Modern Agricultural Science and Technology, ISSN 2375-9402, USA
February 2017, Volume 3, No. 1-2, pp. 27-35
Doi: 10.15341/mast(2375-9402)/01.03.2017/004
Academic Star Publishing Company, 2017
www.academicstar.us

Using Precision Irrigation for Better Corn Yield with Less Water

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Abstract: Improving plant growth and reducing cost justify an automated irrigation will be used. Automated irrigation minimizes the amount of water applied, reduces labours and increases yield. Field experiments were carried out at farm in Sharkia Governorate, Egypt during summer season 2013. The experiments were arranged in strip-plot design with three replicates. The main-plot represented irrigation methods [automated irrigation (M1) & traditional irrigation (M2)]. While, the sup-plot treatments represented irrigation systems [surface (S1) & sub-surface drip irrigation (S2)].

Results indicated that corn grain yield and yield components increased with using M1 and S1. On the other side, the M2 received the lowest with sub-surface drip irrigation. Grain yield increased from 2.14 to 2.34 Mg/fed by percentage 9.32% by using automated irrigation compared with traditional irrigation. Automated irrigation decreased the amount of water applied by 18.3% compared to the traditional irrigation method. Automated irrigation saved water by 474 m^3/fed compared with traditional irrigation, while subsurface drip irrigation system saved water by 100 m^3/fed compared with surface drip.

The higher Water use efficiency of grain yield estimated to 1.11 kg/m^3 was obtained under M1, while M2 induced lower value 0.83 kg/m^3. The highest values of net return (LE/fed), water productivity (LE/m^3), economic efficiency for capital investment (%), and benefit cost ratio were 2413, 1.11, 99.22 and 1.99, respectively, which were achieved with surface drip and automated irrigation, while the lowest values were 1118.7, 0.44, 42.33 and 1.42 which were achieved under sub-surface drip with traditional irrigation.

So, it can be concluded that automated irrigation with surface drip irrigation produced the highest values of grain yield, Water use efficiency, net return and benefit cost ratio, while produced the lowest values of amount of water applied and total cost.

Key words: surface drip, sub-surface drip, automated irrigation, traditional irrigation, net return

1. Introduction

Automatic irrigation method is a new technology to increase water saving, water use efficiency and save labour cost. An automatic irrigation method is a potential solution to optimize water management by controlling irrigation. The idea of automatic irrigation method depends on measuring the soil moisture continuously using moisture sensors.

Automatic irrigation uses a device to operate irrigation system to flow the water from pump to the field automatically without labour. Automatic irrigation method is able to determine and maintain the right amount water for the crop.

Improving irrigation efficiency of crops can contribute greatly to reduce production costs and make the industry more competitive and sustainable.

Through proper irrigation, average corn yields can be increased and we will protect environment from agrichemical leaching.

Irrigation water management involves determining when to irrigate, the amount of water applying at each irrigation event and during each stage of plant. Also, it is informing us the suitable time of operating and maintaining the irrigation system. The main management objective is to make high profit for the production and protect the environment with the available amount of water.

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Water is one of the most essential parameters for crop production. Agriculture use about 80% of the total available water resources, but this amount is not enough for the crops needs and this amount of water will decrease more and more because the growing of domestic and industrial uses.

Irrigation systems are selected, designed and operated to supply the irrigation requirements for each crops also, controlling deep percolation, runoff, evaporation and operational losses to establish a sustainable production process, as sited from [1].

Maximum and minimum water saving was obtained using subsurface drip and furrow irrigation with 2471 m^3/fed and 2845.4 m^3/fed water applied, respectively. The highest and lowest yields were 5.066 and 4.079 ton/fed and the maximum and minimum water use efficiency were 2.12 and 1.43 kg/m^3 for subsurface drip and furrow irrigation methods, respectively [2]. The highest and lowest root yield were 33.3 and 17.3 ton/fed for sugar beet and the highest and lowest water use efficiency in root were 9 and 3.8 kg/m^3 for surface drip and furrow irrigation system respectively[3].

Through new technology, we use soil water sensors for efficient and automatic operation of irrigation systems [4]. Automatic soil water sensor-based irrigation seeks to maintain a desired soil water range in the root zone that it is optimal for plant growth [5]. There was saving in irrigation water by 5.84% and 20.8% by using evapotranspiration ET controllers compared to soil moisture sensors and control irrigation. Also, there was an increase in the yield by using evapotranspiration ET controllers compared to soil moisture sensors and control irrigation by 7.89% and 11.33%, respectively [6].

Maize Considered major cereal crops in Egypt. It is importance in human nutrition, animal and poultry. The total cultivated area of white maize is about 1.5 million Fadden, and total of production amounted about 44.1 million ardeb. It contributes both old and new land by about 92.1% and about 7.9% of total production during 2012, while total cultivated area of yellow maize about 0.292 million Fadden, and total of production amounted about 6.6 million [7].

1.1 Problem Statements

Usually, irrigation of plants consumes a lot of time and huge labour costs. Through, Traditional irrigation method, all steps of irrigation were executed by humans. Also, it consumes more water, water losses by infiltration, increases water table and low efficiency of irrigation scheduling. So, the problem is to determine when and how much water to apply at each irrigation and during each stages of plant. This can be achieved by using automated irrigation and also to reduce the number of labour, the best time and amount to irrigation.

The overall objective of the study, to improve irrigation water use efficiency, control water loss, increase water saving and minimize the costs of labour. This research was implemented to investigate the potential of using automated irrigation to decrease water applied under two irrigation systems and best scheduling of irrigation.

2. Materials and Methods

2.1 Experimental Site and Crop Planting

The field experiments were carried out at open farm in Sharkia Governorate, Egypt during summer season 2013. The physical and chemical properties of soil sites for the two experiments were determined according to [8] as presented in Table 1. Irrigation water used was performed and the results are tabulated in Table 2. Corn was planted manually on 1 June 2013 on 0.25 m planting space and 0.6 m between rows with two seeds per hill and harvested on 15 September 2013. The rate of seed was 14 kg/fed. Twenty one days from seeding, the seeding were thinned to one plant per hill. The Agriculture research center recommended of organic manure and phosphorus fertilizer were added to all plots during the preparation soil in the rate of 20 m^3/fed organic manure and 200 kg/fed. (15.5% P_2O_5). Nitrogen fertilizer was applied by fertigation in the form of Ammonia sulphate (20.5% N) at the rate of 250 kg/fed.

Table 1 Some physical and chemical properties of the experimental site.

Soil depth (cm)	Particle size distribution (%)			$Caco_3$ (%)	Bulk density (g/cm^3)	PH	EC (ds/m^{-1})	O.M (%)	F.C* (%)	W. p* (%)	A.W (%)
	Sand	Silt	Clay								
0-20	88.0	9.7	2.3	2.4	1.35	8.2	1.3	0.4	11.0	5.0	6.0
20-40	89.1	9.0	1.9	2.6	1.24	8.5	1.2	0.3	10.7	5.1	5.6
40-60	88.5	8.5	3.0	2.7	1.30	8.7	1.5	0.25	10.5	5.0	5.5

Table 2 Chemical analysis of irrigation water used.

PH	EC (dSm^{-1})	Cations (meq/L)				Anions (meq/L)				SAR	ESP
		Na+	Ca^{++}	Mg^{++}	K^+	Cl^-	HCO_3^-	CO_3^{--}	SO_4^{--}		
7.5	1.76	10.2	6.4	4.9	0.8	9.4	6.4	-	6.3	4.35	4.88

2.2 Materials

2.2.1 Irrigation Systems and Equipment

The irrigation scheme consisted of control head (centrifugal pump, pressure regulator, pressure gauges, flow meter and filters) and two irrigation systems installed in the experimental area. Both had PVC pipe main, sub-main, and secondary lines. Laterals drip lines with 16 mm diameters, 30 cm emitters distance and 4 l/h emitter's discharges were used for both drip irrigation systems. The type of emitters of both studied systems was GR which was either placed on soil surface or buried approximately 15 cm deep directly under the soil beds. The lengths of laterals and spacing between them were 20 m and 0.6 m respectively, for both systems, as shown in Fig. 1.

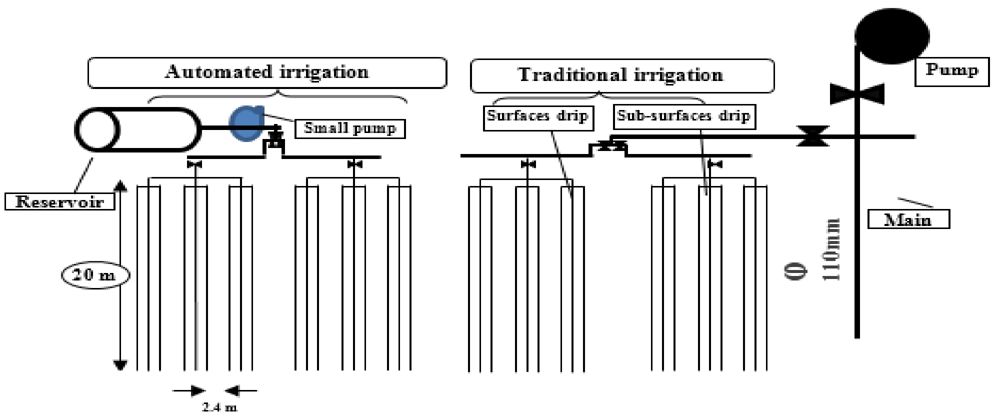

Fig. 1 Layout of Surface and subsurface drip irrigation systems experiment.

2.2.2 The Automated Irrigation

The automated irrigation consists of the following main parts:

• **Sensor** [9]

The sensor is a measuring moisture content used for moisture control in the soil. It consists of the following parts:

(1) Small Zink cone.

(2) Plastic insulator.

(3) Copper tube.

(4) A meter is used to read the electrical resistance of moisture blocks installed in the ground.

(5) Plastic box.

(6) Iron box.

• **Control unit [9]**

It consists of:

(1) Output relay: actuates the solenoid valve to open or close.

(2) Comparator: it compresses the two level of moisture content in the soil. If they equal its out but will be:

a) Lower moisture content (in this point will irrigate).
b) Higher moisture content (this point depend on field capacity).
c) Integrated circuit.
d) Fixed resistance.
e) Socket.
f) Diode.
g) Zinner diode for regulating the input voltage.
h) Light emitting diode.
i) Transistor: us as switch.
j) Power supply.

- **Pump**

An electrical pump was used with 0.5 hp to lift the water from the water source to feed the pipes network.

All of these parts worked together, if the soil moisture is at the irrigating point, the sensor gives a signal to control unit to operate the pump to flow water in the irrigation system network, vice versa is happened, if the soil moisture is at field capacity point, the sensor gives a signal to control unit to close the pump.

- **Irrigating point**

The irrigating point, means when the soil will be irrigated. This point depends on some factors, as soil types (we need to know the field capacity and the wilting point) and the crop stage depletion (in the initial, crop development and mid-season stages were 50%, while 80% in late stage [10]. In this soil and crops irrigating point in the initial, crop development and mid-season stages was 7.9% and in the late stage was 6.12%. As indicated in Fig. 2.

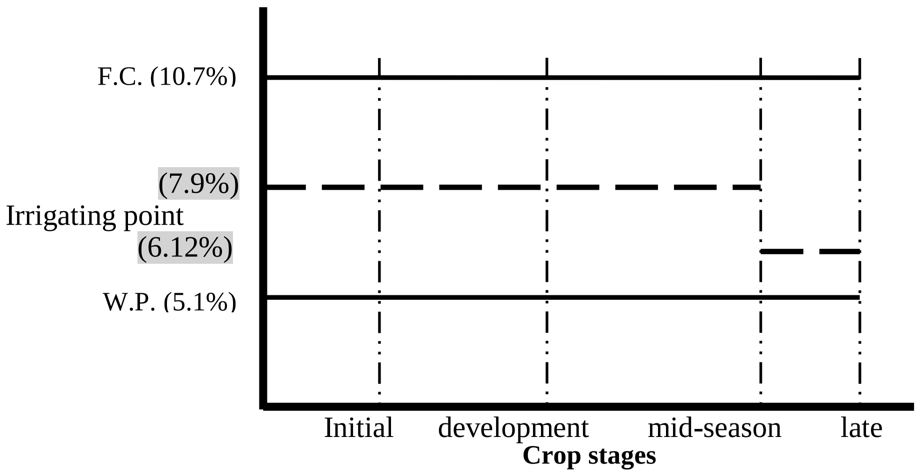

Fig. 2 The irrigating point according to the plant stages.

2.3 Methods

2.3.1 Experimental Design and Treatments

The experiments were arranged in strip-plot design with three replicates. The main-plot represented irrigation methods [automated irrigation (M1) & traditional irrigation (M2)]. While, the sup-plot treatments represented irrigation systems [surface (S1) & sub-surface drip irrigation (S2)]. The sup-plot treatments represented irrigation systems including S1 and S2 are designed under both of the M1 and M2 main plots.

2.3.2 Measurement and Determinations

(1) Water Relations

- Amount of water applied

The amount of water applied under each irrigation system was measured by flow meter under different treatments.

- Water use efficiency (WUE)

WUE was calculated according to [11] as follows:

$$WUE = \frac{Grain\ yield\ (kg/fed)}{Water\ applied\ (m^3/fed)}, kg/m^3$$

(2) Corn Characteristics

- The growth characteristics: included plant height (cm) and leaf area (cm^2/plant).
- Yield components: included ear length, ear diameter and weight of 100 seeds.
- Yield: Grain yield (Mg/fed).

(3) Economic Analysis

- **Total production costs (Ct)** = Irrigation system costs + cost of cultivation (included preparation of soil, different agriculture practices, price of seed, labors and harvesting)

Irrigation system cost:

Capital irrigation system cost was calculated using the current dealer prices equipment and installation according to 2016 price level.

1) **Fixed costs (FC):** was calculated using the following equation:

$$F.C = D + I + T$$

Where:

D = depreciation (LE/year), I=interest (LE/year) and T=taxes and overhead ratio (LE/year)

***Depreciation:** was determined by the following equation:

$$D = \frac{I.C - Sv}{E.L}$$

Where:

I.C= the element initial cost of irrigation system (LE), Sv = Salvage value after depreciation (LE) and E.L = the element expected life (year).

***Capital interest:** was calculated using the following equation:

$$I = \frac{I.C \times 1.10}{2} \times I.R.$$

Where:

I.R = is the interest, rate/year (taken 14%).

* Taxes and overheads ratio, taken 2.0% from initial cost.

2) **Running cost (RC)**: The annual running cost was estimated as follows:

$$RC = E.C + (R \& M) + L.C$$

Where:

L.C = labor costs (LE/year), E.C = energy costs (LE/year) and (R&M) = repairs and maintenance costs (LE/year).

*__Labor cost__: was calculated using the following equation:

$$L.C = T \times N \times P$$

Where:

L.C = annual labor cost (LE/year), T = annual irrigation time (T/year), N = Number of labor/fed and P = labor cost (LE/h).

*__Energy cost (EC):__ was calculated using the following formula:

$$E.C = Bp \times T \times Pr$$

Where:

Bp = the brake power (kW), T = the annual operating time (h) and Pr= cost of electrical power (LE/kW. h)

The brake power required was calculated by using the following equation [12]:

$$B_P = \frac{Q * T_{DH}}{C.E_{overall}}$$

Where:

Q = total discharge rate (l/s), TDH= total dynamic head (m), C = conversion coefficient to energy unit, 102 (according to [13]) and E overall: overall efficiency (67.5% for pump drive by electric motor).

* **Repairs and maintenance costs:** was taken about 2% and 3% of the initial cost, under surface drip irrigation and subsurface drip irrigation, respectively.

The total irrigation cost = Fixed cost + Running cost, (LE/fed.year)

- **Total return (LE/fed)**: was calculated with the following equation:

Total return = Price (LE/Mg) × Grain yield (Mg/fed)

- **Net return**: was calculated with the following equation:

Net return = Total return - Total costs

- **Water productivity (LE/m^3)**: was calculated by using the following formula:

$$Water\ productivity = \frac{Net\ return\ (LE/fed.)}{Amount\ of\ water\ applied\ (m^3/fed)}\ LE/m^3$$

- **Benefit cost ratio (B/C)**: was calculated with the following equation:

$$B/C = \frac{Total\ retun/fed/season}{Total\ cost/fed/season}$$

- **Economic efficiency for capital investment (%)**: was calculated with the following equation:

$$Economic\ efficiency\ for\ capital\ investment\ (\%) = \frac{Net\ return/fed/season}{Total\ cost/fed/season} \times 100$$

(4) Statistical analysis:

Data were statistically analyzed according to the technique of analysis of variance (ANOVA) of the split plot design as described by Ref. [14]. The mean values were compared according to least significant difference (LSD).

3. Results and Discussion

3.1 Water Relations

3.1.1 Amount of Water Applied

Data in table 3 indicated that effect of the study factors on total amount of water applied, water use efficiency and water saving.

- Effect of Irrigation Methods

Data in Table 3 indicated that using automated irrigation method lead to decrease amount of water applied. Automated irrigation reduces the amount of water losses by infiltration. Automated irrigation control the amount of water applied. Whereas, traditional irrigation treatment consume amount of water applied than automated irrigation, where, 2116 and 2590 m^3/fed., respectively.

- Effect of Irrigation Systems

Data in Table 3 showed that, the lowest value of amount of irrigation water applied was 2303 m^3/fed. under subsurface drip irrigation and this is due to irrigation system efficiency higher than surface drip irrigation. Also, surface drip irrigation higher than subsurface drip irrigation by 4.3%. This result is in agreement with those obtained by Ref. [2].

3.1.2 Water Use Efficiency

The amount of water used to produce 1 kg of grain yield under the condition of this experiment is shown in Table 3. The lower amount of water used to produce 1 kg, the higher the water productivity.

- Effect of Irrigation Methods

The results indicated that higher water use efficiency values of grain yield was 1.11 kg/m^3 was obtained under automated irrigation, while traditional irrigation induced lower values 0.83 kg/m^3. This result is in agreement with those obtained by [15]**.**

- Effect of Irrigation Systems

Surface drip irrigation increased the water use efficiency of grain yield by 11.6% compared with traditional irrigation. The lowest value of water use efficiency was recorded with the subsurface drip irrigation system. This result is in agreement with those obtained by Ref. [16].

3.1.3 Water Saving

Considering water saving under different treatments data in table 3 show that automated irrigation method saved 474 m^3/fed by 18.3%. While subsurface drip irrigation saved water by 100 m^3/fed.

3.2 Corn Characteristics

3.2.1 The Growth Characteristics

Data in Table 4 indicated that effect of the study factors on growth characteristics. First of all, effect of irrigation methods and second, effect of irrigation systems and finally, effect the interaction between irrigation methods and irrigation systems on growth characteristics.

Table 3 Effect of Irrigation methods and systems on amount of water applied, WUE and water saving.

Treatments	Amount of water applied (m^3/fed)	WUE (kg/m^3)	Water saving (m^3/fed)
M_1	2116	1.11	474
M_2	2590	0.83	-
S_1	2403	1.02	-
S_2	2303	0.91	100

Table 4 Effect of irrigation methods and systems on some growth characters and yield components.

Measurements	Plant height (cm)			Leaf area (cm^2/plant)			Grain yield (Mg/fed)		
Systems / Methods	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
M_1	261.70	236.97	249.34	1257.86	1225.84	1241.85	2.52	2.16	2.34
M_2	254.13	236.30	245.22	1239.0	1191.23	1215.12	2.31	1.98	2.14
Mean	257.92	236.63	247.28	1248.43	1208.54	1228.48	2.42	2.07	2.24
LSD at 5%									
M		NS			NS			0.097	
S		NS			18.42			0.041	
M × S		NS			NS			NS	

Measurements	Weight of 100 grain (g)			Ear diameter (cm)			Ear length (cm)		
Systems / Methods	S_1	S_2	Mean	S_1	S_2	Mean	S_1	S_2	Mean
M_1	32.98	26.78	29.88	3.87	3.47	3.67	18.69	15.58	17.14
M_2	28.25	24.68	26.47	3.60	3.16	3.38	17.23	14.50	15.86
Mean	30.62	25.73	28.17	3.74	3.32	3.52	17.96	15.04	16.50
LSD at 5%									
M		NS			0.125			NS	
S		NS			NS			1.491	
M × S		NS			NS			NS	

- Effect of Irrigation Methods

Statistical analysis revealed that irrigation methods had no significant effect on plant height and leaf area. Automated irrigation increased the plant height and leaf area from 245.22 to 249.34 cm by percentage 1.7% and from 1215.12 to 1241.9 cm^2/plant by percentage 2.2% compared with traditional irrigation. Because using the automated irrigation to control the amount of irrigation water and therefore possible to control the moisture content in the soil and thus not to increase the percentage of moisture in the soil, leading to lack of ventilation in the soil. Automated irrigation increase the benefit of fertilization by increasing fertilizer use efficiency.

Traditional irrigation do not promote water conservation that result to too much water or too small amount of water in the soil thus poor plant growth. An automated irrigation is suggested to minimize the water input and human intervention, while satisfying the plant's needs.

- Effect of Irrigation Systems

Statistical analysis revealed that irrigation systems had no significant effect on plant height vice versa had a significant effect on leaf area. Surface drip irrigation gave the highest values of plant height and leaf area. Sub-surface drip irrigation decreased the plant height and leaf area by 8.26 and 3.2% compared with surface drip irrigation.

- Effect the Interaction between Irrigation Methods and Systems

The interactions between irrigation methods and systems were not significant on growth characteristics. The highest value of plant height and leaf area was 261.7 cm and 1257.86 cm^2 under automated and drip irrigation.

3.2.2 Yield Components

Results in Table 4 indicated that the highest values of ear diameter, ear length, and 100 grain weight were recorded for treatment automated irrigation followed by treatment with traditional irrigation. Ear diameter, ear length and weight of 100 grain were increased by 8.4, 8.03 and 12.9% when using automated irrigation compared with traditional irrigation. Because automated irrigation increase the benefit of fertilization by increasing fertilizer use efficiency.

Generally, it can be concluded that irrigated by sub-surface drip irrigation system showed slight decrease in yield components and produced the lowest values, which data were 11.24, 16.24 and 15.95% in the Ear diameter, ear length and weight of 100 grain.

3.2.3 Grain Yield

- Effect of Irrigation Methods

Data in Table 4 indicated that using automated irrigation lead to increase grain yield. It is evident that grain yield of the irrigation methods differed significantly. Automated irrigation treatment gave the best value of grain yield was 2.34 Mg/fed. Because automated irrigation increase the benefit of fertilization by increasing fertilizer use efficiency and gave the plant the best amount of water.

- Effect of Irrigation Systems

Data in Table 4 indicated that a significant differences in grain yield. The results show that subsurface drip irrigation has low value of grain yield, vice versa surface drip irrigation has the lowest value. Subsurface irrigation system reduced the grain yield from 2.42 to 2.07 Mg/fed by percentage 14.4% compared with surface drip irrigation.

3.3 Economic Analysis

Economic analysis has been carried out to evaluate the net return (LE/fed) and Net return/m^3 (LE/m^3) in new land under different treatments. All details are presented in Table 5. The maximum cost of irrigation system (LE/fed) and total cost (LE/fed) were achieved with surface drip with traditional irrigation, while the lowest value was achieved with surface drip with automated irrigation, vice versa the maximum total return (LE/fed) was achieved with using surface drip with automated irrigation while the lowest value was achieved with using sub-surface drip with traditional irrigation.

Table 5 The economic analysis under different treatments.

No.	Cost economics	Automated irrigation		Traditional irrigation	
		surface drip	sub-surface drip	surface drip	sub-surface drip
1	Depreciation	501.4	501.4	450.0	450.0
2	Interest	107.3	107.3	96.3	96.3
3	Taxes and overheads ratio	78.0	78.0	70.0	70.0
4	Fixed cost (1+2+3)	686.7	686.7	616.3	616.3
5	Labor cost	0.0	0.0	328.8	318.8
6	Energy cost	77.3	81.4	61.0	64.2
7	Repair and maintenance	234.0	234.0	210.0	210.0
8	Running cost (5+6+7)	311.3	315.4	599.8	593.0
9	Total irrigation cost, LE/fed (4+8)	998.0	1002.1	1216.1	1209.3
10	Cost of cultivation, LE/fed	1434.0	1434.0	1434.0	1434.0
11	Total cost, LE/fed (9+10)	2432.0	2436.1	2650.1	2643.3
12	Yield of produce, ton/fed	2.55	2.16	2.31	1.98
13	Selling price, LE/ton	1900.0	1900.0	1900.0	1900.0
14	Total return, LE/fed (12×13)	4845.0	4104.0	4389.0	3762.0
15	Net return, LE/fed (14-11)	2413.0	1667.9	1738.9	1118.7
16	Water productivity, LE/m^3	1.11	0.81	0.66	0.44
17	Benefit cost ratio	1.99	1.68	1.66	1.42
18	Economic efficiency for capital investment (%)	99.22	68.47	65.62	42.33

Economic analysis refer to, the highest values of net return (LE/fed), water productivity (LE/m^3), Economic efficiency for capital investment (%) and benefit cost ration were 2413, 1.11, 99.22 and 1.99 was found under surface drip with automated irrigation, while the minimum indicators were 1118.7, 0.44, 42.33 and 1.42 was achieved with sub-surface drip with traditional irrigation.

4. Conclusions

(1) Precision irrigation was used less water and increase corn yield.

(2) Automated irrigation can be used in large or small farm in Egypt.

(3) Automated irrigation with surface drip irrigation produced the highest values of grain yield, Water use efficiency, net return and benefit cost ratio, while produced the lowest values of amount of water applied and total cost.

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