which in turn maintained a higher water content in the plant tissues, thus directly affecting plant growth. Cantore *et al.* (2009) and Ibrahim and Selim (2010) concluded the same thing.

The interaction between water stress and different antitranspirants showed that all antitranspirant treatments (A1 through A3) increased growth parameters significantly under different soil moisture levels (W1 through W3) compared with control plants. The highest values in growth parameters were observed in the interaction between the highest soil moisture level (W3) and the kaolin + $MgCO_3$ treatment (i.e., W3 × A3) compared with the other treatments, followed by W2 × A3 (**Table 2C**). These results may be due to the effect of supplemental irrigation, which may have increased the absorption of some nutrients (Ibrahim and Selim 2007), consequently improving the photosynthetic capacity of leaves, in turn enhancing plant growth. Moreover, the use of antitranspirants decreases the loss in moisture content through transpiration (Nakano and Uehara 1996; Ibrahim and Selim 2010).

Relative water content

Increasing stress caused an observed adverse action on RWC% (**Table 3A**). The highest levels obtained were under the highest soil moisture level (W3), followed by the moderate soil moisture level (W2), although the difference between the two moisture levels was insignificant. The negative effect of water stress on RWC% as a result of reducing leaf water status was reported by Gupta *et al.* (2001), who confirmed the decrease in water-related parameters in water-stressed plants; when transpiration exceeds water absorption, cell turgor falls as RWC and cell volume decreases. Similar findings were made by Lawlor *et al.* (2002) and De Pascale *et al.* (2003), who reported that increasing stress severity caused a significant decline in RWC%. Soha and Atef (2011) reported that increasing water stress caused a significant decrease in RWC% of roselle plants.

Foliar application of $MgCO_3$ and kaolin + $MgCO_3$ significantly increased RWC% compared with the control treatment, while a single treatment with kaolin spray showed an insignificant increase in RWC% compared with control plants. The highest significant value for RWC% was obtained in the kaolin + $MgCO_3$ treatment (**Table 3B**). This increase in RWC% as a result of antitranspirant treatments might have resulted from closing stomata thus reducing the transpiration rate. Davenport *et al.* (1972b) also reported that antitranspirant materials effectively retard transpiration, increasing the turgidity of leaves and stomata guard cells. Poljakoff-Mayber and Gale (1975) indicated that antitranspirants showed a major role in increasing plant turgidity due to stomatal closure. Ma and Jian (1991) noted that spraying bean (*Vicia faba*) plants with 2% VaporGuard decreased transpiration and increased the RWC of leaves. Łukaszewska and Skutnik (2003) treated cut *Monstera* flowers with the commercial preservatives (8-HQC + 2% sucrose) to reduce transpiration loss and maintain flower turgidity, thus extending vase life. Khalil (2006) indicated that all antitranspirants (film-forming, stomata, reflecting) tended to significantly increase RWC% compared with the control. Imam and Miseha (1978) and Jones *et al.* (2004) observed the same.

The interaction between soil moisture level and antitranspirants showed a significant effect on RWC% in the summer of both consecutive years (**Table 3C**). Plants grown under the highest soil moisture level and sprayed with kaolin + $MgCO_3$ (W3 × A3) gave the highest significant values for RWC%, followed by W2 × A3, although the difference between both treatments was insignificant. All antitranspirant treatments increased RWC% under different soil moisture levels compared with control plants.

Table 3A Effect of soil moisture levels on some water relations and chemical compositions of *Jatropha curcas* L. (combined analysis of 2009 and 2010 seasons).

Treatments	RWC %	Osmotic pressure (Atm)	Pro (µMole/g)	Carbohydrates %
W1	71.658	7.47	4.431	1.640
W2	74.163	6.90	3.228	1.408
W3	75.605	5.74	1.379	1.193
$LSD_{0.05}$	2.73	0.05	1.68	0.18

Table 3B Effect of antitranspirants treatments on some water relations and chemical compositions of *Jatropha curcas* L. (combined analysis of 2009 and 2010 seasons).

Treatments	RWC %	Osmotic pressure (Atm)	Pro (µMole/g)	Carbohydrates %
A0	71.436	7.17	4.083	1.581
A1	73.083	6.91	3.186	1.446
A2	74.292	6.66	2.480	1.362
A3	76.424	6.06	2.303	1.265
$LSD_{0.05}$	2.30	0.03	0.55	0.06

Table 3C Effect of interactions on some water relations and chemical compositions of *Jatropha curcas* L. (combined analysis of 2009 and 2010 seasons).

Treatments		RWC %	Osmotic pressure (Atm)	Pro (µMole/g)	Carbohydrates %
W1	A0	70.144	8.16	6.366	1.751
	A1	70.514	7.97	4.907	1.640
	A2	71.282	7.33	3.409	1.629
	A3	74.690	6.41	3.043	1.540
W2	A0	71.470	7.30	3.708	1.620
	A1	73.329	7.13	3.409	1.453
	A2	74.992	7.02	3.014	1.337
	A3	76.860	6.13	2.174	1.221
W3	A0	72.694	6.04	2.779	1.372
	A1	75.406	5.64	1.241	1.245
	A2	76.600	5.64	1.015	1.121
	A3	77.721	5.64	1.086	1.034
$LSD_{0.05}$		2.89	0.05	1.89	0.23

W1 = 85% depletion of the available soil water; W2 = 55% depletion of the available soil water; W3 = 25% depletion of the available soil water; A0 = without antitranspirants; A1 = kaolin (6%); A2 = $MgCO_3$ (6%); A3 = kaolin (3%) + $MgCO_3$ (3%).

Osmotic pressure

Osmotic pressure increased significantly with decreasing soil water (equiv. soil moisture level) in the summer of both years (**Table 3A**). This decrease may be due to the accumulation of osmotic agents such as amino acids, especially Pro and organic acids or sugars, for osmotic adjustment in order to maintain turgidity (Abdel-Haleem 1985). Others (Sensoy *et al.* 2007; Zeng *et al.* 2009; Shanan *et al.* 2011) also observed a similar effect of irrigation on osmotic pressure.

Antitranspirants can be effectively used to reduce water loss and enhance the water status of plants. Use of a foliar spray of $MgCO_3$ and/or kaolin decreased the osmotic pressure compared to control plants (**Table 3B**). The lowest results were obtained for kaolin + $MgCO_3$ (A3) in both years, followed by $MgCO_3$ (A2). This may be due to the fact that antitranspirants (either stomatic or reflecting) reduced photosynthesis due to smaller stomata opening or due to the reflection of sunlight, which would lead to a reduction in the accumulation of photosynthate in the cell sap, thus reducing osmotic pressure (Shemshi 1963). Oliver and Barber (1966) indicated that reduced transpiration by antitranspirants reduced the uptake of some important ions such as Ca, Mg, K and P through mass flow processes; therefore, their uptake is affected by the transpiration rate. Mankarios *et al.* (1995) and Gu *et al.* (1998) reported a decrease in osmotic pressure as a result of decreasing transpiration rate caused by antitranspirant treatments. Ibrahim and Selim (2010) found that increasing water stress significantly increased the TSS of summer squash. Similar results were obtained by Shanan *et al.* (2011).

The interaction between water stress and antitranspirant treatments revealed that all antitranspirants decreased osmotic pressure values under different soil moisture levels. Moreover, the lowest osmotic pressure values were obtained when the highest soil moisture level (W3) was combined with any antitranspirant treatment (**Table 3C**).

Pro content

There was an inverse relationship between drought severity and Pro content (**Table 3A**): the highest Pro accumulation occurred in response to the lowest soil moisture level (W1) compared with all other treatments. This increment in Pro content as result of water shortage may be due to the hydrolysis of protein under stress conditions and the accumulation of different amino acids, especially Pro, for intracellular osmotic adjustment to maintain its turgidity (Pushpam and Rangasamy 2000). Wang *et al.* (2003) reported an increase in Pro values in response to drought, considered to be a defense mechanism in stressed plants in order to control osmotic pressure of stressed cells and tissues so as to raise their ability to take up water and solutes. Zlatev and Stoyanov (2005) noted that Pro content increased significantly by stress from 5.03 to 20.60 µm/g FW compared to control plants. Also, a high Pro content following water stress has been reported in wheat (Errabii *et al.* 2006; Vendruscolo *et al.* 2007; Tatar and Gevrek 2008).

Treatment of jatropha leaves with different antitranspirants caused a marked significant decrease in Pro accumulation compared with control plants, where the lowest significant value in Pro content was obtained in the kaolin + $MgCO_3$ (A3) treatment, followed by the $MgCO_3$ (A2) treatment, while the lowest accumulation was obtained in the single spray with kaolin (**Table 3B**). The decrease in Pro content by antitranspirant treatments is likely to be due to a direct increase of mRNA protein synthesis (Shanan *et al.* 2011). Taravati *et al.* (2007) mentioned that hydroxyl groups in polyols are thought to form a hydration sphere around macromolecules, thus protecting cells against stress by stabilizing the quaternary structure of proteins such as membranes and enzymes.

Least Pro accumulated in jatropha leaves under the combined effect of W3 × A2 and W3 × A3, 1.015 and 1.086 µMole/g respectively; W2 × A3 treatment (2.779 µMole/g Pro) was insignificantly different from the previously mentioned treatment combinations (**Table 3C**).

Total carbohydrates

There was a significant decrease in % carbohydrates of jatropha leaves with increasing soil moisture level (**Table 3A**). Increasing soil moisture stimulates some plants to increase their respiration rates as a prerequisite to produce both ATP to activate stressed cells and osmotic soluble substances which reduce cell osmotic potential thus increasing cell water uptake. Several groups (Lutfor-Ruhman *et al.* 2000; Arora *et al.* 2001; Banon *et al.* 2006; Sánchez-Blanco *et al.* 2006) reported an increase in total carbohydrates with increasing drought severity. Abdalla and El-Khoshiban (2007) noted that total carbohydrates extracted from the shoots and roots of *Triticum* plants increased as water stress increased.

All antitranspirant treatments decreased the % carbohydrates significantly compared with control plants: lowest levels were recorded with the kaolin + $MgCO_3$ (A3) treatment, followed by $MgCO_3$, kaolin and control treatments. The percentage decrease in total % carbohydrate was 19.98% for kaolin + $MgCO_3$, 13.85% for $MgCO_3$ and 8.54% for kaolin treatment, respectively (**Table 3B**). Antitranspirants may have caused stomatal closure, leading to a reduction in stomatal conductance, CO_2 concentration in leaf tissues, electron transport system, CO_2 fixation, rate of photosynthesis and the eventual quantity of photosynthates, thus causing a decline in carbohydrate content (Khalil 2006).

Under all soil moisture levels, the leaf carbohydrate % decreased with all antitranspirant treatments. Kaolin + $MgCO_3$ showed the lowest carbohydrate % under different soil moisture levels (**Table 3C**).

CONCLUSIONS

From our study, it can be concluded that:

1) Water stress negatively affected all growth parameters and RWC% of jatropha plants; the higher the level of moisture stress the greater the negative effect.
2) Different antitranspirants enhanced the tolerance of jatropha plants to moisture deficit treatments over two consecutive summers.
3) The interaction between the highest soil moisture level and kaoline + $MgCO_3$ revealed the greatest effect on growth parameters, moisture status and carbohydrate metabolism of jatropha plants.

REFERENCES

Abdalla MM, El-Khoshiban NH (2007) The influence of water stress on growth, relative water content, photosynthetic pigments, some metabolic and hormonal contents of two *Triticum aestivum* cultivars. *Journal of Applied Sciences Research* **3**, 2062-2074

Abdel-Haleem AK (1985) Morphological, physiological and corresponds of cotton plant to drought. PhD thesis, Faculty of Agriculture, Ain Shams University

Achten WMJ, Verchot L, Franken YJ, Mathijs E, Singh VP, Aerts R, Muys B (2008) Jatropha bio-diesel production and use. *Biomass and Bioenergy* **32**, 1063-1084

Ali M, Jonsen CR, Mogensen VO, Andersen MN, Henson IE (1999) Root signaling and osmotic adjustment during intermittent soil during sustain grain yield of field grown wheat. *Field Crops Research* **62**, 35-52

Arora A, Singh VP, Mohan J (2001) Effect of nitrogen and water stress on photosynthesis and nitrogen content in wheat. *Biologia Plantarum* **44**, 153-155

Ashish DP, Nilesh SP, Indu BP, Amar NP (2010) Growth, water status and nutrient accumulation of seedlings of *Jatropha curcas* L. (Euphorbiaceae) in response to soil salinity. *Anales de Biología* **32**, 59-71

Bafeel SO, Moftah AE (2008) Physiological response of eggplants grown under different irrigation regimes to antitranspirant treatments. *Saudi Journal of Biological Sciences* **15**, 259-267

Banon S, Ochoa J, Franco JA, Alarcon JJ, Sánchez-Blanco MJ (2006) Hardening of oleander seedlings by deficit irrigation and low air humidity. *Environment and Experimental Botany* **56**, 36-43

Boutraa A, Sande FE (2001) Influence of water stress on grain yield and vegetative growth of two cultivars of bean (*Phaseolus vulgaris* L.). *Journal of Agronomy and Crop Science* **187**, 251-260

Cantore V, Pace B, Albrizio R (2009) Kaolin-based particle film technology affects tomato physiology, yield and quality. *Environmental and Experimental Botany* **66**, 279-288

Davenport DC, Martin PE, Hagan MR (1972b) Antiranspirants for conservation of leaf water potential of transplanted citrus trees. *Horticultural Science* **7**, 511-520

De Pascale S, Ruggiero C, Barbieri G, Maggio A (2003) Physiological response of pepper to salinity and drought. *Journal of the American Society for Horticultural Science* **128**, 48-54

Dubois M, Cilles KA, Hamilton J, Rebers R, Smith F (1956) colorimetric method 11W determination of sugars and related substances. *Annals of Chemistry* **28**, 350-356

El-Kholy MA, Gaballah MS, El-Ashry S, Oraby A (2005b) Combating drought using yield stabilizing agents in barley. *Journal of Agriculture and Biological Science* **7**, 369-375

Errabii T, Gandonou CB, Essalmani H, Abrini J, Idaomar M, Skali-Senhaji N (2006) Growth, proline and ion accumulation in sugarcane callus cultures under drought-induced osmotic stress and its subsequent relief. *African Journal of Biotechnology* **5**, 1488-1493

Fairless D (2007) Biofuel: The little shrub that could maybe. *Nature* **449**, 652-655

Farrag AM, El-Nagar AM (2005) Response of cucumber plants to drip irrigation levels, NPK fertilization rates and salinity distribution in the soil. In: *3rd Conference on Recent Technologies in Agriculture*, 14-16 November, Cairo University, Egypt, pp 519-534

Francis G, Edinger R, Becker K (2005) A concept for simultaneous waste land reclamation, fuel production, and socio-economic development in degraded areas in India: need, potential and perspectives of jatropha plantations. *Natural Resources Forum* **29**, 12-24

Gaballah MS, Moursy M (2004) Reflectants application for increasing wheat plants tolerance against salt stress. *Pakistan Journal of Biological Science* **7**, 956-962

Gupta NK, Sunita G, Arvind K (2001) Effect of water stress on physiological attributes and their relationship with growth and yield of wheat cultivars at different stages. *Journal of Agronomy and Crop Science* **186**, 55-62

Gu-Sanliang L-H, Cheng L, Guak S-H, Shin C, Gu S-L, Cheng L-L (1998) Effect of antitranspirant and leaching on medium solution osmotic potential, leaf stomatal status, transpiration, abscisic acid content and plant growth in 'Early Girl' tomato plants (*Lycopersicon esculentum*). *Journal of Horticultural Science and Biotechnology* **73**, 473-477

Gusev NA (1960) *Some Methods for Studying Plant Water Relations*, Akad. Nauke SSSR, Leningard

Gush MB (2008) Measurement of water-use by *Jatropha curcas* L. using the heat-pulse velocity technique. *Agrometeorology* **34**, 1816-7950

Ibrahim EA, Selim EM (2007) Effect of irrigation intervals and nitrogen fertilizer rates on summer squash (*Cucurbita pepo* L.) growth, yield, nutritional status and water use efficiency. *Journal of Agriculture Science, Mansoura University* **32**, 10333-10345

Ibrahim EA, Selim EM (2010) Effect of irrigation intervalles and antitranspirants (Kaolin) on summer squash (*Cucurbita pepo* L.) growth, yield quality and economics. *Journal of Soil Science and Agriculture Engineering, Mansoura University* **1**, 883-894

Imam M, Miseha IW (1978) Effect of different PMA concentration and the time of spring young wheat plants. *Egyptian Journal of Botany* **21**, 75-84

Islam AKMA, Anuar N, Yaakob Z, Osman M (2011) Heterosis for seed yield and its components in jatropha (*Jatropha curcas* L.). *International Journal of Plant Breeding* **5 (2)**, 74-79

Jain A, Srivaslava HS (1981) Effect of salicyalic acid on nitrate reductase activity in maize seedlings. *Physiologia Plantarum* **51**, 339-345

Jones LM, Cochran K, Anderson GA, Ferree CD (2004) Effect of presservatives and cold storage on postharvest performance of deciduous holly branches. *HortTechnology* **14**, 230-234

Khalil SE (2006) Physiological study on sesame plants grown under saline water irrigation condition. PhD thesis, Cairo University, 229 pp

Khalil SE, Abd El-Aziz NG, Abou-Leila BH (2010) Effect of water stress and ascorbic acid on some morphological and biochemical composition of *Ocimum basilicum* plant. *Journal of American Science* **6**, 33-44

Klute A (1986) *Methods of Soil Analysis* (2nd Edn, Part 1), Soil Science of America, Madison, WI, USA

Lawlor DW, Cornic G (2002) Photosynthetic carbon assimilation and associated metabolism in relation to water deficit in higher plants. *Plant, Cell and Environment* **25**, 275-294

Lieberman M, Wang SY (1982) Influence of calcium and magnesium on ethylene production by apple tissue slices. *Plant Physiology* **69**, 1150-1155

Lutfor Rahman SM, Nawata E, Domae Y, Sakauratani T (2000) Effects of water stress and temperature on sod activity, growth and yield of tomato. *Acta Horticulturae* **516**, 41-45

Łukaszewska A, Skutnik E (2003) *Guide to Florists*, 156 pp

Ma RK, Jian JL (1991) Effect of antitranspirant on bean (*Vicia faba*) grown under conventional and conservation tillage systems. *Boden Kulture* **42 (4)**, 327 (*Plant Breeding Abstracts* **62**, 2959)

Maes WH, Achten WMJ, Reubens B, Raes D, Samson R, Muys CB (2009) Plant–water relationships and growth strategies of *Jatropha curcas* L. Seedlings under different levels of drought stress. *Journal of Arid Environments* **73**, 877-884

Mankarios AT, Aldesuquy HS, Awad HA (1995) Effect of some antitranspirant on growth and metabolism of saline treated wheat plants. III. Ionic content, proline accumulation and plant adaptability to salinity. *Environmental Science Journal* **10**, 69-75

Metwally MM, Afify MM, Wahba HE, Makarem AM, Mohamed A, Mohamed AE, Mahfouz S (2002) Effect of irrigation and Vapor Guard on growth, yield and chemical composition of roselle plant. *Bulletin of the NRC, Egypt* **27**, 533-548

Nakano A, Uehara Y (1996) The effect of kaolin clay on cuticle transpiration in tomato. *Acta Horticulturae* **440**, 233-238

Nasraui B (1993) Role of antitranspirant films in protecting plants against fungal disease. *Annals de l'Institute National de la Recherche Agronomique de Tunisie* **66**, 125-135

Oliver S, Barber AS (1966) An evaluation of the mechanisms governing the supply of Ca, Mg, K and Na to soybean roots (*Glycine max* L.). *Soil Science Society of America Proceedings* **30**, 82-86

Ouda SA, El-Mesiry T, Gaballah MS (2007) Effect of using stabilizing agents on increasing yield and water use efficiency in barley grown under water stress. *Australian Journal of Basic and Applied Science* **1**, 571-577

Pennazio S, Roggero P (1984) Effect of ABA and DNP on stomatal resistance in detached tobacco leaves. *Giornale Botanico Italiano* **118**, 132-140

Poljakoff-Mayber A, Gale J (1975) Plants in saline environments. In: *Ecological Studies* (Vol 15), Springer Verlag, Berlin, pp 61-69

Pushpam R, Rangasamy SRS (2000) Effect of salinity on protein and proline

content of callus and seedlings of rice. *Crop Research Hisar* **2**, 192-196
Samir AZM (1988) Water use efficiency, growth and yield of corn as influenced by antitranspirant materials. MSc thesis, Ain Shams University, Cairo, Egypt
Sánchez-Blanco J, Fernández T, Morales A, Morte A, Alarcon JJ (2006) Variation in water stress, gas exchange, and growth in *Rasmarinus officinalis* plants infected with *Glomus deserticola* under drought conditions. *Journal of Plant Physiology* **161**, 675-682
Sensoy S, Ertek A, Gedik I, Kucukyumuk C (2007) Irrigation frequency and amount affect yield and quality of field grown melon (*Cucumis melo* L.). *Agriculture and Water Management* **88**, 269-274
Shanan NT, Shalaby AE (2011) Influence of some chemical compounds as antitranspirant agents on vase life of *Monstera deliciosa* leaves. *African Journal of Agricultural Research* **6**, 132-139
Shemshi D (1963) Effect of chemical closure of stomata on transpiration in varied soil and atmospheric environments. *Plant Physiology* **38**, 709-712
Siddique M, Hamid RB, Islam MA (1999) Drought stress effect on photosynthetic rate and leaf gas exchange of wheat. *Botanical Bulletin of Academia Sinica* **40**, 141-145
Snedecor GW, Cochran WG (1980) *Statistical Methods* (7th Edn), Iowa State University, Iowa, USA
Soha EK, Atef AS (2011) The Influence of soil moisture stress on growth, water relation and fruit quality of *Hibisicus sabdariffa* L. grown within different soil types. *Nature and Science* **9**, 62-74
Taravati AM, Shokrzadeh AG, Ebadi P, Valipour TA, Molla F (2007) Various effects of sugar and polyols on the protein structure and function: Role as osmolyte on protein stability. *World Applied Science Journal* **2**, 353-365
Tatar O, Gevrek MN (2008) Influence of water stress on Pro accumulation, lipid peroxidation and water content of wheat. *Asian Journal of Plant Science* **7**, 409-412
Troll WJL (1995) Aphotometric method for defermination of proline. *Journal of Biological Chemistry* **215**, 655-660
Vendruscolo ACG, Schuster I, Pileggi M, Scapim CA, Molinari HBC, Marur CJ, Vieira LGC (2007) Stress-induced synthesis of proline and confers tolerance to water deficit in transgenic wheat. *Journal of Plant Physiology* **164**, 1367-1376
Wang WX, Vinocur P, Altman A (2003) Plant responses to drought, salinity and extreme temperatures: Towards genetic engineering for stress tolerance. *Planta* **218**, 1-14
Weatherly PE (1962) Examination of the moisture stress on carbohydrate development and growth in plants. *American Journal of Botany* **41**, 136-320
Zeng C, Bie Z, Yuan B (2009) Determination of optimum irrigation water amount for drip-irrigated muskmelon (*Cucumis melo* L.) in plastic greenhouse. *Agriculture and Water Management* **96**, 595-602
Zlatev Z, Stotanov Z (2005) Effect of water stress on leaf water relations of young bean plants. *Journal of Central European Agriculture* **6**, 5-14