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Influence of Irrigation Scheduling and Foliar Application with some Antioxidants on Cabbage Yield, Quality and some Water Relations under Drip Irrigation System

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ABSTRACT

A field experiment was established at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate, Egypt during the two successive winter seasons 2018/2019 and 2019/2020 to study the effect of irrigation Scheduling; irrigation with predominant farmer's practice in the studied region as a control treatment (I_1), 1.2 (I_2), 1.0(I_3) and 0.8%(I_4) of accumulative pan evaporation (APE) and four foliar application with some antioxidants; clove oil (F_1), silica nanoparticles (F_2), peppermint oil (F_3) and distilled water as a control (F_4) on the vegetative growth characteristics, yield, quality and some water relations of cabbage under drip irrigation system. The experiments were designed as split- plot with three replications. The results indicated that the amount of applied water and water consumptive use for irrigation treatment of I_2 were increased by 12.2% and11.3 %, respectively compared to control treatment. For productivity of irrigation water interaction of I_4 x F_2 and I_4 x F_1 were recorded the highest values compared to other treatments. The highest values of leaf dry weight, leaf area, outer leaves No., inner leaves No., head diameter, head parameter, mean head weight and total head yield, moreover the concentrations of vitamin C, total soluble solids, nitrogen percentage (N%), phosphorous (P%) percentage and potassium percentage (K%) on cabbage heads were recorded after I_2 compared to all irrigation treatments, as well as after F_2 compared to all foliar application treatments. It could be concluded that the highest values were recorded under the application of I_2 x F_2 interaction because it enhanced cabbage yield and its quality.

Keywords: irrigation Scheduling, water productivity, cabbage, silica nanoparticles, essential oils

INTRODUCTION

Cabbage (*Brassica oleracea* var. capitata) belongs to the family of crucifer, it is consumed mainly as leafy vegetable with great nutritional value. It is a rich source of minerals, protein, vitamins, amino acids, carbohydrates and antioxidantss (Atanasova, 2008). Nowadays, water-shortage is a worldwide problem, especially in arid and semi-arid regions like Egypt, which is limiting agriculture and averts plants from yielding their full genetic potential. Accordingly, to cope with the water-shortage, it is necessary to adopt water saving agriculture counter measures as efficient use of irrigation water is becoming increasingly important. Scheduling irrigation is an important on-farm management practice to guarantee optimum soil moisture status for appropriate plant growth and development as well as optimum yield, water productivity and economic benefits, moreover saves resources of water and energy through applying the exact amount of water needed to replenish the soil moisture to desire level. Also, it is the simplest case based on farmers' experience. It is defined as deciding when to irrigate (the right time) and how much water should apply (the right quantity or amount), that it mainly depending on micro climate. Irrigation scheduling by using the meteorological approach is linking the crop evapotranspiration to evaporation from an open pan, as it is well known that the rate of evapotranspiration is related to the evaporation from open pan (Himanshu *et al.*, 2012). The meteorological approach such as cumulative pan evaporation, pan evaporation replenishment, and ratio between irrigation water and cumulative pan evaporation play very essential role in irrigation scheduling (Mgadala *et al.*, 1995). Irrigation scheduling can increase net income of cabbage production through reduced irrigation cost and increase irrigation efficiency (Fardad and Golgar 2002), and increase marketable yield (Seidel *et al.*2017).

Cabbage has been classified as intermediately susceptible to water stress, the period before head formation is being less sensitive than head formation period (Adeniran *et al.*, 2010). water is a critical stress factors for the cabbage, due to its effect on plant growth, photosynthesis, marketable production and quality (Nyatuame *et al.,* 2013). Increasing the water application, increased significantly cabbage leaf weight, head weight, head diameter, and marketable yield (McKeown *et al.,* 2010). While, less watered treatments were produced more gloomy and crooked heads. Numerous studies had reported that water deficit reduced canopy development, crop growth, dry matter accumulation, plant height, leaves fresh weight and head weight of cabbage plant (Ibrahim al., 2011; Nyatuame *et al.*, 2013 and XU and Leskovar, 2014). So that, the influence of water deficit stress can be detected in smaller leaves or plant height, reduction in leaves area, light absorption and decreasing in total capacity of photosynthesis and which reflected negatively on cabbage growth. (Xu and Leskovar, 2014; Verma *et al.*,

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2017). The authors stated that white cabbage requires a high water demand and mainly the head volume is influenced by water application. They suggested that drought stress during frame development and the early stages of head development may influence yield by reducing frame size and restriction of head leaf expansion (Seidel *et al.*, 2017).

Due to consumer demand, the use of natural compounds has notably increased (Lanciotti *et al.*, 2004). The application of essential oils as natural antimicrobial and antioxidants agents in fresh vegetables may be an alternative to chemically based techniques (Mousavizadeh *et al.*, 2011). One of the most common plant responses to stress is an increase in the concentration of reactive oxygen species (ROS). Plant tissues have an effective defense mechanism against damage caused by ROS (Słowianek and Leszczyńska, 2016). Free oxygen radicals, produced as the usual secondary consequence of environmental stresses, are very dangerous for cell components and must be precisely regulated (Sankar *et al.*, 2007. Shao *et al.*, 2009). Antioxidantss of low molecular weight react directly with the reactive forms of oxygen or indirectly with metabolites of redox reactions, preventing the ROS from formatting (Gill and Tuteja, 2010 and Sharma *et al.*, 2012). Eugenol, β-caryophylene, eugenyl acetate, α-humulene and humulene epoxide were the main components of clove oil (Jirovetz *et al.*, 2006 and Gupta *et al.*, 2015). These components have antioxidants activity and potent ability of free radical scavenging, thus it can help plants to overcome adverse stresses (Sohilait and Kainama, 2019). Cloves have very strong antioxidants activity of 94.9%, and high levels of phenols, thus it has strong free-radical scavenging activity (Słowianek and Leszczyńska, 2016). Peppermint oil also, contain antioxidants, but it measured low to moderate levels of phenolics with antioxidants activity (Zheng and Wang, 2001). The main constituents of peppermint oil are menthol and menthone, further components were menthyl acetate, 1,8-cineole, limonene, β-pinene and β-caryophyllene. Peppermint oil possessed antiradical activity and exercising stronger antioxidants impact on the radical (Schmidt *et al.*, 2009).

Silicon (Si) is the second most abundant element in the soil, and it's not considered an essential element. The Si treatments were considered beneficial to plant growth and production. Recently, some studies have shown that treatment with silicon significantly alleviated salt, drought, chilling and freezing stress in plants (Liang *et al.* 2007; Ma and Yamaji 2008), in addition, Si plays a key role in a number of metabolic and physiological activities in plants (Bao *et al.*, 2004), Si has enhanced water stress tolerance in plants by retaining leaf water potential, leaves erectness, stomatal conductance, the structure of xylem vessels under high transpiration rates, and photosynthetic activity (Gong *et al.*, 2003). Parveen and Ashraf (2010) found that exogenously applied Si significantly enhanced plant water use efficiency and slightly increased photosynthetic rate under saline stress condition in maize. The importance of Si for improving plant growth was also to increase the water use efficiency in plant (Romero-Aranda *et al.*, 2006). Karuppanapandian *et al*. (2011) reported that Si improves antioxidants system which minimizes ROS generation and ROS scavenging, consequently inhibits lipid peroxidation. Abdel-Haliem *et al*., (2013) concluded that Si plays a beneficial effect of application on both enzymatic and non-enzymatic antioxidants systems

But the best of our knowledge, no studies addressed the interaction effect of irrigation scheduling and Silica nanoparticles and essential oils as antioxidants. So, the objective of this work is to study the effect of different irrigation scheduling treatments using simple and applicable method and foliar application of some antioxidants under drip irrigation on yield, yield quality and productivity of irrigation water for cabbage plant.

MATERIALS AND METHODS

Experimental site:

A field experiment was performed at Sakha agricultural research station, Kafr El-Sheikh governorate, Egypt during 2018/2019 and 2019/2020 growing seasons to study the effect of irrigation scheduling treatments and foliar application with some antioxidants on the vegetative growth characteristics, yield, quality and some water relations of cabbage under drip irrigation system. The metrological characteristics data for both the two studied seasons were collected from Sakha agro-metrological station as shown in Table (1).

Table 1. Some agro-meteorological data for Sakha region, (31° 07' N Latitude, 30° 55' E Longitude), during 2018/2019 and 2019/2020 season.

Months		T (c°)			RH (%)			U_2 *km d⁻¹*	Pan	R.F
		Max.	Min.	Mean	Max.	Min.	Mean		Evap. (mm/day)	mm/ month
2018/2019	Nov.	25.00	17.40	21.20	86.60	54.60	70.60	24.20	1.60	---
	Dec.	19.50	13.90	16.70	88.70	62.40	75.55	24.50	0.83	21.70
	Jun.	18.90	12.30	15.60	82.30	53.30	67.80	33.10	1.14	14.90
	Feb.	19.70	14.30	17.00	86.90	58.20	72.55	28.60	1.78	17.60
	March	21.70	17.60	19.65	87.80	56.60	72.20	45.70	2.86	17.30
2019/2020	Nov.	27.40	25.10	26.25	82.80	48.30	65.55	36.60	2.31	------
	Dec.	21.40	13.40	17.40	86.90	58.90	72.9	38.50	2.56	60.68
	Jun.	18.40	11.80	15.10	86.70	62.70	74.4	30.00	2.08	67.50
	Feb.	20.40	12.70	16.55	84.60	56.50	70.55	51.00	1.83	14.30
	March	22.60	15.60	19.10	81.1	53.9	67.50	80.10	5.11	60.80

Soil samples were analyzed at Soils, Water and Environment Research Institute (SWERI), Agricultural Research Center (ARC). Soil particle size distribution and bulk density were determined as described by Klute (1986). Field capacity, permanent wilting point and available water characters were determined according to James (1988). Chemical characteristics of soil were determined as described by Jackson (1973) as shown in Table (2).

Table 2. Average values of some physical and chemical soil properties for the experimental site as mean values of the two growing seasons.

Soil layer depth (cm)	Particle size distribution Sand%	Silt%	Clay%	Textural classes	Bulk density (Kgm^{-3})	Soil- water constant F.C [1] (%,wt/wt)	P.W.P [2] (%,wt/wt)	A.W [3] (%,wt/wt)
0-20	11.50	26.40	62.10	Clayey	1.16	43.20	23.40	19.80
20-40	12.60	28.40	59.00	Clayey	1.17	42.30	22.80	19.50
40-60	16.80	30.70	52.50	Clayey	1.20	39.90	21.60	18.30
Mean	13.63	28.50	57.87	Clayey	1.18	41.80	22.60	19.20

Chemical Soil characteristics

	pH 1:2.5 S.W.S 4	EC dSm^{-1}	Soluble cations, $meqL^{-1}$ Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Soluble anions, $meqL^{-1}$ CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{-5}
0-20	8.10	1.88	3.95	3.86	10.40	0.54	-	4.60	11.30	2.85
20-40	8.12	2.22	4.22	3.98	13.62	0.42	-	4.90	10.08	7.26
40-60	8.13	2.63	4.78	4.32	16.82	0.41	-	6.80	9.88	9.65
Mean	-	2.24	4.32	4.05	13.61	0.46	-	5.43	10.42	6.59

1 = Soil field capacity, 2 = Permanent wilting point,3 = Available soil water, 4 =soil water suspension and 5= SO_4^{--}calculated by difference

The seeds of Cabbage *Brassica-oleracea-Var. Cabitata L cv.* (Brunswick) were sown in the greenhouse 27 days before transplanting, in both seasons into a mixture of vermiculite and peat moss (2:1), the seedlings were transplanted on 4th and 6th of November in the first and the second seasons, respectively, with 0.50 m between each two plants on the ridge and 0.7 m between the ridges and the plot area was (24.0 m length x 3.5 m width) = 84.0 m^2. All other agricultural practices were done according to recommendations of Ministry of Agriculture, Egypt.

Experimental design and treatments:

The experiment was designed as split- plot with three replications as follow:

Main plot: Irrigation scheduling treatments (I):

I_1: Irrigation with the same like the predominant farmer's practice in the studied region as a control,

I_2: Irrigation with 1.2 of a cumulative pan evaporation (APE),

I_3: irrigation with 1.0 (APE)and

I_4: Irrigation with 0.8 (APE).

Sub plot: Foliar application with some antioxidants (F):

F_1 : Clove oil (Syzygium aromaticum L.), it was used at rate 150 cm/200 $Lfed^{-1}$.

F_2: Silica nanoparticles were used at 300 ppm/200 L $fed.^{-1}$. It obtained from Nanotech Egypt Company Limited, Cairo, Egypt. The size was 20 nm with a purity of 99.99%.

F_3: Peppermint oil (Mentha piperita L.), it was used at rate 150 cm/200 L $fed.^{-1}$. The plant extract of peppermint and clove oil were obtained from Al-Badawia Company (commercial preparation).

F4: Control (foliar spray with distilled water).

Foliar application with some antioxidants adds two times after 30 and 60 days after transplanting.

Irrigation system:

The drip irrigation system was consisted of normal polyethylene pipes of 16 mm diameter as laterals with line dripper of 4 Lh^{-1} at 50 cm apart. The laterals were located 70 cm apart, one lateral for each plant row. Irrigation water was filtered through gravel filters and re-filtered through screen filters.

Applied Irrigation Water (AIW):

The amount of applied irrigation water, at each irrigation treatment was calculated from cumulative pan evaporation. The potential evapotranspiration (ETo) was calculated according to the following formula (Doorenbos and Pruitt, 1977):

$$ET_o = K_p \text{ x } E_{pan} \quad \text{mm day}^{-1}$$

Where: **ET_o = Reference evapotranspiration in mm day^{-1}.**

K_p = (Pan coefficient) which was considered as 0.85 for pan Evaporation.

E_{pan} = Evaporation from pan surface.

Water relations:

1- Water consumptive use, cm:

Water consumptive use was calculated as soil moisture depletion (SMD) according to Hansen *et al.* (1979).

$$CU = SMD = \sum_{i=1}^{i=N} \frac{\theta_2 - \theta_1}{100} * Dbi * Di$$

Where:

CU = Water consumptive use in the effective root zone, cm

θ_2 = Gravimetric soil moisture percentage 48 hours after irrigation,

θ_1= Gravimetric soil moisture percentage before irrigation,

Dbi = soil bulk density (Mg m^{-3}) for the given depth,

D_i = soil layer depth (20 cm),

i = number of soil layers each (20 cm) depth and

2- Consumptive use efficiency (Ecu%):

The consumptive use efficiency (Ecu) was calculated as described by Doornbos and Pruitt (1977) as follows:

$$Ecu = \frac{ETc}{AW} \text{ x } 100$$

Where:

Ecu = Consumptive use efficiency%

ETc = Total evapotranspiration ~ consumptive use (m^3ha^{-1}), and

AW = Applied water to the field (m^3ha^{-1}).

3- Productivity of irrigation water (PIW)

The Productivity of irrigation water in kg marketable yield per m^3 of the applied water was calculated according to (Ali *et al.*, 2007), as follows:

$$PIW\ (kg\ m^{-3}) = \frac{\text{Marketable yield (heads yield) in kg ha}^{-1}}{\text{Amount of applied water m}^3 \text{ ha}^{-1}}$$

Where, amount of applied water = irrigation water + effective rainfall

Note: effect rainfall = rianfall*0.7 (Novica, 1979)

Recorded data:

Yield and its component:

The yield was calculated during the harvest, many parameters were evaluated in both seasons of the study as follows: Ten plant samples were taken randomly to measure the growth criteria such as leaves dry weight, leaf area, outer leaves No, inner leaves No, head diameter(cm), head parimeter (cm), mean head weight (kg) and total head yield (ton fed^{-1}).

Chemical analyses*:*

Vitamin C %, Total soluble solids, % were determined in fresh juice using Refract meter. Representative samples of heads (inner part) were dried in an electric oven at 70°C until constant weight. In addition, the digested dry matter was taken for chemical determinations. Nitrogen (%) was determined in the digestion product using the micro-kjeldahl method (AOAC, 1980). Phosphorus (%) was determined colorimetrically at 725 µm (King, 1951). Potassium (%) was determined using a flame photometer (Jackson, 1973).

Statistical analysis:

Data obtained from experimental treatments were subjected to the analysis of variance (ANOVA) using COSTAT software, differences between treatments means were compared using Duncan's multiple range test at 5% level of significance (p= 0.05) according to Snedecor and Cocharn (1989).

RESULTS AND DISCUSSION

1. Water relations

1. Applied water (AW):

Data in Table (3) showed that the effect of irrigation scheduling, foliar application treatments and interaction between them on seasonal applied water. The mean seasonal applied water for the two studied seasons were taken the descending order $I_2 > I_1 > I_3 > I_4$. Applied water for scheduling irrigation treatment of I_2 was increased by 12.2 % compared to farmer treatment, while it reduced by 3.7% and 19.6% for I_3 and I_4 respectively compared to farmer treatment as mean of both seasons.

Table 3. Seasonal applied water as influenced by irrigation scheduling, foliar application with antioxidants treatments during the two growing seasons.

Treatments		Seasonal applied water					
		AW ($m^3 fed^{-1}$)			AW (cm)		
Applied water	Foliar application	2018/2019	2019/2020	mean	2018/2019	2019/2020	mean
I_1	F_1	1755.5	1978.8	1867.2	41.80	47.11	44.46
	F_2	1755.5	1978.8	1867.2	41.80	47.11	44.46
	F_3	1755.5	1978.8	1867.2	41.80	47.11	44.46
	F_4	1755.5	1978.8	1867.2	41.80	47.11	44.46
Mean I_1		1755.5	1978.8	1867.2	41.80	47.11	44.46
I_2	F_1	1961.3	2227.1	2094.2	46.70	53.03	49.87
	F_2	1961.3	2227.1	2094.2	46.70	53.03	49.87
	F_3	1961.3	2227.1	2094.2	46.70	53.03	49.87
	F_4	1961.3	2227.1	2094.2	46.70	53.03	49.87
Mean I_2		1961.3	2227.1	2094.2	46.70	53.03	49.87
I_3	F_1	1672.4	1923.5	1798.0	39.82	45.80	42.81
	F_2	1672.4	1923.5	1798.0	39.82	45.80	42.81
	F_3	1672.4	1923.5	1798.0	39.82	45.80	42.81
	F_4	1672.4	1923.5	1798.0	39.82	45.80	42.81
Mean I_3		1672.4	1923.5	1798.0	39.82	45.80	42.81
I_4	F_1	1383.5	1619.9	1501.7	32.94	38.57	35.76
	F_2	1383.5	1619.9	1501.7	32.94	38.57	35.76
	F_3	1383.5	1619.9	1501.7	32.94	38.57	35.76
	F_4	1383.5	1619.9	1501.7	32.94	38.57	35.76
Mean I_4		1383.5	1619.9	1501.7	32.94	38.57	35.76
Mean I		1693.2	1937.3	1815.3	40.31	46.13	43.22

According to previous literatures on average 2.57 - 5.81 mm day^{-1} of crop water requirement is more observable for cabbage production. The average irrigation water requirements were 553, 596 and 713 mm for cabbage planted on 1st of October, 11th of November, and 21st of December respectively. Soil moisture depletion in most climates should not exceed 30% to 35% of the total available soil water to obtain the optimum cabbage yield (Beshir, 2017). The gross irrigation water requirement was almost 8 mm day^{-1}, it is sufficient for crop production and to prevent eventual salinization in the soil. But it depends on local soil and water conditions (Sitta, 2011).

2. Water consumptive use and consumptive use efficiency

Data in Table (4) shows that there are significant differences of water consumptive use between different irrigation scheduling treatments, application with antioxidants and the interaction between them. Irrigation scheduling treatment of I_2 was recorded the highest values of water consumptive use, it increased by 11.3 % compared to farmer treatment. while irrigation treatment of I_4 was recorded the lowest values, it decreased water consumptive use by 21.1% compared to farmer treatment as an average of both seasons. The values of water consumptive use were affected by the application of some antioxidants and taken the descending order $F_2 > F_1 > F_3 > F_4$ to be 40.31, 39.51, 38.20 and 37.53 cm for F_2, F_1, F_3 and F_4 respectively as a mean of the two seasons. The highest value of water consumptive use (46.29 cm) was obtained after $I_2 \times F_2$ interaction, while the lowest value (30.23 cm) was recorded for $I_4 \times F_4$ interaction as mean of both seasons. This may be due to the high leaves area index of white cabbage, which leading to relatively high transpiration rates and in turn contributes to fast soil drying (Seidel et al.2017). Also, deficit irrigation significantly reduced stomata conductance, transpiration, photosynthetic rate and marketable yield (Xu and Leskovar 2014). Irrigation scheduling practice affected total consumptive water use and leaf yield Chinese cabbage (van Averbeke and Netshithuthuni

2010). The seasonal evapotranspiration of cabbage crop was estimated in Nigeria to be 33.9 cm Adeniran et al., 2010.

Concerning consumptive use efficiency (Ecu) is a parameter which indicates the capability of plants to utilize the soil moisture stored in the effective roots zone. Consumptive use efficiency (Ecu) as affected by the adopted irrigation scheduling and foliar application is presented in Table 4. Data revealed that the highest Ecu value was noticed under irrigation with 1.0 APE (I_3) to be 91.26% and 91.69% in the first and second seasons respectively. These results are in a great agreement with those obtained by Darwesh and farrag (2014) they concluded that by decreasing the applied water, higher amount of irrigation water could be beneficially used by the growing plants which resulting in decreasing water losses.

Data in the same Table indicated that foliar application with silica nanoparticles (F_2) recorded the highest values under all deficit irrigation treatments. Regarding the interaction effect between irrigation scheduling and foliar application with antioxidants, the interaction of I_3 x F_2 achieved the highest values of Ecu in the first and second season.

A positive linear relationship was obtained between applied water and consumptive use (Fig 1). They are highly significant (with correlation coefficient values, r = 0.99 and 0.99 in the first and second seasons respectively. The positive relationship indicated that consumptive use increased, when the applied water increased. These results are agreement with Darwesh *et al.*, (2020)

Table 4. Consumptive use (cm), consumptive use efficiency (Ecu) as affected by irrigation scheduling and foliar application with antioxidants in the two growing seasons

Treatments		Water relations					
		CU (cm)			Ecu (%)		
Applied water	Natural application	2018/19	2019/20	Overall mean	2018/19	2019/20	Overall mean
I_1	F_1	38.10	43.10	40.60	91.15	91.48	91.32
	F_2	38.95	43.56	41.26	93.19	92.46	92.82
	F_3	36.52	42.52	39.52	87.37	90.25	88.81
	F_4	36.20	41.85	39.03	86.61	88.83	87.72
Mean I_1		37.44	42.76	40.10	89.57	90.76	90.17
I_2	F_1	42.60	48.00	45.30	91.23	90.52	90.87
	F_2	43.90	48.67	46.29	94.01	91.78	92.90
	F_3	41.20	46.25	43.73	88.23	87.22	87.72
	F_4	40.45	45.95	43.20	86.62	86.66	86.64
Mean I_2		42.04	47.22	44.63	90.03	89.05	89.54
I_3	F_1	36.70	42.95	39.83	92.17	93.78	92.97
	F_2	37.55	43.55	40.55	94.30	95.09	94.70
	F_3	36.00	41.20	38.60	90.41	89.96	90.19
	F_4	35.10	40.25	37.68	88.15	87.89	88.02
Mean I_3		36.34	41.99	39.17	91.26	91.69	91.47
I_4	F_1	30.10	34.50	32.30	91.38	89.45	90.41
	F_2	31.00	35.26	33.13	94.11	91.42	92.76
	F_3	28.90	33.00	30.95	87.73	85.56	86.65
	F_4	28.05	32.40	30.23	85.15	84.01	84.58
Mean I_4		29.51	33.79	31.65	89.59	87.61	88.60
Mean I		36.33	41.44	38.89	90.12	89.84	89.98

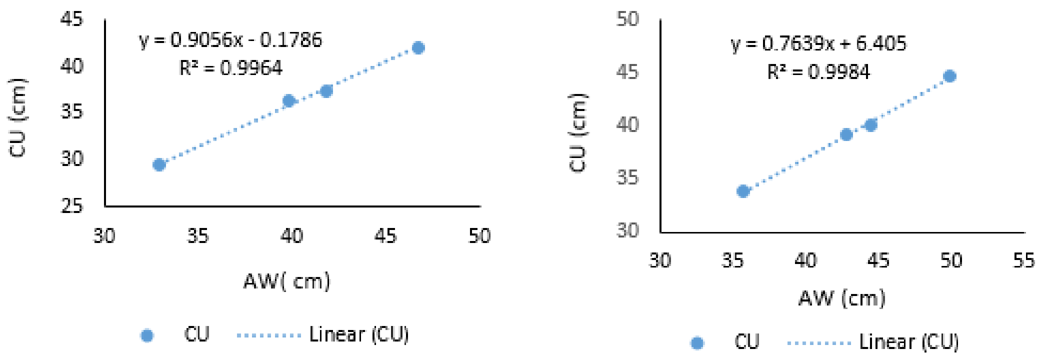

Fig. 1. Correlation between irrigation water applied (cm) and water consumed (cm) overall foliar application with antioxidants in the two growing seasons.

3.Productivity of irrigation water (PIW, Kg m^{-1})

Productivity of irrigation water as shown in Table (5) differs significantly between different irrigation scheduling treatments and foliar application with antioxidants, as well as the interaction between them. The highest values of productivity of irrigation water were found after I_4 and it were taken the descending order $I_4 > I_1 > I_3 > I_2$. Theses result were taken the same trend with those obtained by Himanshu *et al.*, (2012) they found that irrigation production efficiency decreases significantly with increase in irrigation level, it was taken the descending order 25% > 75% > 125 % > 175% of pan evaporation replenishment.

That mean the optimal irrigation water supply is a key to highly efficient water use of horticulture plants and the reduction of off-site effects due to percolation of excess water (Seidel *et al*. 2017). Foliar application of F_2 was recorded the highest values of productivity of irrigation water compared to all foliar application treatments in both growing seasons. The interaction of I_4 x F_2 and I_4 x F_1 were recorded the highest values of productivity of irrigation water compared to other treatments.

Table 5. Effect of irrigation scheduling and foliar application with antioxidants on productivity of irrigation water in both growing seasons

Treatments	Productivity of irrigation water (kg m^{-3})									
	2018/2019					2019/2020				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
I_1	23.43 be	23.95 bc	23.05 de	22.80 e	23.31 b	19.80 c	20.63 b	19.10de	18.68def	19.55 b
I_2	22.08 f	23.50b-e	21.33gh	21.08 h	21.99 d	18.58efg	19.20d	18.03 g	17.45 h	18.31 d
I_3	23.30cde	24.10 b	21.88 fg	21.15 h	22.61 c	19.05 de	20.05 c	18.45 fg	18.03 g	18.89 c
I_4	25.28 a	25.85 a	24.03 b	23.60 bcd	24.69 a	20.90 b	21.88 a	19.90 c	19.10 de	20.44 a
Mean	23.52 b	24.35 a	22.57 c	22.16 c		19.58 b	20.44 a	18.87 c	18.31 d	

2. Cabbage vegetative growth parameters:

Leaves dry weight, leaf area, outer leaves No. and marketable fresh inner leaves No. as influenced by irrigation scheduling treatments and foliar application are shown in Table (6). There are significant differences were found of abovementioned vegetative growth parameters between different irrigation scheduling, application with antioxidants treatments and the interaction between them in the two studied seasons. The highest values of leaves dry weight, leaf area, outer leaves No., and inner leaves No., were recorded for irrigation treatment of I_2 (1.2 APE), while the lowest values of these traits were found of I_4 (0.8 APE) compared to the all studied irrigation treatments in the 1st and 2nd seasons. Irrigation scheduling affected both total consumptive water use and marketable fresh leaves yield of Chinese cabbage and that leaf yield was strongly correlated with total consumptive water use (van Averbeke and Netshithuthuni 2010). Deficit irrigation reduced plant size, leaf area, fresh weight, relative water content and specific leaf area of cabbage (Xu and Leskovar 2014). This may be due to cabbage has been classified as intermediately susceptible to water stress, with the head formation period being more sensitive than the period before Adeniran *et al*., 2010

Table 6. Effect of irrigation scheduling, foliar application with antioxidants treatments and the interaction between them on vegetative growth traits of cabbage plants during 2018/2019 and 2019/2020 growing seasons.

Treatments	Leave dry weight (g)									
	1st season					2nd season				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
I_1	7.76 cd	7.93 cd	7.52 de	7.18 ef	7.60 c	7.62 g	7.95 f	7.42 h	7.18 i	7.54 c
I_2	9.07 b	9.74 a	8.80 b	8.17 c	8.94 a	9.01 ab	9.13 a	8.83 bc	8.65 cd	8.90 a
I_3	7.92 cd	8.81 b	8.11 c	8.12 c	8.24 b	8.66 cd	8.85 b	8.52 d	8.22 e	8.56 b
I_4	7.11 ef	7.48 de	7.00 fg	6.58 g	7.04 d	8.86 d	7.00 j	6.6 k	6.34 L	6.7 d
Mean	7.96 b	8.49 a	7.86 b	7.51 c		8.04 b	8.23 a	7.84 c	7.59 d	
	leaf area (cm^2)									
I_1	37.00def	38.06 d	35.64 fg	35.42 fg	36.53 c	36.28 gh	39.28 f	35.08 id	35.13 id	36.44 c
I_2	44.93 a	45.38 a	41.88 b	40.18 c	43.09 a	46.24 a	46.84 a	44.59 b	42.40 c	45.02 a
I_3	39.83 c	42.88 b	37.64 de	36.61 ef	39.19 b	40.15 e	41.28 d	39.28 f	38.58 f	39.82 b
I_4	34.70 g	35.78 fg	34.53 g	34.58 g	34.89 d	35.60 hi	36.78 g	36.48 g	34.60 j	35.86 d
Mean	39.11 b	40.52 a	37.42 c	36.64 d		39.57 b	41.04 a	38.85 c	37.68 d	
	Outer leaves No.									
I_1	13.50def	13.75cde	13.25efg	12.75fg	13.31 c	14.25 ab	14.25 ab	13.75 bc	13.25 cd	13.88 a
I_2	15.00 b	15.75 a	14.50bc	14.25bed	14.88 a	14.25 ab	14.50 a	13.75 bc	13.25 cd	13.94 a
I_3	14.00cde	14.50 bc	13.50def	13.50def	13.88 b	13.25 cd	13.50 c	12.75 de	12.25 e	12.94 b
I_4	12.50 g	13.25efg	11.75 h	11.25 h	12.19 d	12.25 e	12.50 e	11.50 f	11.25 f	11.88 c
Mean	13.75 b	14.31 a	13.25 c	12.94 c		13.50 a	13.69 a	12.94 b	12.50 c	
	Inner leaves No.									
I_1	108.25 d	110.00 c	105.50 e	103.25 f	106.75b	103.25 d	104.25cd	101.25 e	100.50 e	102.31 b
I_2	112.75 b	116.00 a	111.5be	110.00 c	112.56a	107.00ab	108.75 a	105.75bc	104.00cd	106.38 a
I_3	100.25 g	103.00 f	98.00 hi	96.50 ij	99.44 c	99.25 e	101.25 e	95.25 f	93.25 g	97.25 c
I_4	96.75 hij	98.25 h	95.25 ij	92.00 k	95.56 d	93.00 g	95.25 f	91.00 h	90.5 h	92.44 d
Mean	104.50 b	106.81 a	102.56 c	100.44 d		100.63 b	102.38 a	98.31 c	97.06 d	

As well as, application with antioxidants; Silica nanoparticles, clove oil and peppermint oil significantly increased leaves dry weight, leaves area, outer leaves No., and marketable fresh inner leaves No., of cabbage plant compared to control (application with distilled water), foliar application treatment of silica nanoparticles was achieved the highest values of theses vegetative growth parameters followed by clove oil. The enhancement of growth parameters by foliar application of silica nanoparticles can be attributed to promotion of some elements transport in xylem sap as Fe, Mg, etc., improvement water and fertilizers uptake capacity, stimulation of some key enzymes activity such as nitrate reductase, increase the concentration of Indole-3-acetic acid and enhanced antioxidants activity and indicated that nanoparticles mediated effect on plants growth and development is concentration dependent (Laware and Shilpa, 2014 and Le *et al*., 2014).

The interaction between the different irrigation scheduling and application with antioxidants were recorded significant differences of leaves dry weight, leaf area, outer leaves No., and inner leaves No., of 2018/2019 and 2019/2020 growing seasons. The highest values of leaves dry weight, leaf area, outer leaves No., and inner leaves No., were found of I_2 x F_2 interaction followed by I_2 x F_1 interaction, while the lowest values of the same vegetative growth parameters were obtained of I_4 x F_4 interaction on the two studied seasons. A significant reduction of vegetative growth characters i.e. foliage weight, Plant height, number of leaves, leaves fresh weight and leaf area were happened when irrigation water deficit was increased (Metwaly, and El-Shatoury 2017) as shown in Table (6).

3. Yield and its components

Head diameter, head parimeter, mean head weight and total head yield as affected by irrigation scheduling, application with antioxidants treatments and the interaction between them are presented in Table (7). There are significant differences were found of cabbage yield and its components between different irrigation scheduling, different foliar application treatments and the interaction between them. Irrigation scheduling of I_2 was increased head diameter, head parimeter, mean head weight and total head yield by 3.4%, 2.8%, 3.9% and 5.4% respectively compared to farmer treatment, while irrigation treatments of I_3 and I_4 were reduced these parameters ranged from 3.3% to 15.5% as mean of the two seasons compared to I_1. These results are agreed with those obtained by Himanshu *et al*., (2012), they reported that the highest mean head weight (2.26 kg) and marketable yield of cabbage (90.51 t ha^{-1}) were obtained when irrigation was applied at 175% of pan evaporation replenishment, while they were reduced when decrease the percentage of pan evaporation replenishment, they were taken the descending order 125% >75% >25% of pan evaporation replenishment. More applied water treatments significantly increased yield and quality of cabbage, while less watered treatments formed more crooked and gloomy heads (Nyatuame *et al*., 2013 and Xu and Leskovar 2014). The highest dry matter and yield were increased with the increase of irrigation level (Gao *et al*., 2017) Increasing applied water were increased significantly cabbage head weight, head diameter and marketable yield (McKeown *et al*., 2010). Regarding, irrigation treatments of 100%ETc achieved the highest head width, head length, head density, head volume along with fresh and dry weight (Abdrabbo *et al*., 2015).

Table 7. Effect of irrigation scheduling, foliar application with antioxidants treatments and the interaction between them on yield traits of cabbage plants on the 1st and 2nd seasons.

Treatments	Head diameter (cm)									
	1st season					2nd season				
	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
I_1	19.88 bc	20.38 b	19.50 cd	19.13 de	19.72 b	18.75bcd	19.25 b	18.13 ef	17.88efg	18.50 b
I_2	20.50 b	21.50 a	19.98 bc	19.63 cd	20.40 a	19.25 b	20.00 a	18.88 bc	18.38cde	19.13 a
I_3	18.75 ef	19.38cde	18.38 fg	17.88 gh	18.59 c	17.63fgh	18.25 de	17.25 hi	17.00i	17.53 c
I_4	17.63 h	18.75 ef	17.38 hi	16.88 i	17.66 d	17.13 hi	17.38ghi	16.50 j	16.25 d	16.81 d
Mean	19.19 b	20.00 a	18.81 c	18.38 d		18.19 b	18.72 a	17.69 c	17.38 d	
	Head parimeter (cm)									
I_1	80.00 cd	81.38 c	79.00 de	77.75 ef	79.53 b	73.13 cd	74.38 bc	71.63efg	70.50 gh	72.41 b
I_2	82.75 b	84.38 a	80.88 c	80.25 cd	82.06 a	74.75 b	76.50 a	73.13 cd	72.13def	74.13 a
I_3	77.25 fg	78.25 ef	75.50 h	73.13 i	76.03 c	71.00fgh	72.63 de	70.75 gh	69.13 i	70.88 c
I_4	73.75 i	78.13 gh	71.75 j	71.25 j	73.22 d	67.25 j	70.00 hi	65.50 k	64.00 L	66.69 a
Mean	78.44 b	80.03 a	76.78 c	75.59 d		71.53 b	73.38 a	70.25 c	68.94 d	
	Mean head weight (kg)									
I_1	3.71 cd	3.64 de	3.66 de	3.63 e	3.66 b	3.48 d	3.60 b	3.53 c	3.42 e	3.51 b
I_2	3.84 ab	3.90 a	3.80 b	3.78 bc	3.83 a	3.63 b	3.67 a	3.62 b	3.59 b	3.62 a
I_3	3.35 g	3.44 f	3.33 g	3.28 gh	3.35 c	3.41 e	3.42 e	3.36 f	3.33 fg	3.38 c
I_4	3.19 i	3.21 hi	3.17 i	3.13 i	3.17 d	3.31 g	3.33 fg	3.23 h	3.11 i	3.24 d
Mean	3.52 ab	3.55 a	3.49 bc	3.45 c		3.45 b	3.50 a	3.44 b	3.36 c	
	Total head yield (ton $fedd^{-1}$)									
I_1	41.10 cd	42.06 c	40.48 de	40.00 e	40.91 b	39.16 de	40.84 bc	37.77 fg	36.96 gh	38.68 b
I_2	43.25 b	46.10 a	41.80 c	41.30 cd	43.11 a	41.43 b	42.78 a	40.15 cd	38.89 e	40.81 a
I_3	38.98 f	49.31 de	36.61 g	35.40 h	37.82 c	36.68 h	38.58 ef	35.51 i	34.65 ij	36.35 c
I_4	34.96 h	35.79 gh	33.23 i	32.64 i	34.15 d	33.89 j	35.43 i	32.21 k	30.94 L	33.12 d
Mean	39.57 b	41.06 a	38.03 c	37.33 d		37.79 b	39.40 a	36.41 c	35.36 d	

Foliar application with antioxidants increased head diameter, head parimeter, mean head weight and total head yield by 4.5%, 3.8%, 2.4% and 6.4% respectively for F_1, 8.3%, 6.1%, 3.5% and 10.7% respectively for F_2, and 2.1%, 1.7%, 1.8% and 2.4% respectively for F_3 as mean of both seasons compared to F_4 (foliar application with distilled water). Increasing yield resulted from Si application could be due to increased leaves dry weight, leaves No., leaf area, yield attributes, and photosynthetically active area. A positive influence of Si on crop yield has been reported by Silva *et al*., (2012) on tomato. In this concern, El-Samahy *et al*. (2014) reported a significant increment of total soluble solids and yield of tomato fruits as a result of the silica nanoparticles compared to control without any treatment. The increment of head diameter, head parimeter, mean head weight and head weight under clove oil and peppermint oil application may be due to the antioxidants activity and potent ability of free radical scavenging, thus it can help plants to overcome adverse stresses (Schmidt *et al*., 2009 and Sohilait and Kainama, 2019).

The interaction between scheduling irrigation and foliar application with antioxidants affected significantly head diameter, head parimeter, mean head weight and total head weight, the highest values of these characteristics were recorded for I_2 x F_2 interaction, while the lowest values of these parameters were found after I_4 x F_4 interaction on both seasons. The reduction of marketable yield may be due to the influence of deficit irrigation, which decreased plant growth and size, leaf characteristics, leaf area, relative water content, fresh weight, specific leaf area and gas exchange during development, water content, stomata conductance, transpiration, photosynthetic rate and decreased head fresh weight, size marketable and total yield (Xu and Leskovar 2014, and Metwaly and El-Shatoury 2017). The interaction of I_2 x F_2 was increased head diameter, head parimeter, mean head weight and head weight by 12.1%, 8.5%, 7.4% and 15.5 % compared to I_1 x F_4 interaction (farmer practice) as mean of the two seasons. The linear regression equations between applied water, cm over all foliar application on total head yield, ton fed^{-1} are shown in Fig. (2), these equations reveled that the relationship between applied water quantities and total head yield, ton fed^{-1} is most reliable in the two seasons. These results were taken the same trend with those obtained by Darwesh *et al.*, (2019)

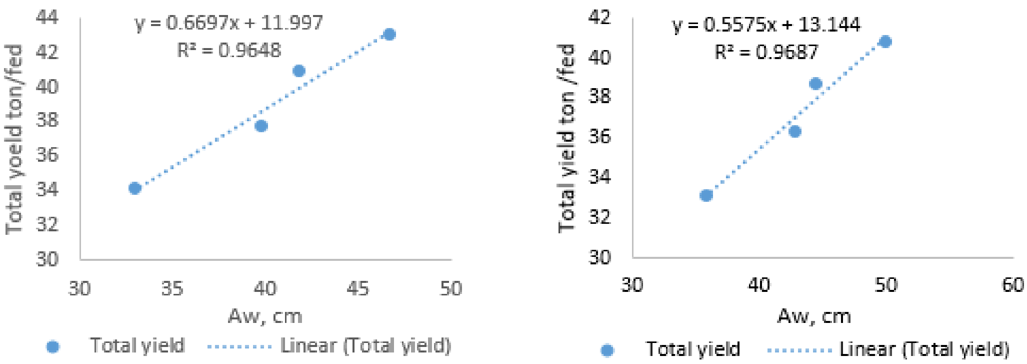

Fig. 2. Correlation between irrigation water applied, cm fed^{-1} and total head yield ton, fed^{-1} overall foliar application with antioxidants in the two growing seasons.

4. Chemical characteristics:

The values of vitamin C mg100g^{-1} fresh weight, total soluble solids %, nitrogen percentage (N %), phosphorous (P %) and potassium percentage (K %) on cabbage heads as affected by different irrigation scheduling, foliar application with antioxidants treatments and the interaction between them are provided in Table (8).

Table 8. Effect of irrigation scheduling, foliar application with antioxidants and interaction on chemical analysis of cabbage heads during 2018/2019 and 2019/2020 growing seasons.

Treatments	Vitamin C (mg100g^{-1} fresh wt.)									
AW	1st season					2nd season				
NA	F_1	F_2	F_3	F_4	Mean	F_1	F_2	F_3	F_4	Mean
I_1	72.43cd	73.45 bc	70.7 ef	69.90 f	71.62 b	66.08 c	68.78 b	63.38 d	61.63 ef	64.96 b
I_2	74.70 b	76.75 a	73.08 c	72.30cd	74.21 a	70.75 a	71.95 a	69.28 b	68.15 b	70.03 a
I_3	67.88 g	71.33de	64.78 h	62.83 i	66.70 c	62.50de	66.78 c	60.25 g	56.85 h	61.59 c
I_4	64.85 h	67.35 g	61.45 j	60.43 j	63.52 d	56.60 h	60.75fg	55.75 h	53.75 i	56.71 d
Mean	69.96 b	72.22 a	67.50 c	66.36 d		63.98 b	67.06 a	62.16 c	60.09 d	
	Total soluble solids %									
I_1	7.50 cde	8.20 b	7.28 ef	7.08 fg	7.51 b	7.00 bc	7.25 b	6.83 cd	6.63 de	6.93 b
I_2	7.83 c	8.53 a	7.68 cd	7.35def	7.84 a	7.25 b	7.65 a	7.08 bc	6.85 cd	7.21 a
I_3	7.40def	7.80 c	7.08 fg	6.78 gh	7.26 c	6.43 e	6.83 cd	6.08 f	5.80 g	6.28 c
I_4	6.50 h	6.88 g	5.98 i	5.68 i	6.26 d	5.98 fg	6.38 e	5.55 h	5.25 i	5.79 d
Mean	7.31 b	7.85 a	7.00 c	6.72 d		6.66 b	7.03 a	6.38 c	6.13 d	
	N%									
I_1	3.52 d	3.65 c	3.43 e	3.35 f	3.49 b	3.36 d	3.42 cd	3.27 e	3.21 f	3.32 b
I_2	3.81 a	3.83 a	3.74 b	3.71 b	3.77 a	3.56 b	3.63 a	3.46 c	3.41 cd	3.52 a
I_3	3.32 f	3.41 e	3.20 g	3.09 h	3.25 c	3.13 g	3.18 fg	2.95 h	2.88 i	3.03 c
I_4	2.90 i	3.03 h	2.80 j	2.77 j	2.87 d	2.80 j	2.98 h	2.57 k	2.51 L	2.71 d
Mean	3.39 b	3.48 a	3.29 c	3.23 d		3.21 b	3.30 a	3.06 c	3.00 d	
	P%									
I_1	0.51 de	0.54 b	0.50def	0.49 ef	0.51 b	0.50 cd	0.51 b	0.49 d	0.47 e	0.49 b
I_2	0.53 c	0.56 a	0.51 de	0.49 ef	0.52 a	0.52 b	0.53 a	0.51 b	0.49 d	0.51 a
I_3	0.49 ef	0.51 de	0.48 gh	0.46 i	0.48 c	0.46 ef	0.49 d	0.43 g	0.41 h	0.45 c
I_4	0.46 i	0.47 h	0.45 j	0.43 k	0.45 d	0.43 g	0.46 f	0.41 h	0.39 i	0.42 d
Mean	0.50 b	0.52 a	0.48 c	0.47 d		0.48 b	0.50 a	0.46 c	0.44 d	
	K%									
I_1	3.61 a-e	3.67 abc	3.54 a-e	3.45def	3.57 b	3.12 cd	3.19 b	3.03 ef	3.02 f	3.09 b
I_2	3.72 ab	3.74 a	3.68 ab	3.63a-d	3.69 a	3.20 b	3.28 a	3.16 bc	3.09 cde	3.18 a
I_3	3.40 ef	3.47 cde	3.26 fg	3.12 g	3.31 c	2.99 fg	3.06def	2.93 gh	2.82 i	2.95 c
I_4	3.51 b-e	3.18 g	2.85 h	2.72 h	3.06 d	2.71 j	2.89 hi	2.64 j	2.52 k	2.69 d
Mean	3.51 a	3.56 a	3.33 b	3.23 c		3.00 b	3.10 a	2.94 c	2.86 d	

High significant differences of the all abovementioned chemical characteristics were found between all studied irrigation scheduling treatments, foliar application and the interaction between irrigation scheduling and foliar application. The highest values of vitamin C mg, total soluble solids%, N%, P% and K% of cabbage heads were recorded after I_2 compared to all studied irrigation scheduling treatments, it increased by 20%, 24.9%, 30.6%, 18.4 % and 19.5% respectively compared to I_4 as mean of both seasons.

The cabbage N% was increased significantly with the increase of irrigation level (Gao *et al*., 2017). Chemical composition of outer leaves (N, P and K), total soluble solids % and vitamin C mg increased significantly under full irrigation compared to deficit, these increment may be due to more water availability that improves nutrient availability and enhancing absorption and uptake of macro- and micro- nutrients, on contrary, the reduction under deficit irrigation may be due to the decrease of cells growth, elongation and development in different plant organs especial in leaves, stem and roots formation causes retarding of nutrients transports and uptake, in addition to the failures of roots to absorb more valuable nutrients (Metwaly, and El-Shatoury 2017). Concerning with the effect of foliar application with antioxidants; Silica nanoparticles, clove oil and peppermint oil, they were increased vitamin C by 10.1 %, 5.9% and 2.5%, respectively, total soluble solids by15.8%, 8.7% and 4.1%, respectively, N% by 8.8%, 5.9% and 1.9% respectively, P% by 12.1%, 7.7% and 3.3%, respectively, and k% by 9.4%, 6.9% and 3.0%, respectively as mean of both seasons compared to control (foliar application with distilled water).

Regarding the interaction effect between irrigation scheduling and foliar application with antioxidants, the interaction of I_2 x F_2 achieved the highest values of vitamin C, total soluble solid, N%, P% and K%. While the lowest values of these chemical characteristics were recorded for I_4 x F_4 interaction compared to the others treatments in the two growing seasons as shown in Table (8).

CONCLUSION

It could be concluded that, the application of irrigation scheduling with 1.2 of cumulative pan evaporation (APE), and foliar application with silica nanoparticles two times after 30 and 60 days after transplanting. Because it achieved the highest values of leaves dry weight, leaf area, outer leaves no., inner leaves no., head diameter, head parimeter, mean head weight and head yield, moreover the concentrations of vitamin C, total soluble solids, nitrogen percentage (N %), phosphorous (P %) percentage and potassium percentage (K %) on cabbage heads compared to all studied treatments. In addition, this interaction enhanced productivity of irrigation water compared to farmer treatment.

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تاثير جدوله الري والرش ببعض مضادات الأكسده علي محصول الكرنب وجودته وبعض العلاقات المائيه تحت نظام الري بالتنقيط

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أجريت تجربتان حقليتان بمحطة البحوث الزراعية بسخا محافظة كفرالشيخ بجمهورية مصر العربية خلال الموسمين الزراعيين ٢٠١٨ / ٢٠١٩ و ٢٠١٩ /٢٠٢٠ لدراسة جدولة الرى والتى تشمل الرى بمعاملة المزارعيين السائدة بالمنطقة والرى ب ١,٢ و١,٠ و٠,٨ من بخر الوعاء التراكمى والرش الورقى ببعض مضادات الاكسدة مثل زيت القرنفل والنانوسليكا وزيت النعناع والرش بالماء المقطر ككنترول على صفات النمو الخضرى ومحصول الكرنب وجودتة تحت نظام الرى بالتنقيط. وقد كان تصميم التجربة فى قطع منشقة مرة واحدة فى ثلاث مكررات. لقد اوضحت النتائج ان كمية المياه المضافة والاستهلاك المائى لمعاملة الرى ب ١,٢ من بخر الوعاء التراكمى ازدادت بمقدار١٢,٢% و ١١,٣% على الترتييب مقارنة بمعاملة المزارعيين .كما سجل التفاعل بين الري ٠,٨ من وعاء البخر والرش سواء بزيت القرنفل أو النانوسليكا أعلي قيم أنتاجية وحدة المياه. لقد سجلت اعلى القيم للوزن الجاف للورقة ومساحة الورقة وعدد الاوراق الخارجية وعدد الأوراق الداخلية وقطر الرأس ومقياس الراس ومتوسط وزن الراس ومحصول الرؤس علاوة على تركيز كل من فيتامين سى والنسبة المئوية للنيتروجين والفسفور والبوتاسيوم بالرووس بعد معاملة الرى ب ١,٢ من بخر الوعاء التراكمى مقارنة بباقى معاملات الرى وايضا بعد معاملة الرش الورقى بالنانوسليكا مقارنة بباقى معاملات الرش الورقى. يمكن التوصية بتطبيق التفاعل بين الرى ب ١,٢ من بخر الوعاء التراكمى و الرش الورقى بالنانوسليكا لانها سجلت اعلى قيم من الصفات السابقة وحسنت محصول الكرنب وجودتة.