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Effect of Different Irrigation Systems, Pulse Irrigation Technique and Silicon Application on Maize Growth, Yield and Water Relations under Toshka Climatic Conditions

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Abstract

Field experiments were carried out at the experimental farm of Water Studies and Research Complex (WSRC) Station, National Water Research Center, Toshka – Abu Simbel city, Egypt during the two summer seasons of 2015 and 2016 to study the effect of three irrigation methods including new types of micro irrigation, pulse irrigation technique and silicon application on water relations of maize (Giza - 358, variety) as well as yield and yield components. The experiments were laid out in split plots design with three replicates and consisted of three treatments.

The results indicated that the effect of pulse irrigation technique on water use efficiency were larger than the effect of irrigation system and silicon application, the mean values of water use efficiency were (0.56, 0.52 and 0.52 kg/m^3) for pulse irrigation technique, irrigation system and silicon application, respectively. Also the results showed that grains yield (ton/fed) was increased for combined irrigation system and pulse irrigation technique which had been recorded (1.4 ton/fed) while the mean values of silicon application were (1.3 ton/fed).

Finally, under the current experimental conditions, it could be concluded that pulse technique and silicon application under combination irrigation system is suitable under Toshka climatic conditions and caused significant increases in WUE and grain yield.

Keywords: *Maize, Silicon application, Pulse irrigation technique.*

Introduction

Agriculture consumes the largest amount of the available water in Egypt, with its share exceeding 85% of the total demand for water. On the other hand, several studies showed that the Nile River is very sensitive to temperature and precipitation changes mainly because of its low run off ratio (4%). Egypt is affected by climate change impacts (MWRI, 2014).

Water is fast becoming an economically scarce resource in many areas of the world especially in arid and semiarid regions. In Egypt, limited water resources coupled with high population induce a great competition for water supply that makes conservation and efficient use of water obligatory. Moreover, the newly reclaimed soils such as in Toshka district are facing numerous problems, amongst the water scheduling of limited amounts of water for high yields of some selected low water consuming and high valuable crops is urgently needed (El-Shamly, 2014).

Field evaluation of irrigation system performance is essential to improve irrigation management. Volumetric water control and distribution uniformity in irrigation system are essential factors in achieving accurate water applications, (Smith and Watts, 1986). Surface irrigation is the most widely used irrigation method; this is due to its low capital and maintenance costs, and low energy requirements (Walker, 1989).

Subsurface drip irrigation (SDI) is the most advanced method of irrigation, which enables the application of the small amounts of water to the soil through the drippers placed below the soil surface with discharge rates generally in the similar range as surface drip irrigation. The performance of drip irrigation system should be quantified in relation to its design, management, operation and efficient use of water. Quantification allows the users to determine and control the discharge, amount and timings of water application, so that the crop water requirements are most important in a planned and effective manner (Ayars *et al*., 1999).

The earth crust by weight is constituted about 25.7% silicon; hence it is the 2nd most plenteous element after oxygen (Epstein, 2009). Earlier it has been reported that under water deficit condition grasses supplied with silicon-applied plants of grasses had higher leaf water potential than those plants grown without silicon fertilization (Agarie *et al*., 1998). Liang *et al*., 1999 reported that silica-cuticle double layer formed on leaf epidermis is liable for this improved water potential. Hence, suggesting an induction of drought tolerance by (Si) due to reducing transpiration loss of water under moisture stress condition. Optimization of (Si) nutrition results in increased weight and volume of roots by 20 to 200%, and enhanced drought and salt resistance of cultivated plants. Active (Si) compounds are shown to be extremely important for formation of soil fertility. They have a direct effect on soil texture and increase water-holding capacity by 20 to 30% and exchange capacity by 10 to 25% (Matichenkov and Bocharnikova 2001). Also, Gong *et al*., 2005 stated that adding Si could improved the water status of water-stressed maize plants.

Overall Silicon nutrition has several beneficial effects on plant growth largely due to its unique physiological role (Kojic *et al*., 2012). Its application improved the leaf chlorophyll contents, leaf water potential, water relations and gas exchange (Mali and Aery, 2008 and Pei *et al*., 2010).

Where drip irrigation is used, you may need to irrigate more than once a day to meet peak water requirements. If the drip system drains out after each irrigation, break the irrigation down into the longest pulses possible to reduce losses to drainage. High irrigation frequency might provide desirable conditions for water movement in soil and for water uptake by roots. (Segal *et al*., 2000).

Maize (Zea mays L.) is considered one of the most important cereal crops in Egypt. Total annual area cultivated with maize varieties was estimated by 1.5-2.0 million feddan. Total national production of maize is about 5.43 million tons, while the demand is for at least 7.0 million tons. This reflects the size of the problem and efforts that needed to increase maize production. This can be achieved by breeding high yielding varieties and by the application of improved agro-techniques (El-Atawy *et al.,* 2010). The actual water use by crop varies greatly due to the variation of seasons and locations, depending on the evaporative conditions of the atmosphere and the crop characteristics (Nabila *et al*., 2014). Therefore, the knowledge of the optimum amounts of water required for obtaining maximum yield and high quality is essential. It has been reported that soil moisture limits the growth of the plants before it reaches the permanent wilting point. Water stress affects nearly every process in the plant, where it reduces cell turgor. The size of assimilation leaf area and number of potential storage sites for produced dry matter (Simpson, 1981). It is well established that water supply affects the growth and production of grown crops, limited soil moisture critically influenced the performance of maize plants by reducing plant height, weight and size of assimilating leaf area and dry matter accumulation (Mahrous, 1991 and Hefni *et al*., 1993). Yield and yield components of maize plants were also affected by limited water supply Ibrahim *et al*., (1992) and El-Sheikh (1994) reported that the plants exposed to water stress or skipping one irrigation during pre or post silking reduced the grain yield by 9 and 10 % compared to the conventional irrigation, respectively.

The objective of this research was to study the effects of different irrigation systems, pulse irrigation technique and silicon application on the growth, yield, yield components and water relations of Zea mays under Toshka climatic conditions.

Materials and Methods

Field experiments were carried-out at the experimental farm of Water Studies and Research Complex (WSRC), station, National Water Research Center, Toshka – Abu simbel city, Egypt during the two summer seasons of soil 2015 and 2016. The soil texture is sand. Some physical and chemical properties and irrigation water were measured according to Klute (1986) and Page (1982) and were given in Table 1.

Table 1. Some physical and chemical properties of the studied soil and ground water of experimental site before cultivation.

A- Some physical properties of the studied soil of the experimental site before cultivation.

Soil depth (cm)	Particle size distribution (%)			Tex. class	S.P. (%)	F.C (%)	W.P (%)	A.W. (%)	BD (g/cm^3)
	Sand	Silt	Clay						
0-20	94.16	0.69	5.15	S	23.80	12.5	2.0	10.5	1.60
20-40	95.77	1.40	2.83	S	23.10	12.5	2.0	10.5	1.58

S = Sand S.P= Saturation percent F.C= Field capacity
W.P = Wilting point A.W= Available water B.D= Bulk density

B- Some chemical properties of the studied soil of the experimental site before cultivation.

Soil depth (cm)	$CaCO_3$ (%)	OM (%)	pH*	EC** (dS/m) (1:1) Soil extract	Soluble ions (meq/l)						
					Anions			Cations			
					Cl^-	CO_3^{-2}+ HCO_3^-	SO_4^{-2}	Na^+	K^+	Ca^{+2}	Mg^{+2}
0-20	13.5	nil	7.78	0.15	0.7	0.4	0.4	0.6	0.1	0.6	0.2
20-40	14.8	nil	7.79	0.16	0.7	0.4	0.5	0.6	0.1	0.7	0.2

*pH in 1:1 soil to water suspension **EC in 1:1 soil to water extract

C- Some chemical analysis of the ground water (irrigation water).

Date	pH	TDS		Cations (meq/l)				Anions (meq/l)			SAR
		EC dS/m	mg/l (ppm)	Na^+	K^+	Mg^{+2}	Ca^{+2}	Cl^-	CO_3^{-2}+ HCO_3-	SO_4^{-2}	
Oct -2016	6.70	0.75	480	2.6	0.1	1.3	3.4	2.3	1.8	3.4	1.7

TDS = Total dissolved solids. SAR= sodium adsorption ratio.

The experiment was laid out in split plots design with three replicates and consisted of three treatments**.** The variables were three irrigation systems two of it are traditional irrigation systems which are (sub surface drip system, I_1 and surface drip system, I_2) while the third one is a new type of micro irrigation (Integral Drip Irrigation, I_3) it is combination system between surface drip line & subsurface drip leak line. Therefore it contains the same component which has been applied in surface & subsurface drip irrigation (E.g. Head control unit and pipe lines network). The only difference was use of two laterals lines to irrigate each row (in the surface GR drip line parallel with leak line in the subsurface and connecting the two lines by tee polyethylene pipe and controlled of water pass in the drip lines by PE valve installed on each drip line). The main plots were bounded with buffer zone (1.5m width) to avoid the horizontal seepage. The split units also bounded with buffer zone 0.3 m to avoid the horizontal seepage. The plot with an area 45 m^2 for sub-drip, combination and drip irrigation.

Also each of the studied sites was divided into two plots to study the effect of silicon application; the first one has non silicon applications **(**Si_0**)** while the other one received silicon applications **(**Si_1**)** at a level of (400 mg/l sodium silicate), each division was subdivided into two areas the first one was used for pulse irrigation ($P.I_{off}$), while the other one was used for continues irrigation ($P.I_{on}$).

In the summer seasons of 2015 and 2016, maize grains (Giza - 358, variety) were sown in rows 800 cm long and 15 cm apart between hills on June 25 under surface drip, subsurface drip and combined irrigation systems. The lateral lines were spared at 50 cm apart and the drippers were at 30 cm apart on the lateral. Harvesting of maize plants was 100 days after planting for each season. All the agriculture practices were applied as commonly used for growing maize and carried out according to the recommendations set by the Ministry of Agriculture. Nitrogen, phosphorus and potassium fertilizers were added according to the recommended doses. Nitrogen fertilizer was applied in the form of ammonium sulphate (20.6% N) at the level of 600 kg/fed in eight equal doses, the first one after seven days from planting and the final dose before flowering stage time. Phosphorus fertilizer in the form of calcium super phosphate (15.5% P_2O_5) was added at the level of 200 kg/fed in one dose before planting. Potassium fertilizer in the form of potassium sulphate (48% K_2O) at the level of 50kg/fed was added in the same time of adding phosphorus fertilizer.

To obtain the actual water consumptive use (C.U), the soil moisture percentage was determined gravimetrically on dry weight basis just before irrigation. Soil samples for moisture determination were taken from each 0 cm depth up to 30 cm from the soil surface by soil auger. The amount of water consumed in each irrigation interval was obtained from the difference between soil content before the following irrigation and field capacity. This was calculated according to Israelsen and Hansen (1962) as follows:

C.U. = D × Pb × (Q2-Q1)/100

Where:

C.U.= actual evapotranspiration**.**

D= the irrigated soil depth (cm).

Pb= Bulk density in g/cm^3.

Q2= the percent of soil moisture at field capacity**.**

Q1= the percent of soil moisture before irrigation.

Er= irrigation system efficiency (%).

The Water use efficiency (WUE) values were calculated as follows (Viets, 1965):-

WUE = {Grains yield (kg / fed.) / Actual evapotranspiration (m^3 / fed.)}

Also the irrigation water use efficiency (IWUE) is expressed as kg seeds / m^3 of water applied; it has been used to evaluate efficiency of the irrigation methods in producing maximum yield per water unit consumed by the crop Viets (1965) :-

IWUE = {Grains yield (kg / fed.) / Irrigation water requirement (m^3 / fed.)}

At harvest time, ten plants were chosen randomly from each sub-plot to estimate the following characters:

I. Plant height (cm).
2. Leaves (no / plant).
3. Ear length (cm).
4. Rows (no / ear).
5. Grains no / ear
6. Grains index
7. Grains yield (gm / m^2).
8. Grains yield (ton / fed).

Statistical analysis:

Mean values were compared for each other using the least significant differences (LSD).

Results and Discussion

Maize yield and yield components.

The effects of different irrigation systems, pulse system and silicon application on growth characteristics (plant height, leaves no / plant, Ear length / cm, Ear diameter / cm, Grains weight/ Ear, Grains index (weight as g/ 100 grains), Grains yield ton / fed) at 100 days of sowing during the two growth seasons were presented in Tables 2a to 2c .

The obtained results which are represented in Tables 2a to 2c revealed that the experimental treatments has significant by affected growth characteristics. The results indicated that the (plant height, Leaves no / plant, Ear length / cm, Ear diameter / cm, Grains weight/ Ear, Grains index (weight as g/ 100 grains), Grains yield ton / fed) were significantly affected by using different irrigation systems, pulse system and silicon application in both seasons .

a- The Effect of irrigation systems on plant characteristics.

The ear length or grain index (weight as g/ 100 grains) was not changed significantly by irrigation system treatments (Tables 2a and 2b). On the other hand, the plant height for combination irrigation system was higher than the subsurface and surface drip irrigation (Table 2a). The number of leaves per plant was significantly changed where as the combination irrigation system increases the number of leaves per plant (Table 2a). This resulted in higher grain yield (gm/m^2). Also, the results indicated that grain yield (ton/fed) was increased for combined irrigation system by 33% and 60% more than that of the sub-surface drip irrigation in both seasons, respectively (Table 2c).

b- The Effect of pulse technique on plant characteristics.

The number of leaves per plant, ear length, number of rows per ear and grain index (weight as g/ 100 grains) was not changed significantly by pulse technique treatments (Tables 2a and 2b). On the other hand, the plant height for pulse technique treatment was higher than the treatments without pulse technique (Table 2a). The number of grain per ear was significantly changed where the pulse technique increased the number of grain per ear (Table 2b). This resulted in higher grain yield (gm/m^2). Also, the results indicated that grain yield (ton / fed) was increased due to pulse technique treatments by 46% and 35.7% in both seasons respectively more than that was in without pulse technique treatments (Table 2c).

c- The Effect of silicon application on plant characteristics.

The plant height, ear length, number of rows per ear and number of grain per ear were not changed significantly by silicon treatments (Tables 2a and 2b). On the other hand, the number of leaves per plant was significantly changed where the silicon application increases the number of leaves per plant (Table 2a). This resulted in higher grain yield (gm/m^2). Also, the results indicated that grains yield (ton/fed) was increased for silicon application treatments by 25% and 23% in both seasons, respectively more than that without silicon application treatments (Table 2c).

Table 2a. Effect of irrigation systems, pulse irrigation technique and silicon application on some growth parameters and yield of maize plant.

Characters		plant height (m)			No. leaves / plant			Ear length(cm)		
Treatment		2015	2016	mean	2015	2016	mean	2015	2016	mean
Irrigation systems	$I_{1(Sub\ surface)}$	0.9	1.5	1.2	10.45	13.8	12.1	15.9	15.8	15.9
	$I_{2(surface)}$	1.2	1.6	1.4	10.9	14.3	12.6	17.6	16.5	17.1
	$I_{3(Combinated)}$	1.8	1.7	1.7	11.7	15.3	13.5	17.8	16.6	17.2
	$L.S.D_{0.05}$	0.2	0.1	-	0.56	0.9	-	N.S.	N.S.	-
Pulse once time	without	1.1	1.7	1.4	11.2	14.3	12.8	16.2	15.9	16.1
	with	1.5	1.6	1.6	10.9	14.7	12.8	18.0	16.7	17.4
	$L.S.D_{0.05}$	0.2	N.S.	-	N.S.	N.S.	-	N.S.	N.S.	-
Si 400(mg)	without	1.3	1.6	1.5	10.6	14.0	12.3	17.0	15.7	16.4
	with	1.3	1.7	1.5	11.4	14.9	13.2	17.2	16.9	17.1
	$L.S.D_{0.05}$	N.S.	N.S.	-	0.64	0.9	-	N.S.	N.S.	-

NS No significant differences at 0.05 level

Table 2b. Effect of irrigation systems, pulse irrigation technique and silicon application on some growth parameters and yield of maize plant.

Characters		No. rows/ ear			No. Grains / ear			Grains index (weight as g/ 100 grains)		
Treatment		2015	2016	mean	2015	2016	mean	2015	2016	mean
Irrigation systems	$I_{1(Sub\ surface)}$	13	11.2	12.1	132	107.0	119.5	28.9	29.6	29.3
	$I_{2(surface)}$	11	14.7	12.9	163	215.1	189.1	30.6	31.1	30.9
	$I_{3(Combinated)}$	13	15.1	14.1	184	300.6	242.3	31.5	34.6	33.1
	$L.S.D_{0.05}$	N.S.	2.2	-	N.S.	44.4	-	N.S.	N.S.	-
Pulse once time	without	12	13.2	12.6	117	177.7	147.4	29.7	32.0	30.9
	with	13	14.7	13.9	202	237.4	219.7	31.0	31.5	31.3
	$L.S.D_{0.05}$	N.S.	N.S.	-	49	36.2	-	N.S.	N.S.	-
Si 400(mg)	without	12	14.0	13.0	145	195.9	170.5	28.4	30.0	29.2
	with	13	13.9	13.5	174	219.1	196.6	32.3	33.5	32.9
	$L.S.D_{0.05}$	N.S.	N.S.	-	N.S.	N.S.	-	2.7	N.S.	-

NS No significant differences at 0.05 level

Table (2c): Effect of irrigation systems, pulse irrigation technique and silicon application on some growth parameters and yield of maize plant.

Characters		Grains yield (gm/m^2)			Grains yield (t / fed)		
Treatment		2015	2016	mean	2015	2016	mean
Irrigation systems	$I_{1(Sub\ surface)}$	40.1	32.2	36.2	0.8	0.6	0.7
	$I_{2(surface)}$	49.7	67.2	58.5	1.1	1.4	1.3
	$I_{3(Combinated)}$	57.6	72.4	65.0	1.2	1.5	1.4
	$L.S.D_{0.05}$	N.S.	12.6	-	0.1	0.1	-
Pulse once time	without	35.1	46.1	40.6	0.7	0.9	0.8
	with	63.2	68.4	65.8	1.3	1.4	1.4
	$L.S.D_{0.05}$	13.2	10.3	-	0.1	0.1	-
Si 400 (mg)	without	41.5	48.4	45.0	0.9	1.0	1.0
	with	56.8	66.1	61.5	1.2	1.3	1.3
	$L.S.D_{0.05}$	14.7	N.S.	-	0.2	0.2	-

NS No significant differences at 0.05 level

Table 3. Effect of irrigation systems, pulse irrigation technique and silicon application on Water use efficiency (WUE) and Irrigation water use efficiency (IWUE).

Characters		Water use efficiency (Kg / m^3)			Irrigation water use efficiency (Kg / m^3)		
Treatment		**2015**	**2016**	**mean**	**2015**	**2016**	**mean**
Irrigation systems	**$I_{1(Sub\ surface)}$**	0.36	0.29	0.33	0.24	0.20	0.22
	$I_{2(surface)}$	0.42	0.55	0.49	0.30	0.41	0.36
	$I_{3(Combinated)}$	0.44	0.60	0.52	0.31	0.48	0.40
	L.S.D $_{0.05}$	0.02	0.01	-	0.02	0.02	-
Pulse once time	**without**	0.29	0.37	0.33	0.20	0.29	0.25
	with	0.53	0.59	0.56	0.36	0.44	0.40
	L.S.D $_{0.05}$	0.01	0.01	-	0.02	0.01	-
Si 400 (mg)	**without**	0.35	0.40	0.38	0.24	0.29	0.27
	with	0.47	0.57	0.52	0.33	0.44	0.39
	L.S.D $_{0.05}$	0.08	0.11	-	0.06	0.10	-

NS No significant differences at 0.05 level.

a- The Effect of irrigation systems on Water use efficiency (WUE) and irrigation Water use efficiency:

Table (3) presents the effects of irrigation systems treatments on (WUE and IWUE) in both seasons. The I_3 (combinated system) significantly increased (WUE and IWUE) over all other systems in both the years. Similarly, I_2 (drip system) treatment were also superior in (WUE and IWUE) I_1 (control) in both the seasons. Minimum (WUE and IWUE) were observed in I_1 (control).

b- The Effect of pulse technique on water use efficiency (WUE) and irrigation water use efficiency:

The Table (3) showed the relation between pulse irrigation technique, and WUE and IWUE. From the above data, (WUE and IWUE), were increased due to using the pulse irrigation. This may be due to decreasing of water penetration downward by increasing of initial moisture content which, was increased by increasing number of pulses. Hence, pulse technique increased from water movement in horizontal direction than vertical direction this action increased the wetted soil volume inside root zone and this mean increasing in (WUE). These results are agreement with Scott, 2000 and Oron, 1981.

c- The Effect of silicon application on water use efficiency (WUE) and irrigation water use efficiency:

Data of Table 3 reveal that silicon treatments had significant effect on WUE and IWUE. Result might be attributed to the positive effect of silicon that improve the (WUE and IWUE) that might be due decrease in unnecessary transpiration. These results are agreement with those obtained by Hellal *et al*., 2012 and Putra *et al.,* 2012.

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تأثير إستخدام نظم الري المختلفة وتقنية الري النبضي والسليكون على النمو الخضري والمحصول والعلاقات المائية للذرة الشامية تحت ظروف توشكى المناخية

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الملخص

أجريت هذه الدراسة في مزرعة تجارب الأبحاث بمجمع الدراسات والبحوث المائية بتوشكي خلال موسمي ٢٠١٥ و ٢٠١٦ لدراسة تأثير إستخدام نظم ري مختلفة (تنقيط تحت سطحي – تنقيط سطحي وتكاملي) والري النبضي والسليكون على العلاقات المائية لمحصول الذرة الشامية ومكوناته تحت الظروف المناخية لمنطقة توشكى وقد أوضحت النتائج التالي:

بالنسبة لتأثير نظم الري المختلفة على الإنتاجية وكفاءة إستخدام المياه أظهرت النتائج أن أعلى متوسط إنتاجية لحبوب الذرة الشامية بالنسبة للموسمين محل الدراسة قد سجلت (١,٤ طن/ فدان) عند إستخدام نظام الري التكاملي ، بينما سجل أقل متوسط إنتاجية للحبوب بالنسبة للموسمين (٠,٧ طن/ فدان) عند إستخدام نظام الري تحت السطحي. كما أظهرت النتائج أن أعلى متوسط كفاءة لإستخدام المياة قد سجلت عند إستخدام نظام الري التكاملي (٠,٥٢ كجم/م٣) بينما سجل أقل متوسط كفاءة لإستخدام المياة عند إستخدام نظام الري تحت السطحي (٠,٣٣ كجم/ م٣).

بالنسبة لتأثير الري النبضي فقد أظهرت النتائج أن أعلى متوسط إنتاجية لحبوب الذرة الشامية بالنسبة للموسمين محل الدراسة قد سجلت(١,٤ طن/ فدان) عند إستخدام الري النبضي ، بينما سجل أقل متوسط إنتاجية للحبوب (٠,٨ طن/ فدان) عند إستخدام الري المتواصل (بدون ري نبضي). كما أظهرت النتائج أن أعلى متوسط كفاءة لإستخدام المياه بالنسبة للموسمين محل الدراسة عند إستخدام الري النبضي وقد سجل (٠,٥٦ كجم/ م ٣) بينما سجل أقل متوسط عند إستخدام الري المتواصل (بدون ري نبضي) وقد سجل (٠,٣٣ كجم/م٣).

بالنسبة لتأثير السليكون فقد أظهرت النتائج أن أعلى متوسط إنتاجية لحبوب الذرة الشامية بالنسبة للموسمين محل الدراسة قد سجلت (١,٣ طن/ فدان) عند إستخدام السليكون ، بينما سجل أقل متوسط إنتاجية للحبوب (١,٠ طن/ فدان) بدون إستخدام السليكون. كما أظهرت النتائج أن أعلى متوسط كفاءة لإستخدام المياه بالنسبة للموسمين محل الدراسة (٠,٥٢ كجم/ م ٣) وذلك عند إستخدام السليكون ، بينما سجلت أقل قيمة لكفاءة إستخدام المياه بالنسبة للموسمين محل الدراسة (٠,٣٨ كجم / م ٣) مع معاملات بدون سليكون.

ومن خلال النتائج السابقة يتضح أن إستخدام نظام الري التكاملي وتقنية الري النبضي وإضافة السليكون ذو مردود إيجابي على إنتاجية محصول الذرة الشامية وعلى علاقاته المائية تحت ظروف توشكى المناخية.

الكلمات الدالة: *تقنية الري النبضي ، إستخدام السليكون ، الذرة الشامية*