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INFLUENCE OF IRRIGATION LEVELS, ANTITRANSPIRANTS AND POTASSIUM SILICATE ON GROWTH, FRUIT YIELD AND QUALITY OF SWEET PEPPER PLANTS (*Capsicum annuum* L.) GROWN UNDER DRIP IRRIGATION

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ABSTRACT

Two field experiments were conducted at a private farm near EL-Mansoura city, El-Dakahlia Governorate, Egypt, during the two successive seasons of 2011 and 2012 to study the effect of three water irrigation levels, the first was 2600 m^3 fed^{-1} as the control treatment (the traditional irrigation amount used by the farmers in the area), the 2nd and the 3rd treatments were 1800 and 1000 m^3 fed^{-1}, respectively, as deficit irrigation treatments as well as four foliar applications, *i.e.,* control, magnesium carbonate, kaolin and potassium silicate on growth, chemical composition, yield, water use efficiency and fruit quality of sweet pepper plants (Gedeon F1 Hybrid) cultivated under drip irrigation system in clay-loam soil at northern of Nile Delta lands.

The main results could be summarized as follows:

- Applying the high irrigation water level (2600 m^3 fed^{-1}) or the deficit level (1800 m^3 fed^{-1}) combined with foliar application of kaolin or potassium silicate showed the highest significant values of all studied vegetative growth aspects, *i.e.*, stem diameter, relative growth rate, net assimilation rate and leaf relative water content.
- Applying 2600 m^3 fed^{-1} combined with foliar application of potassium silicate and 2600 or 1800 m^3 fed^{-1} combined with foliar application of kaolin or potassium silicate significantly increased NPK uptake by sweet pepper plants foliage.
- Applying 1000 m^3 fed^{-1} combined with foliar application of kaolin or potassium silicate significantly increased total chlorophyll contents in sweet pepper leaves.
- All studied yield characteristics, *i.e.*, number of fruits per plant, average fruit weight, early yield and total yield per feddan as well as water use efficiency were significantly increased by applying 1800 m^3 fed^{-1} of irrigation water combined with foliar application of kaolin or potassium silicate.
- The highest significant values of vitamin C, total soluble solids, reducing sugars and total sugars contents in sweet pepper fruits were significantly affected by applying the deficit irrigation treatments (1800 or 1000 m^3 fed^{-1}) combined with foliar application of kaolin or potassium silicate.
- Fruit flesh thickness was significantly increased by applying 2600 m^3 fed^{-1} combined with kaolin or potassium silicate foliar application.
- The highest net return was obtained by applying 1800 m^3 fed^{-1} combined with foliar application of kaolin; such treatment returns the highest benefit-cost ratio (2.51).

In conclusion, this investigation demonstrate that irrigation sweet pepper plants with 1800 m^3 fed^{-1} combined with kaolin foliar application (4%, 4 times during the season) could be recommended to improve the vegetative growth characteristics, chemical composition, total yield, water use efficiency and fruit quality, saving about 30% of the total used irrigation water quantity in sweet pepper production. Such treatment can be recommended under drip irrigation system in clay-loam soil at northern of Nil Delta lands, giving the highest net return and benefit-cost ratio to the farmers.

INTRODUCTION

Sweet pepper (*Capsicum annuum* L.) is one of the most important, popular and favorite vegetable crops cultivated in Egypt for local consumption and exportation. To achieve both water and food security, Egypt has to adapt alternative strategies directed towards efficient management of Nile River irrigation water particularly in Nile Delta lands.

Since sweet pepper plants are very sensitive to water stress, management of irrigation water is very important to produce economic yield and good fruit quality. Under water stress conditions, root density of pepper plants was reduced by about 20% compared with sufficiently irrigated plants (Silber, 2005), this in turn reflected on yield aspects (Ismail, 2010). Therefore, increasing productivity and irrigation efficiency under water stress conditions are greatly required. Deficit irrigation was proposed long time ago as a technique that irrigates the entire root zone with less evapotranspiration and leads to reduce the irrigation water use with maintaining farmers' net profits (Hoffman *et al*., 1990). Thus, deficit irrigation can be used as a practical technique to save large amounts of irrigation water.

Another technique that claim to reduce water use by plant is the reflectance type of antitranspirants as magnesium carbonate and kaolin, which are natural white materials form a coating film on the leaves, it increase the leaf reflectance by reflecting the radiation and increase the vapour pressure gradient and thus reduce transpiration (Glenn *et al*., 2002 and Creamer *et al*., 2005). In this respect, Abd El-Aal *et al*. (2008) mentioned that foliar application of $MgCO_3$ at rate 2% gained more growth vigor and more fruits yield as well as better physical and chemical properties of eggplant compared with no-treated plants. Kaolin also is an important material used in this concern, it is considered as an effective natural antitranspirant and was reported to mitigate the negative effects of water deficiency and environmental stresses, such as heat stress and sunburn damage as well as suppress diseases and protect crops from insect pests (Kahn and Damicone, 2008). Spraying tomato plants with 5% of kaolin suspension improved water status and yield under water stress conditions (Srinivasa Rao, 1985). Creamer *et al*. (2005) illustrated that applications of kaolin at hot temperatures might help hot Chile pepper plants from being subjected to severe water stress.

Many researchers mentioned the role of silicon in plant resistance to both biotic and abiotic stress including drought (Adatia and Besford, 1986; Efimova and Dokynchan, 1986; Hanafy *et al*., 2008 and Crusciol *et al*., 2009). Potassium silicate is a source of highly soluble silicon; it is used in agricultural production system primarily as a silicon fertilizer (Romero-Aranda and Cuartero, 2006 and Abou-Baker *et al*., 2011). Many studies demonstrated that silicon has been shown to have several distinct advantages in improving plant growth, chemical composition and productivity as well as fruit quality of several plants (Romero-Aranda and Cuartero, 2006 on tomato; Lynch, 2008 on grapes and banana; Crusciol *et al*., 2009 on potato and Abou-Baker *et al*., 2011 on faba bean).

The objective of the present investigation was to study the effect of irrigation levels, some antitranspirants and potassium silicate as well as their interactions on growth, fruit yield and quality of sweet pepper plants cultivated under drip irrigation system at northern of Nile Delta lands.

MATERIALS AND METHODS

Two field experiments were conducted at a private farm near EL-Mansoura city, El-Dakahlia Governorate, Egypt, during the two successive seasons of 2011 and 2012 to study the effect of irrigation levels, some antitranspirants and potassium silicate on growth, chemical composition, yield, water use efficiency and fruit quality of sweet pepper plants cultivated under drip irrigation system in clay-loam soil at northern of Nil Delta lands. Table 1 shows some physical and chemical properties of the experimental soil before planting, according to the methods described by Page (1982).

Table 1: Physical and chemical properties of the experimental soil

Physical properties	Value		Chemical properties	Value	
	1st season	2nd season		1st season	2nd Season
Sand (%)	24.2	21.4	Available N (%)	0.16	0.19
Silt (%)	32.6	33.5	Available P (ppm)	8.9	12.8
Clay (%)	43.2	45.1	Available K (ppm)	255	289
Texture class	Clay-loam	Clay-loam	Bulk Density (gm/cm^3)	1.42	1.38
Organic matter (%)	1.7	1.3	Field capacity (%)	35.1	34.6
$CaCO_3$	2.8	3.0	Wilting point (%)	15.3	16.4
pH	8.2	8.0	Available water (%)	14.1	15.7
EC dSm^{-1}	0.79	0.84	Saturation (%)	84.9	84.4

On March, 1st week of both seasons, 45 day old sweet pepper seedlings, Gedeon F1 Hybrid, were transplanted in open field at 40 cm apart on one side of the ridge. The experiment was adopted in a split plot design with three replicates, containing 12 treatments, which were the combination between three water irrigation levels, the first was 2600 m^3 fed^{-1} as a control treatment (the traditional irrigation water amount by farmers in the area), the 2nd and the 3rd treatments were 1800 and 1000 m^3 fed^{-1} as deficit irrigation treatments as well as four foliar applications, *i.e.,* control (tap water), magnesium carbonate, kaolin and potassium silicate. Water irrigation levels were distributed in the main plots, whereas the foliar spraying treatments were arranged in the sub plots. The experimental unit consisted of four ridges each of 1 m wide and 5 m long with an area 20 m^2. A distance of 2 m was left between each irrigation treatments to avoid the infiltration of water irrigation. Drip irrigation was used from the beginning to the end of the two seasons using Nile water with EC of 0.74 dSm^{-1}. The drippers used were of a standard 4 L h^{-1} discharge at 1.5 bar working pressure. The irrigation treatments started after 35 days from sweet pepper transplanting. The amount of irrigation water at different treatments were adjusted using a water counter and were added according to growth stage of sweet pepper plants during growth season.

Magnesium carbonate ($MgCO_3$) and kaolin (Aluminum silicate) powder, agriculture grade, were used as a fine mist foliar application at 4% till run-off with care being taken to cover all plant foliage. Potassium silicate (K_2SiO_3) in a powder form (manufactured by Fusion chemicals Co., Ltd., India), contain 22.5% SiO_2 and 10.25% K_2O, was dissolved first in hot water and used as foliar spray at 1.5 kg fed^{-1} in every addition. Foliar application of magnesium carbonate, kaolin and potassium silicate were applied 4 times starting 35 days after transplanting and repeated at 30 days intervals during the growth seasons using spreading agent (Super Film 1 ml/l). The untreated plants (control) were sprayed with tap water using the same spreading agent only. The other agricultural practices for growing sweet pepper plants were followed according to the instruction laid down by the Egyptian Ministry of Agriculture, Egypt.

Five plants from each plot were randomly taken for determination of stem diameter (105 days after transplanting), foliage dry weight and leaf area per plant (75 and 105 days after transplanting). Foliage dry weight and leaf area were used to calculate relative growth rate (Hunt, 1990) and net assimilation rate (Gardner *et al*., 1985) as follows:

RGR (mg/ gm. day^{-1}) = $((\ln W_2 - \ln W_1)/ (T_2 - T_1)) \times 1000$

NAR (mg/ cm^2 day^{-1}) = $((W_2 - W_1)/ (T_2 - T_1)) \times ((\ln LA_2 - \ln LA_1)/ (LA_2 - LA_1)) \times 1000$

Where; RGR: Relative growth rate; NAR: Net assimilation rate; In: Natural logarithm; W_1 and W_2: Dry weight of plant shoots at time one and time two (in gram), respectively; T_1 and T_2: Time one and time two, respectively (in day); LA_1 and LA_2: Leaf area/ plant (Koller, 1972) at time one and time two, respectively (cm^2).

Leaf relative water content (LRWC) was determined in the fully expanded topmost leaf of the main shoot according to the methods of Turner (1981) by recording the fresh weight of the leaves sample and then the leaves were immersed in distilled water. After 2 hours, the leaves were removed, the surface water was blotted-off and the turgid weight recorded. Samples were then dried in an oven at 70 °C to constant weight. Leaf relative water content was calculated using the following formula:

LRWC (%) = $((FW - DW) / (TW - DW)) \times 100$

Where; FW: Fresh weight; DW: Dry weight; TW: Turgid weight.

At 105 day after transplanting, representative samples of 5 plants from each plot were used to determine N, P and K contents (%) in foliage dry weight. Total nitrogen was determined according to the methods described by Bremner and Mulvaney (1982); phosphorus was estimated colormetrically according to Olsen and Sommers (1982) and potassium was determined flame photometrically as described by Jackson (1973). N, P and K uptake were calculated based on mineral content (%) and foliage dry weight. Representative samples from the 4^{th} upper leaves were taken to determinate total chlorophyll content (SPAD units) using a portable leaf chlorophyll meter (Minolta Model SPAD 501) according to Murquard and Timpton (1987).

All harvested fruits from each plot at marketable green ripe stage along the season were used to determine number of fruits per plant, average fruit weight and total yield (ton fed^{-1}). Early yield (ton fed^{-1}) was calculated

from the first three pickings. Water use efficiency (WUE) was calculated according to the equation of Begg and Turner (1976) as follows:
WUE (kg/ m^3) = yield (kg fed^{-1})/ water quantity (m^3 fed^{-1}).

A representative sample of 10 sweet pepper fruits from each experimental plot at the marketable green ripe stage was taken from the 3^{rd} harvest for determination of fruits quality characteristics, *i.e.*, fruit flesh thickness, vitamin C, total soluble solids (TSS) according to the methods described by AOAC (1990). Reducing sugars and total sugars in fruits were analyzed according to the method of Sadasivam and Manickam (1992) and Sen *et al*. (2005), respectively.

The obtained data were subjected to statistical analysis by the technique of analysis of variance (ANOVA) according to Snedecor and Cochran (1982). The treatment means were compared using New Least Significant Difference at 5% level of probability as mentioned by Waller and Duncan (1969). Economic feasibility of sweet pepper plants production, *i.e.*, gross return, treatment cost, total variable cost, net return and benefit-cost ratio were calculated based on market prices as average of the two seasons. The benefit-cost ratio was determined according to Boardman *et al*. (2001) by dividing the gross return (LE fed^{-1}) on total variable cost (LE fed^{-1}).

RESULTS AND DISCUSSION

Vegetative growth characteristics:

The present data in Table 2 declare the effect of irrigation levels on vegetative growth characteristics of sweet pepper plants. Such data indicate that the deficit irrigation treatment (1000 m^3 fed^{-1}) applied to sweet pepper plants recorded the lowest significant values of vegetative growth characteristics, *i.e.*, stem diameter, relative growth rate, net assimilation rate and leaf relative water content. The highest significant values in this respect were obtained using the highest irrigation water level (2600 m^3 fed^{-1}, control). The data are coincided in both seasons of the study. The results are in harmony with those reported by Ezzo *et al*. (2010) who indicated that the highest plant length, stem diameter, fresh weight, dry weight and root/ shoot ratio of sweet pepper plants were obtained by the high irrigation level (110% of ET_0).

The negative effects of the lowest irrigation level (1000 m^3 fed^{-1}) on sweet pepper plants growth may be related to the drought stress, which affects plant growth by reducing number of leaves and leaf area, resulting in less photosynthesis of sweet pepper plants (Silber, 2005). Moreover, deficit irrigation as a water stress condition eventually reduces plant growth, chlorophyll content, water potential and transpiration rate as well as the free water in plant tissue, leading to deleterious effect on photosynthetic rate, stomatal conductance and intercellular CO_2 (Mingchi *et al*., 2010 on tomato).

The same data demonstrate the effect of foliar application of magnesium carbonate, kaolin and potassium silicate on vegetative growth characteristics of sweet pepper plants. It is clear that foliar applications with kaolin or potassium silicate significantly increased vegetative growth characteristics, *i.e.,* stem diameter, relative growth rate, net assimilation rate and leaf relative water content. It is also clear that the lowest significant values in this respect were recorded by the control treatment in both seasons of this work. The significant responses of kaolin foliar application on vegetative growth of sweet pepper plants were confirmed by Creamer *et al*. (2005) on Chile pepper and Ezzat *et al*. (2009) on potato. Also, Romero-Aranda and Cuartero (2006) found that treating tomato plants with potassium silicate (K_2SiO_3) as a source of silicon (2.5 mM) improved fresh, dry weight, leaf area and net photosynthesis rates as well as water storage within plant tissues. Furthermore, Abou-Baker *et al* (2011) indicated that spraying faba bean plants with silicon at 300 ppm as potassium silicate form recorded the highest significant values of plant height, root length, shoot and root dry.

Table 2: Effect of irrigation levels and some foliar applications as well as their interactions on vegetative growth characteristics of sweet pepper plants during 2011 and 2012 seasons

Treatments		Stem diameter (cm)		Relative growth rate (mg/gm day^{-1})		Net assimilation rate (mg/cm^2 day^{-1})		Leaf relative water content (%)	
		1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Irrigation levels (m^3 fed^{-1}):									
2600		1.78	1.80	37.97	39.50	0.384	0.431	86.18	86.97
1800		1.70	1.65	35.69	36.71	0.358	0.407	84.84	85.92
1000		1.39	1.33	27.82	26.69	0.283	0.306	82.37	84.28
New LSD at 5%		0.134	0.139	2.11	2.01	0.019	0.022	2.21	2.11
Foliar applications:									
Control*		1.47	1.41	28.52	28.61	0.301	0.323	82.99	83.40
$MgCO_3$		1.58	1.48	33.03	31.42	0.325	0.368	83.01	85.23
Kaolin		1.71	1.71	36.19	37.94	0.365	0.413	85.25	86.45
K-silicate		1.73	1.76	37.57	39.22	0.375	0.421	86.60	87.81
New LSD at 5%		0.124	0.157	2.24	1.97	0.021	0.025	2.40	2.28
Irrigation levels (m^3 fed^{-1}) X Foliar applications:									
2600	Control	1.63	1.67	33.71	31.94	0.335	0.376	85.27	84.41
	$MgCO_3$	1.75	1.73	37.12	39.14	0.373	0.418	85.32	86.93
	Kaolin	1.84	1.87	39.75	42.60	0.410	0.458	85.89	87.44
	K-silicate	1.91	1.94	41.31	44.32	0.418	0.471	88.23	89.10
1800	Control	1.51	1.43	28.99	26.47	0.306	0.322	83.35	83.42
	$MgCO_3$	1.69	1.49	33.47	34.11	0.321	0.401	82.36	85.39
	Kaolin	1.81	1.79	40.71	43.58	0.399	0.455	86.31	86.99
	K-silicate	1.79	1.87	39.59	42.66	0.407	0.451	87.35	87.88
1000	Control	1.26	1.12	22.86	27.43	0.263	0.272	80.36	82.38
	$MgCO_3$	1.31	1.23	28.51	21.01	0.281	0.285	81.35	83.36
	Kaolin	1.48	1.48	28.10	27.64	0.285	0.327	83.54	84.92
	K-silicate	1.50	1.47	31.82	30.68	0.301	0.340	84.23	86.46
New LSD at 5%		0.134	0.167	2.32	2.08	0.020	0.023	2.37	2.12

* Plants sprayed with tap water

Regarding the effect of the interaction between irrigation levels and foliar application of magnesium carbonate, kaolin and potassium silicate on vegetative growth characteristics of sweet pepper plants. Data in Table 2 clearly show that applying the high irrigation water level (2600 m^3 fed^{-1}) or the deficit level (1800 m^3 fed^{-1}) combined with foliar application of kaolin or potassium silicate had the highest significant stem diameter, relative growth rate, net assimilation rate and leaf relative water content. It is also clear that the lowest significant values in this respect were recorded by the lowest irrigation level (1000 m^3 fed^{-1}) with no additional foliar antitranspirants or potassium silicate. In addition, foliar application of kaolin or potassium silicate improved all studied growth aspects and leaf relative water content of 1000 m^3 fed^{-1} plants relative to 1000 m^3 fed^{-1} plants without any foliar antitranspirants or potassium silicate.

The pronounced promotional effect of the foliar application of kaolin and potassium silicate under water stress conditions (1800 m^3 fed^{-1}) on vegetative growth characteristics of sweet pepper plants may be related to the direct effects of kaolin on plant resistance to both biotic and abiotic stress including drought (Glenn *et al*., 2002 and Creamer *et al*., 2005). In addition, kaolin foliar application was reported to improve CO_2 assimilation under high temperature (Glenn *et al*., 2002). Also, silicon was reported to alleviate water stress by its reduction effect on the diameter of stomatal pores (Efimova and Dokynchan, 1986) that in turn, reduces transpiration rate resulting in reduction in water loss. Another possible action of silicon is the improvement in the efficiency of osmotic adjustment of plant tissues (Romero-Aranda and Cuartero, 2006). Silicon plays a key role in retaining the water capacity of stressed cells, which thereby can tolerate severe drought (Crusciol *et al*., 2009 on potato). Silicon was reported to enhance rigidity, strengthening and elasticity of cell wall, also silicon promotes plant growth by correcting the levels of endogenous growth hormones, *i.e.*, auxins, gibberellins and cytokinins under stress conditions (Hanafy *et al*., 2008). Furthermore, potassium silicates as a foliar application provide a supplemental source of potassium. Since potassium has substantial effect on enzyme activation, protein synthesis, photosynthesis, stomatal movement and water-relation (turgor regulation and osmotic adjustment) in plants (Marschner, 1995). Increasing application of K^+ has been shown to enhance photosynthetic rate, plant growth and yield as well as drought resistance under water stress conditions (Egilla *et al*., 2001). It was reported also that when K^+ is deficient, the stomata cannot function properly and water losses from plant may reach damaging levels (Gething, 1990). Such gains can explain the enhancement of plant growth in associated with higher plant water content in sweet pepper plants grown under deficit irrigation condition.

Chemical composition of sweet pepper foliage:

Data presented in Table 3 are concerning with the effect of irrigation levels on NPK uptake and total chlorophyll contents of sweet pepper plants. It is obvious that increasing irrigation water quantity up to the highest used level (2600 m^3 fed^{-1}) significantly increased NPK uptake by plants foliage. Meanwhile, it is clear that total chlorophyll contents in plant leaves reached the highest significant values with the low irrigation level (1000 m^3 fed^{-1}), in both seasons of the study. These results were in accordance with those obtained by Sabli (2012) on bell pepper.

The positive effects of increasing irrigation quantities on NPK uptake by sweet pepper plants foliage can be attributed to its enhancing effect on transport of dissolved nutrients by mass flow, because of the higher timeaveraged water content in the soil (Silber *et al*., 2005). In addition, the proper balance of moisture in plant creates favorable conditions for photosynthesis and metabolites translocation (Ezzo *et al*., 2010 on sweet pepper), which accelerate the rate of nutrients uptake. Moreover, sweet pepper plants of the water deficit treatment (1000 m^3 fed^{-1}) gave the highest chlorophyll content in leaves, this may be due to the physiological dilution effect of water stress, since such treatment give the lowest relative growth rate, net assimilation rate and leaf relative water content (Table 2).

Table 3: Effect of irrigation levels and some foliar applications as well as their interactions on NPK uptake and total chlorophyll of sweet pepper plants during 2011 and 2012 seasons

Treatments		N uptake (mg/dry plant foliage)		P uptake (mg/dry plant foliage)		K uptake (mg/dry plant foliage)		Total chlorophyll (SPAD unit)	
		1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Irrigation levels (m^3 fed^{-1}):									
2600		3389	3012	295.1	265.7	4175	4010	53.54	51.46
1800		3238	2787	281.7	250.9	4023	3823	59.07	55.99
1000		2496	2256	226.3	207.0	3247	3122	61.47	58.56
New LSD at 5%		105.4	114.1	19.31	12.81	160.3	150.4	1.84	2.04
Foliar applications:									
Control*		2759	2507	238.3	212.0	3446	3322	55.99	53.60
$MgCO_3$		2851	2570	250.8	229.2	3586	3501	57.90	55.15
Kaolin		3225	2787	283.4	258.1	4041	3835	60.09	56.61
K-silicate		3328	2874	298.2	265.4	4187	3948	58.13	55.99
New LSD at 5%		111.8	103.4	16.91	14.84	152.9	157.8	2.09	NS
Irrigation levels (m^3 fed^{-1}) X Foliar applications:									
2600	Control	3112	2941	270.5	237.1	3945	3701	50.25	48.47
	$MgCO_3$	3188	2960	275.8	252.8	3924	3911	53.87	51.10
	Kaolin	3559	2996	303.6	277.2	4311	4122	55.57	52.86
	K-silicate	3695	3149	330.3	295.6	4520	4305	54.47	53.41
1800	Control	2789	2505	235.1	208.2	3503	3392	57.60	54.54
	$MgCO_3$	2967	2586	257.7	229.8	3644	3509	58.81	56.43
	Kaolin	3604	3038	320.8	285.5	4460	4162	61.09	57.40
	K-silicate	3593	3018	313.2	280.2	4485	4230	58.78	55.60
1000	Control	2376	2075	209.3	190.7	2889	2873	60.11	57.58
	$MgCO_3$	2399	2165	218.8	205.0	3191	3084	61.03	57.60
	Kaolin	2513	2326	225.8	211.7	3351	3221	63.60	59.57
	K-silicate	2695	2456	251.1	220.5	3557	3308	61.95	58.96
New LSD at 5%		107.1	135.7	18.11	16.63	175.3	160.4	2.01	1.92

* Plants sprayed with tap water

With respect to the effect of the used foliar applications, *i.e*., magnesium carbonate, kaolin and potassium silicate on NPK uptake and total chlorophyll contents of sweet pepper plants, the same data illustrate that foliar applications with kaolin or potassium silicate significantly increased NPK uptake and total chlorophyll contents in both seasons. The unique exception was that of total chlorophyll which did not show any significant response in the second season of this work. In this respect, foliar application of kaolin was reported to increase chlorophyll contents in Chile pepper leaves (Creamer *et al*. 2005).

The positive significant effect of kaolin foliar application on NPK uptake and total chlorophyll contents may be related to its cooling effect as it reduces leaf temperature (Glenn *et al*., 2002). Although, the shading effect of kaolin film application have been shown to reduce the light available to the leaf by increasing light reflection (Wunsche *et al*., 2004) and such reduction in light may have negative effect on photosynthesis process, fortunately, this negative impact did not occur here in our case, which suppose that the amount of the reflected light due to kaolin foliar application is neglected or little to cause any reverse effect on photosynthesis process. The results of the relative growth rate and net assimilation rate (Table 2) as affected by kaolin foliar application are greatly confirm this concept. Such conclusion is confirmed by the finding of Glenn *et al*. (2002). Otherwise, the affirmative effect of potassium silicate on NPK uptake and total chlorophyll contents of sweet pepper plants may be attributed to the effect of silicon on improving photosynthesis activity, which was related with leaf chlorophyll content (Adatia and Besford, 1986). Furthermore, potassium silicate is considered as a rich source of potassium. Since potassium is directly involved in the nutrients absorption through the process of phloem loading as a counter ion to H^+ (Komor *et al*., 1980) and so enhancing the mineral content of plant foliage.

As for the effect of interaction between irrigation levels and foliar application of magnesium carbonate, kaolin and potassium silicate on NPK uptake and total chlorophyll contents of sweet pepper plants (Table 3). It is obvious clear that applying 2600 m^3 fed^{-1} of irrigation water combined with foliar application of potassium silicate and 2600 or 1800 m^3 fed^{-1} of irrigation water combined with foliar application of kaolin or potassium silicate significantly increased NPK uptake. Meanwhile, applying 1000 m^3 fed^{-1} combined with foliar application of kaolin or potassium silicate significantly increased total chlorophyll contents, in both seasons. Similar results were confirmed by Ezzat *et al*. (2009) who stated that under insufficient water quantity (800 m^3 fed^{-1}) foliar application of 4% kaolin significantly increased photosynthetic pigments, *i.e.*, chlorophyll a, b and carotenoids in potato leaves.

Yield characteristics:

Data of the effect of irrigation levels on yield characteristics and water use efficiency of sweet pepper plants are presented in Table 4. It is obviously clear that increasing water quantity up to 2600 m^3 fed^{-1} led to the highest significant increases in number of fruits per plant, average fruit weight, early and total yield per feddan in comparison to other treatments. However, using the two deficit irrigation treatments (1800 or 1000 m^3 fed^{-1}) showed the highest values of water use efficiency compared with the high irrigation level, *i.e.*, 2600 m^3 fed^{-1} (control), in both seasons of study. Such results are in line with those of Ezzo *et al*. (2010) who showed that the highest early yield, total yield, fruit length, fruit diameter and average fruit weight were achieved when pepper plants were irrigated by 110% of the calculated water requirements. Also, Ismail (2010) observed that deficit irrigation tends to increase water use efficiency and decrease the fresh fruit yield of chili pepper.

Table 4: Effect of irrigation levels and some foliar applications as well as their interactions on yield characteristics and water use efficiency of sweet pepper plants during 2011 and 2012 seasons

Treatments	No of fruits/ plant		Average fruit weight (g)		Early yield (Ton fed^{-1})		Total yield (Ton fed^{-1})		Water use efficiency (kg/m^3)	
	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Irrigation levels (m^3 fed^{-1}):										
2600	16.40	15.91	89.74	99.03	2.58	2.38	14.72	15.76	3.07	3.28
1800	16.10	15.67	86.41	95.88	2.50	2.30	13.98	15.09	3.89	4.19
1000	14.17	13.44	65.98	71.11	2.21	1.99	9.37	9.57	3.91	3.99
New LSD at 5%	0.341	0.233	2.34	3.07	0.071	0.061	0.448	0.442	0.191	0.176
Foliar applications:										
Control*	14.46	14.28	77.26	83.73	2.28	2.11	11.28	12.08	3.19	3.41
$MgCO_3$	15.05	14.54	78.72	87.41	2.38	2.18	11.92	12.82	3.41	3.64
Kaolin	16.47	15.74	84.19	92.36	2.56	2.32	13.99	14.70	4.01	4.19
K-silicate	16.25	15.46	82.65	91.19	2.50	2.28	13.56	14.28	3.86	4.05
New LSD at 5%	0.412	0.351	2.56	2.84	0.084	0.074	0.431	0.457	0.186	0.180
Irrigation levels (m^3 fed^{-1}) X Foliar applications:										
2600 Control	15.80	15.50	88.92	97.04	2.53	2.31	14.05	15.04	2.93	3.13
2600 $MgCO_3$	15.97	15.47	89.15	99.39	2.58	2.39	14.24	15.38	2.97	3.20
2600 Kaolin	16.97	16.36	90.35	100.1	2.64	2.42	15.33	16.38	3.19	3.41
2600 K-silicate	16.87	16.29	90.53	99.57	2.62	2.41	15.27	16.22	3.18	3.38
1800 Control	14.43	14.24	80.26	88.24	2.26	2.08	11.58	12.57	3.22	3.49
1800 $MgCO_3$	15.03	14.86	82.10	91.98	2.35	2.18	12.34	13.67	3.43	3.80
1800 Kaolin	17.64	16.92	92.32	102.5	2.71	2.49	16.29	17.34	4.53	4.82
1800 K-silicate	17.28	16.64	90.94	100.8	2.63	2.43	15.71	16.77	4.36	4.66
1000 Control	13.14	13.09	62.59	65.90	2.05	1.93	8.22	8.63	3.43	3.60
1000 $MgCO_3$	14.16	13.29	64.92	70.86	2.21	1.96	9.19	9.42	3.83	3.93
1000 Kaolin	14.79	13.93	69.91	74.48	2.31	2.06	10.34	10.38	4.31	4.33
1000 K-silicate	14.60	13.46	66.48	73.20	2.28	1.99	9.71	9.85	4.05	4.10
New LSD at 5%	0.419	0.390	2.55	2.96	0.097	0.089	0.593	0.574	0.208	0.269

* Plants sprayed with tap water

Concerning the effect of the used foliar applications, *i.e.*, magnesium carbonate, kaolin and potassium silicate on yield characteristics and water use efficiency of sweet pepper plants. The same data clearly reveal that foliar applications of kaolin or potassium silicate had the highest significant number of fruits per plant, average fruit weight, early and total yield per feddan as well as water use efficiency compared to foliar application of magnesium carbonate and control, in both seasons. The obtained results are in line with those of Glenn *et al*. (2002) who observed that foliar applications of kaolin was corresponded by the remarkable improve in water use efficiency by apple plants. On the other hand, Romero-Aranda and Cuartero (2006) reported that treating tomato plants with potassium silicate (2.5 mM Si, as K_2SiO_3) enhanced water use efficiency by 17%. Such results were confirmed also by the findings of Abou-Baker *et al*. (2011) on faba bean plants.

Regarding the effect of the interaction between irrigation levels and foliar application of magnesium carbonate, kaolin and potassium silicate on yield characteristics and water use efficiency of sweet pepper plants. It is obviously clear that number of fruits per plant, average fruit weight, early and total yield per feddan as well as water use efficiency were significantly affected by applying 1800 m^3 fed^{-1} of irrigation water combined with foliar application of kaolin or potassium silicate followed by applying 2600 m^3 fed^{-1} (control) combined with foliar application of kaolin or potassium silicate. These results had the same trend during the two seasons. In this respect, Srinivasa Rao (1985) reported that under deficit irrigation conditions, a single spray of 5% kaolin improved the water status and yield of tomato plants compared with control plants. Such results also are in line with those of Creamer *et al*. (2005) on Chile pepper. On the other hand, Crusciol *et al*. (2009) stated that silicon application under drought stress conditions increased potato yield.

It is clear that foliar application of potassium silicate or kaolin tended to increase average fruit weight, early and total yield of sweet pepper fruits as well as water use efficiency under the deficit irrigation level (1800 m^3 fed^{-1}). This result could be explained on the basis that such treatment showed the pronounced positive effects on the vegetative growth aspects (Table 2), NPK uptake and chlorophyll content (Table 3) leading to healthy sweet pepper plants and hence increasing yield aspects.

Fruit quality characteristics:

Data listed in Table 5 show the effect of irrigation levels on fruit quality characteristics of sweet pepper plants. It is clear that increasing water quantity applied to sweet pepper plants up to the highest level (2600 m^3 fed^{-1}) resulted in the highest significant increase in fruit flesh thickness. On the other hand, the deficit irrigation treatments (1800 or 1000 m^3 fed^{-1}) showed the highest values of vitamin C, total soluble solids, reducing sugars and total sugars in sweet pepper fruits. These results had the same trend in both growing seasons. The results are coincided with those of Ezzo *et al*. (2010) who indicated that the highest significant values of total soluble solids were recorded with the lowest water levels while the lowest values were recorded with the highest water level. Moreover, Mingchi *et al*. (2010) demonstrated that drought stress improved tomato fruit quality, *i.e.*, acidity, vitamin C and sugar/acid ratio.

Since Sweet pepper fruits with higher sugars have a more acceptable flavor, such character are considered as one of the important quality aspect. Water stress was reported to increase the levels of soluble sugars (glucose, sucrose, sorbitol, galactose, etc.) and total soluble proteins (Abdalla and El-Khoshiban, 2007). Therefore, the stimulatory effect of deficit irrigation on fruit quality aspects of sweet pepper may be explained by a decrease in water accumulation by the fruit without any significant modification in the quantity of the accumulated sugars (Guichard *et al*., 1999).

Concerning the effect of foliar application of magnesium carbonate, kaolin and potassium silicate applications on fruit quality characteristics of sweet pepper plants. The same data clearly reveal that foliar application of potassium silicate resulted in the highest significant values of fruit flesh thickness. Meanwhile, foliar applications of kaolin or potassium silicate tended to increase vitamin C, total soluble solids, reducing sugars and total sugars contents in pepper fruits, in both seasons of this work. The exception was that of vitamin C in the first season and total sugars in the second season which did not show any significant response. These results were in conformity with those obtained by Lynch (2008) who found that silicon increased the level of sucrose and water-soluble carbohydrates in grapes and banana.

Table 5: Effect of irrigation levels and some foliar applications as well as their interactions on fruit quality characteristics of sweet pepper plants during 2011 and 2012 seasons

Treatments		Fruit flesh thickness (mm)		Vit. C (mg 100 gm FW)		TSS (%)		Reducing sugars (mg g^{-1} DW)		Total sugars (mg g^{-1} DW)	
		1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season	1st Season	2nd Season
Irrigation levels (m^3 fed^{-1}):											
2600		4.54	4.68	105.5	102.4	5.22	5.40	10.68	10.61	30.47	30.71
1800		4.34	4.42	112.4	112.0	5.51	5.96	11.33	11.74	34.77	34.47
1000		3.95	3.97	113.4	112.5	5.57	5.94	11.50	11.75	35.74	35.87
New LSD 5%		0.171	0.211	2.84	2.97	0.157	0.187	0.192	0.247	1.12	1.11
Foliar applications:											
Control*		4.13	4.16	107.9	104.9	5.31	5.53	10.81	10.84	32.47	31.88
$MgCO_3$		4.17	4.27	109.5	106.7	5.34	5.69	11.05	11.20	33.31	33.57
Kaolin		4.48	4.63	112.8	112.6	5.56	5.93	11.44	11.67	34.92	34.84
K-silicate		4.32	4.38	111.5	111.6	5.52	5.92	11.38	11.76	33.93	34.43
New LSD 5%		0.154	0.236	NS	2.87	0.161	0.197	0.184	0.235	1.09	NS
Irrigation levels (m^3 fed^{-1}) X Foliar applications:											
2600	Control	4.45	4.49	102.4	99.12	5.04	5.27	10.08	10.19	29.26	28.28
	$MgCO_3$	4.47	4.61	104.3	99.73	5.13	5.34	10.57	10.54	30.02	31.44
	Kaolin	4.68	4.86	108.5	107.7	5.36	5.47	11.04	10.79	32.36	32.30
	K-silicate	4.58	4.75	106.8	102.9	5.34	5.53	11.02	10.91	30.25	30.80
1800	Control	4.15	4.21	109.9	107.2	5.41	5.70	11.04	11.25	33.40	32.06
	$MgCO_3$	4.22	4.36	111.9	110.9	5.38	5.92	11.20	11.58	34.22	33.86
	Kaolin	4.57	4.70	114.1	114.1	5.62	6.15	11.57	11.98	35.92	36.00
	K-silicate	4.42	4.42	113.5	115.7	5.63	6.07	11.51	12.16	35.52	35.96
1000	Control	3.80	3.77	111.5	108.5	5.49	5.61	11.31	11.07	34.75	35.31
	$MgCO_3$	3.82	3.83	112.2	109.4	5.51	5.82	11.37	11.49	35.68	35.42
	Kaolin	4.18	4.33	115.7	115.9	5.69	6.18	11.72	12.23	36.49	36.21
	K-silicate	3.98	3.96	114.3	116.2	5.59	6.16	11.60	12.20	36.03	36.52
New LSD 5%		0.181	0.223	3.16	3.04	0.174	0.191	0.201	0.269	1.24	1.10

* Plants sprayed with tap water

The positive significant effect of potassium silicate on the quality aspects of sweet pepper fruits in comparison with the other treatments may be attributed to the significant absorption of NPK nutrients (Table 3). In addition, potassium silicate is conceder as significant supplement of K, since potassium plays an important role in water status of plant, promoting the translocation of newly synthesized photosynthetics and mobilization of metabolites as well as promoting the synthesis of sugars and polysaccharides (Mengel and Kirkby, 1982).

With respect to the effect of the interaction on fruit quality characteristics of sweet pepper plants, the same data illustrate that fruit flesh thickness was significantly increased by applying 2600 m^3 fed^{-1} of irrigation water combined with kaolin or potassium silicate foliar application. On the other hand, vitamin C, total soluble solids, reducing sugars and total sugars contents recorded the highest significant values using the deficit irrigation treatments (1800 or 1000 m^3 fed^{-1}) combined with foliar application of kaolin or potassium silicate, during both seasons of the study. The results are coincided with those of Ezzat *et al*. (2009) who indicated that under insufficient water quantity, treating potato plants with kaolin as a foliar application at 4% improved tuber quality.

Economic feasibility:

The economic feasibility of cultivation sweet pepper plants as affected by irrigation levels, magnesium carbonate, kaolin and potassium silicate applications are presented in Table 6. The results showed that the highest net return (15185 LE fed^{-1}) was obtained under the irrigation with 1800 m^3 fed^{-1} combined with foliar application of kaolin; such treatment returns the highest benefit-cost ratio (2.51) in comparison with the other treatments. Therefore, this treatment considered to be economical for sweet pepper production under the conditions of the present study.

Table 6: Economic feasibility of sweet pepper production as affected by irrigation levels and some foliar applications during 2011 and 2012 seasons

Treatments		Total yield (Ton fed^{-1})(1)	Gross return (LE fed^{-1})(2)	Treatment cost (LE fed^{-1})(3)	Total variable cost (LE fed^{-1})(4)	Net return (LE fed^{-1})(5)	Benefit cost ratio(6)	Order
2600	Control	14.55	21825	1095	9890	11935	2.21	5
	$MgCO_3$	14.81	22215	1695	10490	11725	2.12	6
	Kaolin	15.86	23790	1615	10410	13380	2.29	3
	K-silicate	15.75	23625	1595	10390	13235	2.27	4
1800	Control	12.08	18120	730	9525	8595	1.90	8
	$MgCO_3$	13.01	19515	1330	10125	9390	1.93	7
	Kaolin	16.82	25230	1250	10045	15185	2.51	1
	K-silicate	16.24	24360	1230	10025	14335	2.43	2
1000	Control	8.43	12645	548	9343	3302	1.35	12
	$MgCO_3$	9.31	13965	1148	9943	4022	1.40	11
	Kaolin	10.36	15540	1068	9863	5677	1.58	9
	K-silicate	9.78	14670	1048	9843	4827	1.49	10

(1) Sweet pepper total yield as average of two seasons. **(2)** Gross return as total yield (ton fed^{-1}) x 1500 LE ton^{-1}. **(3)** Treatment cost was calculated according to the following prices: Magnesium carbonate 25 LE kg^{-1}; Kaolin = 20 LE kg^{-1}; Potassium silicate = 50 LE kg^{-1}. **(4)** Total variable cost (LE fed^{-1}) include: Treatment cost plus land leasehold, transplants, N, P and K fertilizers, microelements, pesticides, labors and other cultural practices which equal nearly 8795 LE fed^{-1}. **(5)** = **(2)**-**(4)**. **(6)**= **(2)**/ **(4)**.

Finally, this investigation imply that irrigation sweet pepper plants with 1800 m^3 fed^{-1} combined with foliar application of kaolin (4%, 4 times during the season) could be recommended to improve the vegetative growth characteristics, chemical composition, total yield, water use efficiency and fruit quality, saving about 25% of the total used irrigation water quantity in sweet pepper production. Such treatment can be recommended under drip irrigation system in clay-loam soil at northern of Nil Delta lands, giving the highest net return and benefit-cost ratio to the farmers.

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تأثير مستويات الري ومضادات النتح وسليكات البوتاسيوم على النمو والمحصول وجودة ثمار نباتات الفلفل الحلو المنزرعة تحت نظام الري بالتنقيط

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أجريت تجربتان حقليتان خلال موسمي ٢٠١١ و٢٠١٢ في مزرعة خاصة بالقرب من مدينة المنصورة، محافظة الدقهلية، مصر وذلك لدراسة تأثير ثلاثة كميات من مياه الري وهي ٢٦٠٠ م٣/فدان وتمثل الكمية التي يستخدمها المزارعين بالمنطقة (معاملة المقارنة) وكذلك مستويان من الري المُخفض وهما ١٨٠٠، ١٠٠٠ م٣/فدان مع الرش الورقي ببعض مضادات النتح (كربونات المغنيسيوم والكاؤلين) وكذلك سليكات البوتاسيوم وذلك على النمو والمحصول وجودة ثمار نباتات الفلفل الحلو المنزرعة تحت نظام الري بالتنقيط في أراضي شمال دلتا النيل.

وكانت أهم النتائج المتحصل عليها ما يلي:

- كان لاستخدام أعلي مستوي من مياه الري (٢٦٠٠ م٣/فدان) أو المستوي المُخفض (١٨٠٠ م /فدان) مع الرش الورقي بالكاؤلين أو سليكات البوتاسيوم أفضل تأثير في الحصول علي أعلي زيادة معنوية في جميع صفات النمو الخضري تحت الدراسة وتشمل سمك الساق ومعدل النمو النسبي ومعدل التمثيل الصافي والمحتوي النسبي للماء بأوراق النبات.
- أدي الري بأعلى مستوي من المياه (٢٦٠٠ م٣/فدان) مقترناً مع الرش الورقي بالكاؤلين أو سليكات البوتاسيوم وكذلك الري بأعلى مستوي من مياه الري (٢٦٠٠ م٣/فدان) أو المستوي المُخفض (١٨٠٠ م٣/فدان) مقترناً مع الرش الورقي بالكاؤلين أو سليكات البوتاسيوم إلى الحصول على أفضل تأثير معنوي فيما يخص الامتصاص الكلي لعناصر النيتروجين والفوسفور والبوتاسيوم، بينما أدي استخدام أقل مستوي من مياه الري (١٠٠٠ م٣/فدان) مقترناً مع الرش الورقي بسليكات البوتاسيوم إلى الحصول علي أعلي زيادة معنوية في محتوي الأوراق من الكلوروفيل.
- أدي استخدام المستوي المُخفض من مياه الري (١٨٠٠ م٣/فدان) مع الرش الورقي بالكاؤلين أو سليكات البوتاسيوم إلى الحصول علي أعلي زيادة معنوية في صفات المحصول متمثلة في متوسط وزن الثمرة والمحصول المبكر وكذلك المحصول الكلي للفدان وكذلك كفاءة استخدام المياه بواسطة نباتات الفلفل.
- أدي الري بأعلى مستوي من مياه الري (٢٦٠٠ م٣/فدان) مقترناً مع الرش الورقي بالكاؤلين أو سليكات البوتاسيوم إلى الحصول على أفضل تأثير معنوي فيما يخص سمك لحم الثمرة، بينما أدي استخدام الري المُخفض من المياه بمعدل ١٨٠٠ أو ١٠٠٠ م٣ /فدان مقترناً مع الرش الورقي بالكاؤلين أو سليكات البوتاسيوم إلى الحصول على أفضل تأثير معنوي فيما يخص صفات الجودة للثمار متمثلة في محتوي الثمار من فيتامين ج والمواد الصلبة الذائبة الكلية والسكريات المختزلة والكلية.
- أدي الري المُخفض لنباتات الفلفل الحلو بمعدل ١٨٠٠ م٣/فدان مع الرش الورقي بالكاؤلين إلى الحصول على أكبر عائد اقتصادي مع تحقيق أكبر قيمة لنسبة المنافع إلى التكاليف (٢.٥١) بالمقارنة مع المعاملات الأخرى وذلك تحت ظروف الدراسة.

وبناء عليه توصي هذه الدراسة بري نباتات الفلفل الحلو بمعدل ١٨٠٠ م٣/فدان مع الرش الورقي بالكاؤلين (بتركيز ٤% أربعة مرات خلال موسم النمو) وذلك للحصول على أفضل النتائج بالنسبة للمحصول الكلي وجودة الثمار وكذلك تعظيم كفاءة استخدام المياه وتقليل الاحتياجات المائية لنباتات الفلفل بمعدل ٣٠% من كمية المياه المستخدمة عند الزراعة التقليدية مع تحقيق أفضل عائد اقتصادي وذلك عند الزراعة في أراضي شمال دلتا النيل باستخدام الري بالتنقيط.

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