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EFFECT OF ALTERNATE FURROW IRRIGATION TECHNIQUE AND ANTIOXIDANTS SPRAYING ON CROP WATER PRODUCTIVITY IN THE ALLUVIAL SOIL OF NILE DELTA OF EGYPT

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ABSTRACT

The main objective of the present study was to find out a simple on-farm irrigation strategy that might enable farmers to increase water productivity under furrow irrigation systems. Therefore, two field experiments were carried out during the two successive seasons of 2007 and 2008, at a private farm, Kaha District, Kalyoubia Governorate, to investigate the efficiency of two improved furrow irrigation techniques as compared with the conventional furrow irrigation system (CFI), which means irrigating all furrows.

The examined furrow irrigation techniques were: exchangeable alternate furrow irrigation (EAFI), which means that neighboring two furrows are alternatively watered, and fixed alternate furrow irrigation (FAFI), which means that fixed one of every two furrows is watered.

Two antioxidant substances; salicylic acid (in the form of Na-salicylate), and ascorbic acid were foliarly sprayed to find out their prospective effect on mitigating the moderate water stress, which could be happen with using alternate furrow irrigation techniques as compared with water spraying as the control treatment.

The used experimental design was split plot with three replicates. Furrow irrigation techniques were presented in the main treatments, and antioxidant substances were allocated in the sup treatments.

The obtained results showed that alternate furrow irrigation techniques saved substantial amounts of irrigation water, and EAFI was the superior. There was a significant increase in cabbage fresh yield with using of EAFI. However, a slight decrease was recorded in FAFI as compared with CFI. Crop water use efficiency in alternate furrow irrigation techniques was higher than those of CFI. Antioxidants spraying led to an increase in fresh weight yield and crop water use efficiency. Nitrogen concentration in cabbage was enhanced with alternate furrow irrigation techniques, and EAFI was more efficient in this concern. Meanwhile, these techniques were associated with a decrease in phosphorus and potassium concentrations in plant as compared with CFI. In addition, Antioxidants spraying stimulated the nutritional status of cabbage, and ascorbic acid was the superior. The remained nitrogen in soil was enhanced with alternate furrow irrigation techniques, although a slight increase in soil salinity was observed. In conclusion, it can be recommended that the use of EAFI technique is the most superior to maintain crop water use efficiency in the Egyptian Nile Delta, especially under water scarcity.

Keywords: Alternate furrow irrigation, Crop water use efficiency, cabbage, nutritional status, Nitrogen recovery.

INTRODUCTION

To sustain the rapidly growing population in Egypt, agricultural production will need to increase. However, the Egyptian water budget is still fixed since the Nile water agreement among Nile basin countries. This rapidly growing population, in addition to the urgent political problems for redistribution of Nile water resources need to change the conventional method of irrigation in the Nile Delta to modern strategies. Proponents of using modern irrigation methods i.e. drip or sprinkler irrigation systems, point to the huge amounts of water saving, although those are contested by some. The debate about using these modern irrigation methods is mainly concerned with a possible salinization danger, especially in Northern Delta regions. Within this context, developing surface irrigation system is the key-factor for optimizing plant growth alongside with water saving. There are numerous modern strategies for developing the conventional surface irrigation system viz. surge irrigation, tubes irrigation and siphon irrigation. However, the high costs of the infrastructure of these methods will hamper the extension of using these methods. On the other hand, deficit irrigation was introduced as a valuable and sustainable production strategy for saving irrigation water in dry regions. However, the sensitivity of most vegetable crops to water stress in some growth stages led to a high reduction in the obtained yield.

Scientists around the globe are looking for simple on-farm strategy for optimizing growth and yield of plants alongside with water saving. New water-saving methods and techniques, such as the partial root-zone irrigation (PRI) or alternate furrow irrigation (AFI), have been proposed as a modern irrigation strategy for more efficient use of the limited water resources (Hu *et al*., 2009). AFI could be applied in two ways, i.e. exchangeable alternate furrow irrigation (EAFI) and fixed alternate furrow irrigation (FAFI).

In addition to the substantial amounts of water saving, AFI also reduces excessive vegetative growth of crops (Graterol *et al*., 1993; Kang and Cai, 2002), and maintains or even increases, crop yield. Temporal and spatial change of soil water contents in different root-zones showed that AFI successfully achieved a completely different soil moisture environment to the plant root system: approximately half of the root system being always in a drying state while the remainder was fully irrigated. The wetting and drying sides of the root system were alternated on a time cycle. This made it possible that half root of the plant absorbed water easily, whereas the other side was subjected to the modest water deficit stress. This moderate stress conditions could be managed through using some antioxidants to face this water stress conditions, and salicylic acid or ascorbic acid are very effective in this concern.

It is well known that, 2-hydroxybenzoic acid (salicylic acid) belongs to an extraordinary diverse group of plant phenolics usually defined as substances that possess an aromatic ring bearing a hydroxyl group or its functional derivative. One of the roles of SA, which attributed with increasing photosynthesis process and dry matter yield production is the improving of chlorophyll content in plant tissues and activation of the synthesis of carotenoids, xanthophylls and the rate of de-epoxidation (Ghai *et al*., 2002; Moharekar *et al*., 2003**).** The very first physiological response, ever attributed to SA in plants, was its impact on flower induction, supplemented with kinetin and indole acetic acid (Eberhard *et al*., 1989). Concerning the effect of SA on nitrate metabolism, it could be concluded that SA increase the activity of nitrate reductase enzyme, which will decrease the accumulation of free nitrate in plant tissues, and increase the protein content (Hayat *et al*., 2005). The involvement of SA in heat production in plants is well documented, and this is through its action on respiration, which increase rate elevates the surface temperature (Van der Straeten *et al*., 1995). On the other hand, it is stated that SA has a vital role on stress tolerance in plant including toxic metals tolerance (Yang *et al*., 2003), drought tolerance (Hamada and Al-Hakimi 2001), heat tolerance (Dat *et al*., 1998), cold tolerance (Kang and Saltveit 2002**)**, ozone stress (Rao and Davis 1999) and ultraviolet radiation (Ervin *et al*., 2004).

Ascorbic acid (AsA) is a highly abundant metabolite and has important roles in plant stress physiology as well as growth and development. In the detoxification of reactive oxygen species, AsA is a key antioxidant. As an enzyme cofactor, AsA plays significant roles in photoprotection, the wounding response, and insect herbivory as well as cell expansion and division (Conklin 2001). AsA is also a cofactor for peptidyl-prolyl and -lysyl hydroxylases, active in the synthesis of hydroxyproline and hydroxylysine (Padh 1990). In plants, the extensively studied and highly abundant hydroxyproline-rich glycoproteins (HRGPs) are key components of the cell wall. These glycoproteins are thought to be involved in structural support of the cell wall and are induced (along with the prolyl hydroxylation reaction) by wounding, ethylene and pathogens (Sommer-Knudsen *et al*., 1997).

Cabbage (Brassica oleracea var. capitata) is a very important vegetable crop. In Egypt, it has an important prestige as one of the most famous traditional dishes. Generally, the heavier loam soils are more suited to cabbage production. Cabbage is characterized by slow development during the first half of the growing period. Therefore, a restricted management strategy should be directed toward increasing nitrogen use efficiency for cabbage production to sustain for the fast growing period at the end of the growing season. Cabbage is moderately sensitive to soil salinity. Yield decrease due to soil salinity at different levels of ECe is recorded as 0% at ECe 1.8, 10% at 2.8, 25% at 4.4, 50% at 7.0 and 100% at ECe 12.0 dSm^{-1} (Ayers and Westcot 1985).

The main aim of this study was to investigate the role of salicylic acid or ascorbic acid application as antioxidants on alleviating water stress, which could be occurred with two alternate furrow irrigation systems; exchangeable alternate furrow irrigation (EAFI) system and fixed alternate furrow irrigation system in comparison with the conventional furrow irrigation (CFI) system.

MATERIALS AND METHODS

Location of the experiment and its layout.

Two field experiments were carried out during the two successive seasons of 2007 and 2008 at a private farm at Kaha District, Kalyoubia Governorate, Egypt, to evaluate the effect of the alternate furrow irrigation techniques and foliar spraying of salicylic acid or ascorbic acid as antioxidant substances on water use efficiency and nutritional status of cabbage (*Brassica olerace* cv capitata).

The experimental design was split-plot with three blocks. The main plots were assigned to the furrow irrigation techniques; (i) conventional furrow irrigation technique (CFI) as the control treatment where all furrows are irrigated during each watering, (ii) exchangeable alternate furrow irrigation (EAFI), which means that neighboring two furrows alternatively watered and (iii) fixed alternate furrow irrigation (FAFI), which means fixed one of every two furrows watered. The sub plots were presented the spraying of antioxidants, which were (i) salicylic acid (as sodium salicylate) at concentration of 0.01 mM, (ii) ascorbic acid at concentration of 10 mM, and (iii) water spraying as the control treatment. The total area of the experimental field was 4200 m^2, 70 m in length and 60 m in width, and the distance between furrows was 1 m. The area of each plot was approximately 220 m^2, and borders between plots were fitted to control the treatments

Soil sampling and analysis

Soil samples (0-40 cm) were collected from the experimental field. The collected samples were air-dried, ground, passed through a 2-mm sieve and merged to obtain a composite sample. Particle size distribution for the soil was carried out using the pipette method as described by Dewis and Fertias, (1970). Soil reaction (pH) was determined in soil paste, and the soil electrical conductivity (EC) was determined in soil paste extract according to Richards (1954). Soluble cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) and anions (CO_3^{2-}, HCO_3^- and Cl^-) were determined in soil paste extract by the methods described by Hesse (1971), whereas (SO_4^{2-}) ions were calculated by difference between total cations and anions. Total carbonate was estimated gasometrically using Collin's Calcimeter and calculated as calcium carbonate according to Dewis and Fertias, (1970). Soil organic matter content was determined using Walkley & Black method as described by Hesse (1971). Soil available nutrients (N, P and K) were extracted and determined according to Hesse (1971). Soil available nitrogen was extracted using KCl (2.0 M) and determined by using macro-Kjeldahl method. Soil available phosphorus was extracted with $NaHCO_3$ (0.5 M) at pH 8.5 and determined colorimetrically after treating with ammonium molybdate and stannous chloride using spectrophotometer. Available potassium was determined by extracting soil with ammonium acetate (1.0 M) at pH 7.0 using flame photometer. Some physical and chemical analysis of the soil is shown in Table 1.

Irrigation scheduling and management.

The amount of irrigation water, which applied in each watering was measured using water counter apparatus, which attached with the irrigation machine. A pre-irrigation of 800 m^3ha^{-1} was applied to all furrows in the field of the experiment in both seasons, in order to adjust the moisture content in the root zone (60 cm) to the field capacity to prepare the seedbed for the seedlings. The life watering of 700 m^3ha^{-1} was also applied to all furrows in the field of the experiment to encourage the plant growth in the early growth stage. Water consumptive use was calculated according to the following equation which described by Israelson and Hansen (1962).

$$Cu = \frac{\Theta 2 - \Theta 1}{100} \times \text{B.D.} \times 10000 m^2$$

Where :

Cu = Amount of water consumptive use, (m^3 ha^{-1}).

Θ2 = Soil moisture content in percent after irrigation.

Θ1 = Soil moisture content in percent before next irrigation.

B.D.= Bulk density in g cm^{-3}

Table (1): The main physical and chemical properties of the experimental soil.

Soil properties		**Values**
Soil physical properties		
Particle size distribution (%)	Sand	20
	Silt	23
	Clay	57
Soil texture		Clay
Soil chemical properties		
Calcium carbonate (%)		4.1
pH*		7.8
EC** (dSm^{-1})		1.44
Soluble cations ($meqL^{-1}$)	Ca^{2+}	5.74
	Mg^{2+}	2.95
	Na^+	5.22
	K^+	0.32
Soluble anions ($meqL^{-1}$)	CO_3^{2-}	n.d***
	HCO_3^-	5.10
	Cl^-	7.14
	SO_4^{2-}	1.99
Available nutrients ($mgKg^{-1}$)	Nitrogen	78.12
	Phosphorus	6.85
	Potassium	253

***Soil pH was determined in soil paste.**
****Soil Electrical Conductivity (EC) was determined in soil paste extract.**
*****n.d. means not detected.**

Cultivation

Cabbage seedlings were cultivated on September 6, 2007 and September 15, 2008 in the first and second season, respectively. The distance between each plant was 0.5 m. Phosphorus fertilizer was applied, before plowing, at the rate of 60 kg P ha^{-1} in the form of mono calcium phosphate (7% P). Plants were fertilized with 150 kg N ha^{-1}, in the form of Ammonium Nitrate (33.5% N), which was divided into two equal doses; the first dose was applied before the second irrigation, and the second one was applied before the fourth irrigation. Potassium was applied, before the fourth irrigation, in the form of potassium sulfate (50% K) at a rate of 100 kg K ha^{-1}.

Antioxidants were applied to the sub-plots of each treatment at the volume of 500 L ha^{-1} as a foliar spraying. Antioxidants were added in series of three foliar applications at biweekly intervals following the third irrigation event.

Plants were harvested after 90 days from cultivation. Total fresh weight was measured as Mg ha^{-1}, and crop water use efficiency (CWUE) was calculated by dividing the weight of the produced marketable crop per the volume unit of the applied irrigation water according to Michael (1978).

Plant analysis

At harvesting stage, a random representative sample of 10 plants, from each plot, was chosen and prepared for chemical analysis. These samples were oven dried at 70°C, and ground using stainless steel mill. Oven dried plant samples (0.2 g) were wet digested using 5 mL from 1:1 mixture of sulfuric acid (H_2SO_4) and perchloric acid ($HClO_4$) as described by Peterburgski (1968) to determine N,P and K concentrations. The amounts of total nitrogen was determined by micro-Kjeldahl method, phosphorus was determined colorimetrically using spectrophotometer and potassium was determined by using Gallen Kamp flame photometer as described by Cottenie *et al*.(1982).

Statistical analysis

The obtained data were statistically analyzed according to the procedure outlined by Duncan (1955). The treatment means were considered significantly when it were more than least significant differences (LSD) at the confidence level of 5% according to Gomez and Gomez (1984).The used software for data analysis was CoStat (Version 6.303, CoHort, USA, 1998-2004).

RESULTS AND DISCUSSION

The total amounts of irrigation water applied.

The volume of applied irrigation water, which given in Fig. (1) is the sum of the amounts of the pre-irrigation, and all subsequent irrigations in both seasons. Alternate furrow irrigation techniques saved substantial amounts of irrigation water as compared with (CFI), and these amounts were 25.4% and 31.9% in the first season, whereas these amounts were 24.31% and 29.74% in the second season with (FAFI) and (EAFI) respectively. These results are in harmony with those obtained by Webber *et al*., (2006).

Alternate furrow irrigation technique has been fundamentally based on alternately wetting and drying opposite parts of the surface soil under which the plant root system is thought to be located. This is commonly applied as part of a deficit irrigation program because it does not require the application of more than 50–70% of the water used in a fully irrigated program.

Soil water relationships in both seasons.

Figures 2 and 3 show the monthly water consumption of evapotranspiration (mm ha^{-1}) as affected by furrow irrigation techniques. It is clear that the evapotranspiration increased during the crop growing period with a peak toward the end of the season. Close results have been obtained by Webber *et al*., 2008. On the other hand, AFI techniques recorded lower values of total evapotranspiration as compared with CFI technique. This may be due to less evaporation from the dry furrow that was reflected on decreasing total evapotranspiration (Tsegaye *et al*., 1993). It is also clear that EAFI recorded lower values than FAFI. This could be due to the better distribution of water between furrows in the root zone.

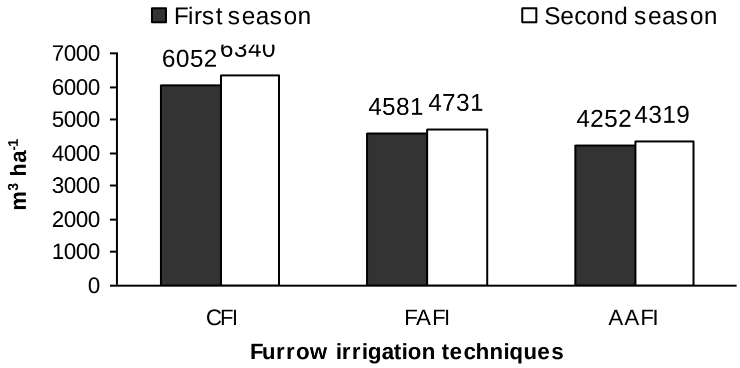

Fig. (1): Effect of different furrow irrigation techniques on the total amounts of irrigation water applied (m^3 ha^{-1})

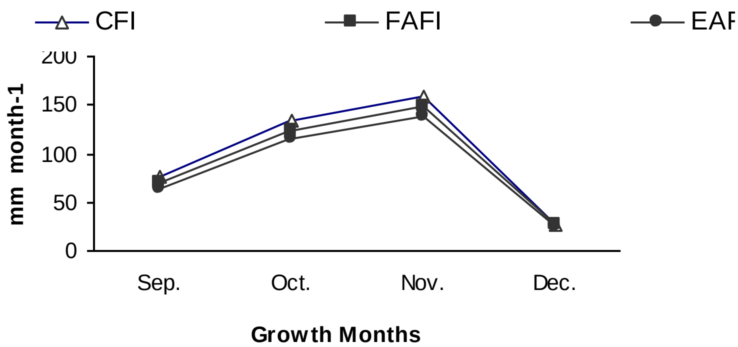

Fig. (2):Effect of different furrow irrigation techniques on the total amounts Evapotranspiration (mm $month^{-1}$)in the first season.

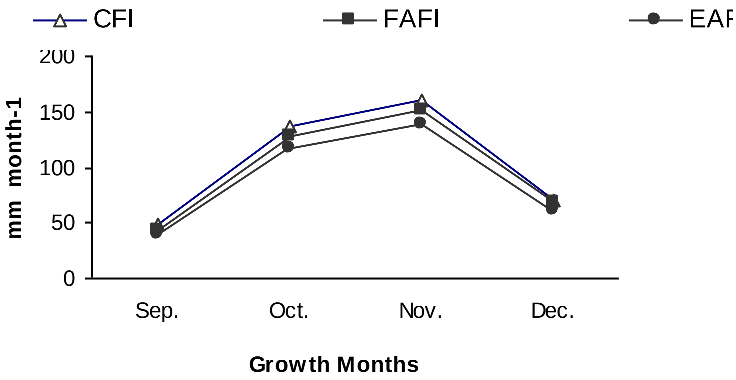

Fig. (3):Effect of different furrow irrigation techniques on the total amounts Evapotranspiration (mm month^{-1})in the second season.

Fresh weight yield and water use efficiency in both seasons.

Table (2) revealed that alternate furrow irrigation techniques significantly increased fresh weight yield. While the EAFI was the superior treatment on increasing fresh weight yield, followed by CFI, and finally FAFI, which achieved the lowest fresh weight yield.

Earlier studies indicated that partial root zone drying had enhanced root growth (Dry *et al*., 2000) and root mass (Mingo *et al*., 2003). Moreover, plant water uptake rate is enhanced after re-watering under water stress condition as compared with full irrigation. This is due to the improvement of hydraulic conductivity of root systems that is subjected to water stress (Kang and Zhang, 2004).

It has been shown that several biochemical parameters could be affected by partial root zone drying due to changes in hormone and enzyme activities. Abscisic acid is a plant hormone that is produced in the roots in drying soils and it is transported by water flow in xylem to the shoot for regulating the shoot physiology and limits stomatal conductance (Kang and Zhang, 2004). It is well known that water is lost as transpiration, and CO_2 is absorbed for photosynthesis through stomata. Therefore, any variations in stomata opening will affect stomatal conductance and photosynthesis rate. Reduced stomatal conductance in early stages of water stress inhibits transpiration rate more than it reduces the intercellular CO_2 concentration, which is the driving factor for photosynthesis. The advantage of alternate furrow irrigation over most of deficit irrigation systems is that water uptake from the wetted side of the root system would maintain a favorable plant water status, while the roots in the dry side promote the increase in abscisic acid production and decrease the stomatal conductance (Du *et al*., 2008; Saeed *et al*., 2008). However, at severe water stress, the leaf water potential in mesophyll cells decreases and stomata will close to a greater extent that inhibits the photosynthesis rate. This is known as hydraulic signaling (Taiz and Zeiger, 2006).

It was observed in this study that EAFI was more efficient than FAFI on improving fresh weight yield and water use efficiency of cabbage plant. This could be due to sequential dissolution of mineral fertilizers in each ridge, which led to the increase of fertilizers use efficiency and enhanced nutrients uptake. This is beside the sequential aeration among furrows, which enhanced gas exchange system. Furthermore, EAFI was attributed with a decline in soil salinity as compared with FAFI as a result of leaching the accumulated salts in the sequential irrigations. However, in FAFI salts are pushed across the bed from the irrigated side of the furrow to the dry side.

Antioxidants spraying was attributed with a significant increase in fresh weight yield and water use efficiency of cabbage plants, and salicylic acid (SA) treatment was the superior. It is well documented that phenolic compounds exert their influence on physiological and biochemical processes including, photosynthesis, ion uptake, membrane permeability, enzyme activities, flowering, heat production and growth and development of plants. It was reported that SA application to the foliage of plants improved the chlorophyll contents of higher plant, thereafter, increased photosynthesis process (Ghai *et al*.,2002). Foliar spraying of SA has a direct effect toward stomata closure. Consequently, increased plant resistant against water stress conditions (Larque-Saavedra, 1978). Foliar spraying of SA has a pronounced effect on nitrogen metabolism through stimulating the activity of nitrate reductase enzyme (Rane *et al*., 1995). Ascorbic acid (AsA) has a vital process in plant growth such as cell division and cell wall expansion (Pignocchi and Foyer, 2003). Moreover, AsA plays important role in ascorbate-glutathione pathway and scavenges ROS in chloroplast (Foyer and Harbinson, 1994) and cytosol (Asada, 1999).

Table (2): Effect of different furrow irrigation techniques and spraying with antioxidant substances on fresh weight yield (Mg ha^{-1}) and CWUE (Mg m^{3} ha^{-1}) in both seasons.

Treatments		First season		Second season	
Irrigation	**Antioxidants**	**Fresh yield (Mg ha^{-1})**	**WUE (Mg m^{-3} ha^{-1})**	**Fresh yield (Mg ha^{-1})**	**WUE (Mg m^{-3} ha^{-1})**
CFI	Control	96.48	24.30	96.19	23.04
	Sal.A	97.15	24.47	96.95	23.22
	ASC.A	96.88	24.40	96.69	23.16
FAFI	Control	96.22	26.13	96.01	24.53
	Sal.A	97.08	26.36	96.84	24.74
	ASC.A	96.43	26.19	96.26	24.59
EAFE	Control	97.71	28.64	97.49	27.36
	Sal.A	98.76	28.95	98.19	27.55
	ASC.A	98.22	28.79	97.95	27.49
Mean values as affected by furrow irrigation techniques					
CFI		96.83b	24.39	96.61b	23.14
FAFI		96.57b	26.23	96.37b	24.62
EAFE		98.23a	28.79	97.87a	27.46
Mean values as affected by antioxidants spraying					
Control		96.80c	24.38	96.56c	23.13
Sal.A		97.66a	26.52	97.32a	24.86
ASC.A		97.17b	28.48	96.96b	27.21

nutrients concentration in cabbage in both seasons.

Table (3) showed that when alternate furrow irrigation techniques were practiced, N concentration in cabbage recorded a significant increase (p<0.05). Such effect possibly resulted from the mechanism of unevenly of N supply in the root zone induced by alternate furrow irrigation. Skinner *et al*. (1999) indicated that alternate furrow irrigation successfully increased N uptake and reduced the potential for NO_3^- leaching under environmental conditions, which allowed adequate root development in the non irrigated furrows, and when the growing season was long enough to allow the crop to reach physiological maturity. This was reflected positively on increasing N concentration in cabbage plants. On the other hand, AFI techniques was attributed with a decrease in P and K concentration in cabbage (Kang and Zhang 2004). It is obvious that soil nutrients availability is a function of soil chemistry and regulated by the dynamic changes of soil moisture. For the nutrient transport from the soil to the root surface, mass flow and diffusion are two different mechanisms. Alternate furrow irrigation, as one of the water deficit techniques, reduces both mass flow and diffusion rates and the release of slowly released nutrient into available form. To explain these results, we should mention that diffusion is the main mechanism for the movement of phosphorus and potassium to the root surface and it contributes with more than 90% for P and 80 for K from the whole P and K uptake (Marschner 1995),

Table (3): Effect of different furrow irrigation techniques and antioxidant substances on nutrients concentration in cabbage.

Treatments		First season			Second season		
Irrigation	**Antioxidants**	**N (%)**	**P (%)**	**K (%)**	**N (%)**	**P (%)**	**K (%)**
CFI	Control	2.51	0.36	2.39	2.49	0.35	2.38
	SA	2.52	0.34	2.33	2.49	0.34	2.35
	AsA	2.56	0.38	2.42	2.54	0.37	2.41
FAFI	Control	2.58	0.31	2.32	2.57	0.30	2.30
	SA	2.57	0.28	2.30	2.56	0.30	2.28
	AsA	2.62	0.34	2.36	2.62	0.32	2.34
EAFE	Control	2.63	0.33	2.36	2.63	0.31	2.32
	SA	2.61	0.30	2.35	2.59	0.29	2.29
	AsA	2.68	0.37	2.39	2.66	0.33	2.37
Mean values as affected by furrow irrigation techniques							
CFI		2.53c	0.36a	2.38	2.50c	0.35a	2.38a
FAFI		2.59b	0.31b	2.32	2.58b	0.30b	2.30b
EAFI		2.64a	0.33ab	2.36	2.62a	0.31b	2.32b
Mean values as affected by antioxidants spraying							
Control		2.57b	0.33ab	2.35ab	2.54b	0.32	2.33ab
SA		2.57b	0.30b	2.32b	2.56ab	0.31	2.30b
AsA		2.62a	0.36a	2.39a	2.60a	0.34	2.37a

Soil salinity after harvesting.

The EC values in the soil surface layer indicated that salt accumulation under the conventional furrow irrigation technique was proportionally lower than AFI techniques (Fig. 3). Meanwhile, the EC value in

FAFI was higher than in EAFI . This is mainly attributed to the leaching of accumulated salts from the root zone in the CFI. However, in the AFI, lower water quantity was applied that did not leach the accumulated salts completely (Kaman *et al*., 2006). In the same context, EAFI was more efficient than FAFI on decreasing the EC values. This is attributed to the exchanging of the irrigated furrows in each irrigation, which was attributed with leaching of the accumulated salts in each irrigation. The salt accumulation observed in AFI treatments did not reach, in any case, cabbage salt tolerance threshold level. In this respect, the AFI practice do not require additional salt leaching over what is normally practiced under CFI to sustain soil fertility. Therefore, AFI should be practiced to maximize crop water use efficiency with the least salinization risk.

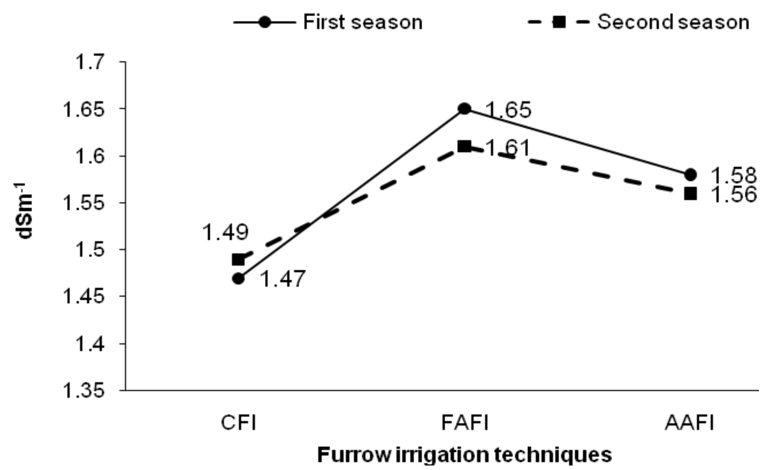

Fig. 3: Effect of different furrow irrigation techniques on the EC values (dSm^{-1}) after harvesting stage in both seasons

Available nitrogen remained in soil after harvesting stage.

In addition to the effect of alternate furrow irrigation techniques on water saving, it may influence nitrogen supply potential of soil and nitrogen recovery at the end of the growing season. Figure 4 indicated that alternate furrow irrigation techniques recorded the highest values of available N remained in soil at the end of the growing season (after harvesting), especially FAFI. This is mainly attributed to the minimal leaching of $NO3^-$ from the root zone as compared with CFI technique. Kirda *et al*. (2005) reported that AFI irrigation improved N-fertilizer recovery of maize (*Zea mays* L.), compared to CFI technique. Moreover, this technique was more efficient than the deficit irrigation technique, which involved irrigation with water quantity lower than potential evapotranspiration. In agreement with this, Wang *et al*., 2009 found that AFI technique improved soil nitrogen availability late in the season and maintained top 'greenness' to a greater extent, as compared with the conventional furrow irrigation technique.

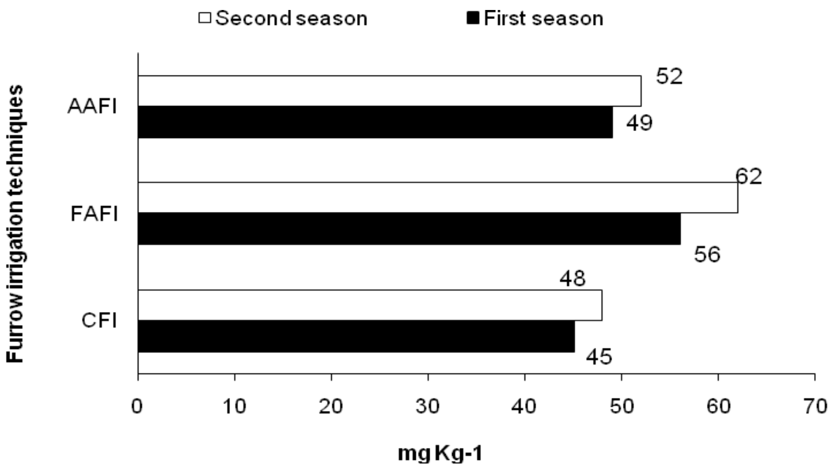

Fig. 4: Effect of different furrow irrigation techniques on available N (mg Kg^{-1}) remained in soil after harvesting stage in both seasons

Conclusion

Based on the obtained results of this study it could be concluded that exchangeable alternate furrow irrigation technique could be used as on-farm irrigation strategy for maximizing crop water use efficiency. Antioxidants spraying, especially salicylic acid, should be used alongside with exchangeable alternate furrow irrigation technique to face the possible water stress danger, which could be happen. Beside the substantial amounts of water saving, alternated furrow irrigation decreased NO_3^- leaching and improved nitrogen recovery, especially fixed alternate furrow irrigation technique.

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تــأثير الــري بــالخطوط التبــادلي والــرش بمضــادات الأكســدة علــي إنتاجيــة الميــاه المحصولية للأراضي الرسوبية في دلتا النيل بمصر

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تهدف هذه الدراسة هو البحث عن إستراتيجية بسيطة يمكن تطبيقها في الحقل والتي من الممكن أن تتيح للمزارعين زيادة غلة المياه تحت نظام الري السطحي بالخطوط. ولذلك أقيمت تجربتين حقليتين في مزرعة خاصة بقها- محافظة القليوبية لاختبار كفاءة تقنيتين من نظام الري بالخطوط المطور مقارنة بنظام الري بالخطوط التقليدي (ري كل الخطوط) في تحسين كفاءة استخدام المياه المحصولية والحالة الغذائية لنبات الكرنب.

شملت تقنيتي الري بالخطوط المطورتين نظام الري التبادلي بالتبادل والتي تعني أن كل خطي ري متجاورين يتم ريهما بالتبادل. و نظام الري التبادلي الثابت والتي تعني ري خط واحد من كل خطين متجاورين بشكل ثابت. وكذلك استخدام مادتين كمضدات أكسدة وهما حمض السلسليك (في صورة صوديوم سلسلات) وحمض الأسكوربيك حيث تم رشهما علي النباتات لدراسة تأثيرهما المتوقع علي الإجهاد المائي المتوسط والذي من الممكن أن يحدث نتيجة استخدام تقنيتي الري التبادلي ومقارنتهما بالرش بالماء كمعاملة مقارنة. كان التصميم التجريبي المستخدم هو نظام القطع المنشقة. مثلت تقنيات الري بالخطوط في المعاملات الرئيسية. بينما وزعت مضادات الأكسدة في المعاملات الشقية.

أشارت النتائج إلي أن تقنيات الري بالخطوط التبادلي قد وفرت كميات كبيرة من مياه الري وكانت تقنية الري التبادلي بالتبادل هي الأفضل و كان هناك زيادة معنوية في المحصول الطازج باستخدام تقنية الري التبادلي بالتبادل. بينما سجل انخفاض قليل في المحصول باستخدام تقنية الري التبادلي الثابت مقارنة بنظام الري بالخطوط التقليدي. كانت قيم كفاءة استخدام المياه المحصولية أعلي في تقنيتي الري بالخطوط التبادلي مقارنة بنظام الري بالخطوط التقليدي. أدي الرش بمضادات الأكسدة إلي زيادة في المحصول الطازج وكفاءة استخدام المياه المحصولية. زاد تركيز النيتروجين في الكرنب مع استخدام تقنيتي الري بالخطوط التبادلي وكانت تقنية الري التبادلي بالتبادل هي الأكفأ في هذا الإطار. ومع ذلك كان استخدام هاتين التقنيتين متبوعا بانخفاض في تركيزات الفسفور والبوتاسيوم مقارنة بنظام الري بالخطوط التقليدي. وقد أدي الرش بمضادات الأكسدة إلي تحسين الحالة الغذائية للكرنب وكان الرش بحمض الأسكوربيك هو الأفضل. وتشير النتائج إلي زيادة قيم النيتروجين المتبقي مع تقنيتي الري بالخطوط التبادلي علي الرغم من وجود زيادة قليلة في تركيز الأملاح تمت ملاحظته. وعليه فانه يوصي باستخدام تقنية الري التبادلي بالتبادل لزيادة كفاءة استخدام المياه المحصولية في دلتا ووادي نهر النيل خاصة تحت ظروف مشكلة ندرة المياه.

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