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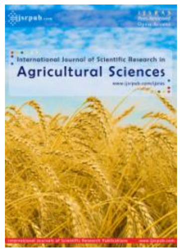

Full Length Research Paper

Effect of Sprinkler Irrigation Systems and Irrigation Frequency on Water Use Efficiency and Economical Parameters for Wheat Production

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Abstract. As for population of more than 90 million, Egypt cannot meet its need for food as adequate water is not available for crop production .So to identify and adopt measures that will reduce water use and increase crop production, this study was conducted in farmers' fields during 2009/2010–2010/2011to evaluate the water use efficiency and economic viability of sprinkler irrigation system for growing wheat crop. Two field experiments were conducted in the Research and Production Station of the National Research Centre in El-Nubaria El-Behera Governorate. The water-use characteristics of wheat were studied in the field under sprinkler irrigation system. Treatments consisted of two sprinkler irrigation systems, solid set sprinklers (S_1) and hand move laterals (S_2), and three irrigation frequencies (IF_1: once per week; IF_2: twice per week, IF_3: three times per week). Total irrigation amount values varied from 3924.373 to 4081.3 $m^3.ha^{-1}$ in 2009-2010 and 4313.6 to 4486.2 $m^3.ha^{-1}$ in 2010-2011. The highest seasonal ET was obtained from the S_2IF_3 treatment in 2010-2011 (5417.1 $m^3.ha^{-1}$); the lowest value was observed in the S_1IF_1 treatment in 2009-2010 (4513.0 $m^3.ha^{-1}$). On average, the S_1IF_3 treatment gave the highest grain yield (5832.5 $kg.ha^{-1}$), whereas S_2IF_1 treatment gave the lowest grain yield (3332.5 $kg.ha^{-1}$). IWUE values varied from 1.0 to 1.43 $kg.m^{-3}$ in 2009-2010 and from 0.87 to 1.34 $kg.m^{-3}$ in 2010-2011. WUE values varied from 0.87 to 1.19 $kg.m^{-3}$ in 2009-2010 and from 0.79 to 1.16 $kg.m^{-3}$ in 2010-2011. Also, under solid set sprinkler irrigation system and irrigation frequency occurred maximum value of net income. For winter wheat in the El-Nubaria, the recommended sprinkler system and irrigation frequency for each event is solid set sprinkler (S_1) and irrigation three times per week (IF_3).

Keywords: Irrigation Frequency, Solid Set Sprinkler, Hand Move Laterals, IWUE, WUE, Economical Parameters for Wheat Production

1. INTRODUCTION

In many arid and semi-arid countries where population growth is unlimited, and freshwater is in short supply, there is pressure on the agricultural sector to reduce its water consumption and make it available for the urban and industrial sectors. This drives the demand to produce cereals, especially rice and wheat, using lower amount of irrigation water. Irrigation frequency is one of the most important factors in pressurized irrigation scheduling. Due to the differences in soil moisture and wetting pattern, crop yields may be different when the same quantity of water is applied under different irrigation frequencies. The higher the irrigation frequency the smaller the wetted soil volume and the higher mean soil water content can be maintained in the wetted soil volume during a period when the total irrigation water is equal. High irrigation frequency might provide desirable conditions for water movement in soil and for uptake by roots (Segal et al., 2000). Several experiments have shown positive responses in some crops to high frequency drip irrigation (Freeman et al., 1976; Segal et al., 2000; Sharmasarkar et al., 2001). However, seeming inconsistencies as to what frequency might be optimum can also be found in the literature. Dalvi et al. (1999), found that the maximum yield was obtained at every second day frequency. Sprinkler irrigation is an advanced irrigation technique for water-saving and fertigation and in accurately controlling irrigation time and water amount (Li and Rao, 2003). Study on winter wheat showed that crop yield and water use efficiency in sprinkler-irrigated fields was higher than that in surface irrigated fields (Yang et al., 2000). Tolk et al. (1995) found sprinkler irrigation resulted in crop transpiration reduction by more than 50% during irrigation process. The increasing in photosynthesis rate and reduction in leaf respiration rate at night also has been found in sprinkler-irrigated area (Chen, 1996; Yang et al., 2000). The nutrient concentrations in the rhizosphere may be high or even excessive immediately after irrigation and may fall to deficit levels as time proceeds (Xu et al., 2004). Reducing the time interval between successive irrigations in order to maintain constant, optimal water content in the root zone may reduce the variations in nutrient concentration, thereby increasing their availability to plants (Silber et al., 2003). Wheat is one of the most important crops in the world. Well-drained clay loam, loam, and sandy loam soils are particularly suitable for this crop. Therefore, proper management of inputs particularly irrigation water using modern technology is essential for maximizing production and for providing high returns to farmers. Provided the area of cropped land does not increase, increasing water use efficiency is one of the most important ways to increase crop production, save water and protect the environment (Haijun Liu et al., 2011). Wheat is quite sensitive to water stress. Therefore, it needs frequent irrigation for good growth and yield (Mishra et al., 1995; Alderfasi and Nielsen, 2001). The main objective of this study is studying the effect of sprinkler irrigation systems and irrigation frequency on water use efficiency and economical parameters of wheat production to determine the best treatment which will achieve the highest water use efficiency and maximum net income.

2. MATERIALS AND METHODS

Field experiments were conducted during two seasons from December to May of 2009–2011 at the experimental farm of National Research Center, El-Nubaria, Egypt (latitude 30^o 30$^\backslash$ 1.4$^{\backslash\backslash}$ N, and longitude 30^o 19$^\backslash$ 10.9$^{\backslash\backslash}$ E, and mean altitude 21 m above sea level) as shown in fig. (1). The experimental area has an arid climate with cool winter and hot dry summer.

2.1. Soil physical and chemical properties:

The soil of experimental site is classified as Sandy soil. Some physical and chemical properties of the experimental soil is presented in Table 1 and Table 2. Irrigation water was obtained from an irrigation channel passing through the experimental area, with pH 7.35, and an average electrical conductivity of 0.41 dS m^{-1}.

2.2. Experimental design:

The water resource for rotational irrigation where the water exist in the channel just for three days every week and the residual four days the channel is empty, the idea was to apply water more than once per week and to evaluate its effect on water saving, irrigation water use efficiency (IWUE), yield and growth characteristics and financial parameters using two types of sprinkler systems, solid set and hand move laterals fig. (2) and three irrigation frequency treatments, each replicated three times. The variables of Irrigation frequency were to apply irrigation water once per week (IF_1) which represents the control, twice per week (IF_2)) and three times per week (IF_3). The treatments and replications are shown in (Fig. 3). For the sprinkler irrigation treatments, each replicate subplot was 60m × 24m layout. There was 3m spacing between subplots. Each subplot was irrigated using 90^O, 180^O and 360^O angle sprinklers, the sprinkler is a metal impact sprinkler 3/4" male (NAAN Sprinkler 233 A-S, Israel) with a discharge of 1.170 m^{3}h^{-1}, wetted radius of 13.5m, working pressure of 300 KPa and irrigation intensity of 8.10 mmh^{-1}. The irrigation system’s control unit had a two sand filters (Amiad, Israel) 3" inlet/outlet diameter, 36" vessel diameter, 35-50 m^{3}h^{-1} and 200kg vessel weight (empty) , and screen filter 200 mesh, a flow-meter and a pressure regulated valve were installed at the head of the irrigation system to measure the applied water and to control the system pressure. After the filtration system the solid set sprinkler irrigation system had 27 laterals 60m long installed on a 1.944ha field (approximately 324 m long and 60 m wide) with an average slope of 0.0 %.

The hand move Laterals system had the same area but just 3 laterals were installed at each irrigation event with the same laterals length and sprinklers spacing. A good procedure for the irrigator was followed when moving the lateral from one setting to the next by start moving the valve-opening elbow and the section of pipe connected to it. As soon as these pieces are in place at the new location, the valve was slightly opened so a very small stream of water runs out the end of the first pipe section. As each subsequent section of pipe was put into place, the small stream of water runs through it, flushing out any soil or debris that may have been picked up during the move. The last section of pipe with its end plug in place was connected before the stream of water reaches the end and builds up pressure. Then the irrigator walks back along the lateral, correcting any plugged sprinklers, leaky gaskets, or tilted risers. After returning to the main line, the valve was opened further until the desired pressure was obtained. A quick check was applied with a pitot gauge on the first sprinkler confirms the valve adjustment. To save time on each lateral move, there is a tendency to completely open the valve and fill the line as quickly as possible. This causes water hammer at the far end of the line, so a surge plug at that end was installed.

2.3. Cultural Practice:

The experimental field was deep ploughed before planting. First disc harrow, then duck food was used for further preparation of the field for planting. A combined driller that facilitated concurrent application of fertilizer and seeds was used. A wheat variety (Sakha-93) was planted on 6 December on both growing seasons 2009-2010 and 2010-2011, respectively. The driller setting was such that it applied 250 kg of seed per hectare, at 5 cm soil depth with 13.5 cm row spacing. Fertilizer applications were based on soil analysis recommendations. All treatment plots received the same amount of total fertilizer. A compound fertilizer was applied according to (Taha, et al., 1999) as follow: 285 kg $N.ha^{-1}$ as ammonium nitrate, ten percent applied to the soil before planting and at tillering, the remainder being applied in irrigation water, 70 kg $P_2O_5.ha^{-1}$ as single superphosphate applied to the soil in two equal doses before planting and at tillering and 115 kg $K_2O.ha^{-1}$ as potassium sulphate applied in three doses (half applied to the soil before planting, one quarter at tillering and one quarter during the growing season in irrigation water).

2.4. Crop Factors:

Leaf area, plant density and above ground biomass were measured every 5–7 days from December to February in each season. For each measurement, 25 plants were selected randomly from the experiment replicates for each treatment. The plant density for each treatment was determined as the mean value of three 1m long crop samples. Leaf area was determined using leaf length and the maximum width. The calibrated relationship between the leaf area and the length and width was LA = 0.7634 × L × W (R^2 = 0.967, n = 18), where LA is leaf area, L and W are length and maximum width, respectively. Crop yield for each treatment was measured by randomly collecting five samples. Therefore, each treatment has 15 samples for the three replicates. Sample area was $1m^2$.

2.5. Water-use efficiency:

(WUE) and irrigation water-use efficiency (IWUE) values were calculated with fowling Eqs. (Howell et al., 1990).

$$\mathrm{WUE} = (\frac{E_y}{E_t}) \times 100 \qquad (1)$$

Where WUE is the water use efficiency (t ha^{-1} mm); Ey is the economical yield (t ha^{-1}); Et is the plant water consumption, mm.

$$I\mathrm{WUE} = (\frac{\mathrm{E_y}}{\mathrm{I_r}}) \times 100 \qquad (2)$$

Where IWUE is the irrigation water use efficiency (t ha^{-1} mm), Ey is the economical yield (t ha^{-1}), Ir is the amount of applied irrigation water (mm).

2.6. Economical analysis:

Net income was determined by the following equation: Net income, "NI" = Total income for output – Total costs for Inputs. Table (4) shows some details around above equation Rizk, (2007).

2.7. Cost analysis of Irrigation:

Partial cost was conducted to evaluate differences between tested variables, and it was computed according to Worth and Xin (1983). The total cost for each treatment was calculated based on feddan dimensions (60 m x 70 m). According to the market price level of 2012 for equipment and installation. The analysis was followed the outlined procedure:

Total annual cost (LE/year)=Annual fixed cost (F) + Operating cost (O)

1. Annual fixed cost (F): Annual fixed cost, (LE/year) invested in the irrigation system were calculated according to following the equations: F = D + I + T Where, D= Depreciation rate, (LE/year), I= the interest, (LE/year) and T= Taxes and overhead ratio, (LE/year). Depreciation cost was calculated using the following equation: D = (I.C - E.C)/ E.L Initial cost (I.C) (LE/fed.) = Irrigation network item price, (LE) x Item quantity per fed. E.C = Price after the depreciation, (LE) and E.L = Expected life, (year) and Interest on Initial was calculated as follows: I = (I.C + E.C) x I.R /2 Where, I.R = Interest rate/year, (taken 14 %) Taxes and overhead ratio were taken as 1.5 % of Initial cost.
2. Operating cost (O): Annual operating cost (LE/year) of the capital investment in the irrigation system was calculated as follows: O = L + E + (R&M) + IS Where, L = Labor cost, (LE/year) E = Energy cost, (LE/year) R&M = Repair and maintenance cost, (LE/year) IS = Lateral installation cost, (LE/year). Energy cost was calculated as follows: E = Energy consumed (kW.h) x Energy unit price (LE/kW.h) R&M cost taken as 3 % of initial cost.

2.8. Statistical Analysis:

Statistical analysis was done by standard analysis of variance (ANOVA) with SPSS 11.5 software (SPSS

Inc., Chicago, IL, USA). Least significant difference (LSD) method was used to determine whether differences existed among mean growth characteristic, yield, WUE and IWUE of winter wheat among experimental treatments for each season. The probability level for determination of significance was 0.05.

Table 1: Soil physical characteristics of experimental site

Soil depth (cm)	Particle size distribution			Texture Class	SP. (%)	F.C. (%)	W.P. (%)
	Coarse Sand	Fine sand	Clay + Silt				
20	47.76	49.75	2.49	Sandy	21.0	10.1	4.7
40	56.72	39.56	3.72	Sandy	19.0	13.5	5.6
60	59.40	59.40	3.84	Sandy	22.0	12.5	4.6

Table 2: Soil chemical properties of experimental site

Soil depth (cm)	OM (%)	pH (1:2.5)	EC (dSm^{-1})	$CaCO_3$ (%)
20	7.02	0.35	8.7	0.65
40	2.34	0.32	8.8	0.40
60	4.68	0.44	9.3	0.25

Table 3: Method for calculation the net income

Item	Sprinkler Irrigation Systems	All treatments
	Irrigation Frequency	
List of inputs	Cost of irrigation, LE/ha.	
	Cost of land preparation, LE/ha.	
	Cost of tubers seeds, LE/ha.	
	Cost of Microbin, LE/fed	
	Cost of weed control, LE/ha.	
	Cost of pest control, LE/ha.	
	Cost of harvesting, LE/ha.	
	Total costs for inputs, LE/ha.	
Output	Yield, ton/ha.	
	Total revenue for output, LE/fed.	
Net income = list of outputs – list of inputs		

3. RESULTS AND DISCUSSIONS

3.1. Irrigation

The results of total irrigation water amount are shown in Table 4. Treatments S_1IF_1 and S_2IF_1 received the lowest amount of water and treatments S_1IF_3 and S_2IF_3 received the highest amount of water, respectively, throughout the entire experiment. Similarly, ET increased as the amount of water applied enhanced. There was a significant positive linear and exponential correlation between I and ET, R^2 = 0.8364 in 2000-2010 and R^2 = 0.8368 in 2010-2011 (Fig. 4). Total irrigation water amount (I) was in general higher in the treatments irrigated with high amount of water than those irrigated with low amount of water. Irrigation water amount (I) values of the IF_3 treatment were higher than those of the IF_1 and IF_2 treatments under both sprinkler irrigation systems (Table 4). This might be because plants were not suffered from water deficit in short irrigation intervals. According to Radin et al. (1989), frequent irrigations prevent the large fluctuation in plant water stress caused by infrequent irrigations.

Table 4: Total irrigation water amount (I), plant water consumption (ET), Biological yield, grain yield, irrigation water use efficiency and water use efficiency in different years and treatments

Growing season	Treatments	I (m^3/ha)	ET (m^3/ha)	Biological yield (Kg/ha)	Grain yield (Kg/ha)	IWUE (kg/m^3)	WUE (kg/m^3)
2009-2010	S_1IF_1	3924.4	4513.0	9917.0 c	3917.5 cd	1.00 d	0.868 a
	S_1IF_2	3983.0	4620.6	12250.0 b	5082.5 b	1.28 b	1.100 d
	S_1IF_3	4081.3	4897.6	13917.5 a	5832.5 a	1.43 a	1.191 b
	S_2IF_1	3924.4	4648.4	7417.5 d	3332.5 d	0.85 e	0.717 b
	S_2IF_2	3983.2	4759.2	10000.0 c	4167.5 c	1.05 c	0.876 d
	S_2IF_3	4081.3	5044.5	12582.5 b	5082.5 b	1.25 b	1.008 c
	L.S.D.	Ns	Ns				
2010-2011	S_1IF_1	4313.6	4745.0	9832.5 c	3750.0 cd	0.87 d	0.790 e
	S_1IF_2	4378.3	4991.3	12417.5 b	5250.0 b	1.20 b	1.052 b
	S_1IF_3	4486.2	5159.1	13832.5 a	6000.0 a	1.34 a	1.163 a
	S_2IF_1	4313.6	4839.9	7500.0 d	3417.5 d	0.79 e	0.706 f
	S_2IF_2	4378.3	5091.1	10082.5 c	4417.5 c	1.01 c	0.868 d
	S_2IF_3	4486.2	5417.1	12667.5 b	5250.0 b	1.17 b	0.969 c
	L.S.D.	Ns	Ns				
2009-2010		3996.3 b	4747.2 b	11014.2	4569.2	1.14 a	0.960 a
2010-2011		4392.7 a	5040.5 a	11055.4	4680.8	1.06 b	0.925 b
L.S.D.				Ns	Ns		

Note: Numbers followed by different letters are statistically different ($P < 0.05$).

Table 5: Effect of treatments on Biological Yield, Straw Yield and Grain Yield, (Average of two seasons)

Treatments	Biological Yield (Kg/ha)	Straw Yield (Kg/ha)	Grain Yield (Kg/ha)
S_1IF_1	9875	6041	3834
S_1IF_2	12334	7168	5166
S_1IF_3	13875	7959	5916
S_2IF_1	7459	4084	3375
S_2IF_2	10041	5748	4293
S_2IF_3	12625	7459	5166

3.2. Wheat yield

The biological and grain yield of wheat based on 2 years, irrigation frequencies and sprinkler irrigation systems are given in Table 4. There was a statistically no significant difference in biological and grain yield between the years ($P < 0.05$) possibly due to that there was not a notable climate differences. The effect of irrigation frequency was statistically significant effects ($P < 0.05$) on wheat yield. The maximum grain yield of wheat was found in 2010-2011 (6000 $kg.ha^{-1}$) under S_1IF_3 treatment whereas the lowest grain yield was found in 2009-2010 (3332.500 $kg.ha^{-1}$) under S_2IF_1 treatment (Table 4)

Fig. 1: Location of the experimental farm in EL-NUBARIA Region, Egypt

Fig. 2: Side from disadvantages of hand move sprinkler laterals

3.3. Irrigation water use efficiency

Applied irrigation water varied from 3924.4 to 4081.3 $m^3.ha^{-1}$ in 2009-2010, and 4313.6 to 4486.2 $m^3.ha^{-1}$ in 2010-2011. IWUE values varied from 1.00 to 1.43 $kg.m^{-3}$ in 2009-2010 and from 0.87 to 1.34 $kg.m^{-3}$ in 2010-2011. WUE values varied from 0.87 to 1.19 $kg.m^{-3}$ in 2009-2010 and from 0.79 to 1.16 $kg.m^{-3}$ in 2010-2011. On the other hand, IWUE and WUE values in the treatments with the high total water application were generally high. The irrigation water use efficiency data shows that wheat plants use water efficiently during the vegetation period. The ET value increased markedly when total irrigation water amount (I) raised (Table 4). The highest seasonal evapotranspiration was obtained from the S_2IF_3 treatment in 2009-2010 (5044.5 $m^3.ha^{-1}$), whereas the lowest value was observed in the S_1IF_1 treatment in the same growing season (4513.0 m^3/ha). The other treatments had ET values between these extremes. There was a statistically significant difference in total irrigation water amount (I), plant water consumption (ET), irrigation water use efficiency (IWUE) and water use efficiency (WUE) between the years ($P < 0.05$). Kanber et al. (1991) reported that the amount of irrigation water decreased when IWUE and WUE values increased. Studies have shown that frequently applied low irrigation water increases the yield because ET was higher when irrigation started at low soil water tensions (Stansell and Smittle, 1989). Goldberg et al. (1976) stated that irrigation period was more effective than the total amount of water applied, when plants were irrigated with a limited amount of water in early growth stage because of higher photosynthetic efficiency and vegetative growth. In this study, IWUE and WUE values from S_1IF_1 to S_1IF_3 and from S_2IF_1 to S_2IF_3 have been generally increasing. This indicates that wheat uses water economically. These findings agree with those of Dallyn (1983). On over all the values solid set sprinkler (S_1) were higher than of those under hand move laterals (S_2) which represent the applied systems by farmers this related to that the distribution uniformity under hand move laterals was low because there was an overlapping just between sprinklers along laterals not overlapping between sprinklers along laterals and between laterals which made a square plan. The second reason is related to the long irrigation period related to transform lateral to another location which make an obligation to irrigate under high temperature and which accordingly increase water losses through evaporation. On the other hand sold set sprinkler (S_1) was irrigate the whole area at the same time approximately from 7:00 to 9:00 am so the water losses through evaporation were almost negligible.

Table 6: Total costs (TC), total income (TI) and net return (NR) in different years and treatments (Average of two seasons)

	Treatments	S_1IF_1	S_1IF_2	S_1IF_3	S_2IF_1	S_2IF_2	S_2IF_3
List of inputs	Cost of water pumping (L.E./ m^3)	0.35	0.20	0.13	0.37	0.20	0.14
	Total amount of irrigation water /season/ha (m^3)	4629	4806	5028	4744	4925	5231
	Cost of Irrigation, L.E/ha.	1620	961	654	1755	985	732
	Cost of land preparation, LE/ha.	200	200	200	200	200	200
	Cost of seeds, LE/ha	552	552	552	552	552	552
	Cost of mineral fertilizers, LE/ha.	1500	1500	1500	1500	1500	1500
	Cost of bio-fertilizers LE/ha	100	100	100	100	100	100
	Cost of weed control, LE/ha.	1000	1000	1000	1000	1000	1000
	Cost of pest control, LE/ha.	360	360	360	360	360	360
	Cost of harvesting, LE/ha	360	360	360	360	360	360
	Cost of labor, LE/ha.	960	960	960	960	960	960
Total costs, LE/ha.		11281	10799	10714	11531	10942	10995
Output	Grain Yield (ton/ha)	3834	5166	5916	3375	4293	5166
	Straw Yield, (ton/ha)	6041	7168	7959	4084	5748	7459
Total Income, LE/ha.		12562	16343	18566	10318	13456	16517
Net Return = TI of outputs – TC of inputs		1281 d	5544 b	7852 a	-1213 e	2514 c	5522 b

IF_1: once per week; IF_2: twice per week, IF_3: three times per week, The prices according to 2012 where 1$ = 6.09 L.E. , Yg = 350 * 6.66 ardb , Yg: Grain yield, Ys: Straw yield

3.4. Economical analysis

Appling any technique depending on two sides, technical side and the other is economical side. Total costs, total income and net return were studied as a evaluation parameters to the effect of sprinkler irrigation systems and irrigation frequency. Table (5) represents the effect of treatments on biological Yield, straw yield and grain yield (Average of two seasons). Table (6) shows the estimation of total costs and calculating total income (TI) needs to price all outputs from straw yields and grain yields under each treatment. One Grain yield (Yg) = 350 L.E. for ardab and ton = 6.66 ardab and straw yield (Ys) = 600 L.E. so, Yg = 2331 L.E/ton and Ys = 600 L.E/ton. according to the fowling Eq

$$TI_{1\text{-}6} = Yg_{1\text{-}6} * 2331 + Ys_{1\text{-}6} * 600$$

$$NI_{1\text{-}6} = TI_{1\text{-}6} - TC_{1\text{-}6}$$

Where : $TI_{1\text{-}6}$ = Total income from treatment 1 to treatment 6; $Yg_{1\text{-}6}$= Grain yield form treatment 1 to treatment 6; $Ys_{1\text{-}6}$ = Straw yield form treatment 1 to treatment 6; Table (6) indicate the maximum value of NR occurred under S_1IF_3 which was 7852 L.E. ha^{-1} and the minimum value was – 1213 L.E. ha^{-1} under S_2IF_1.

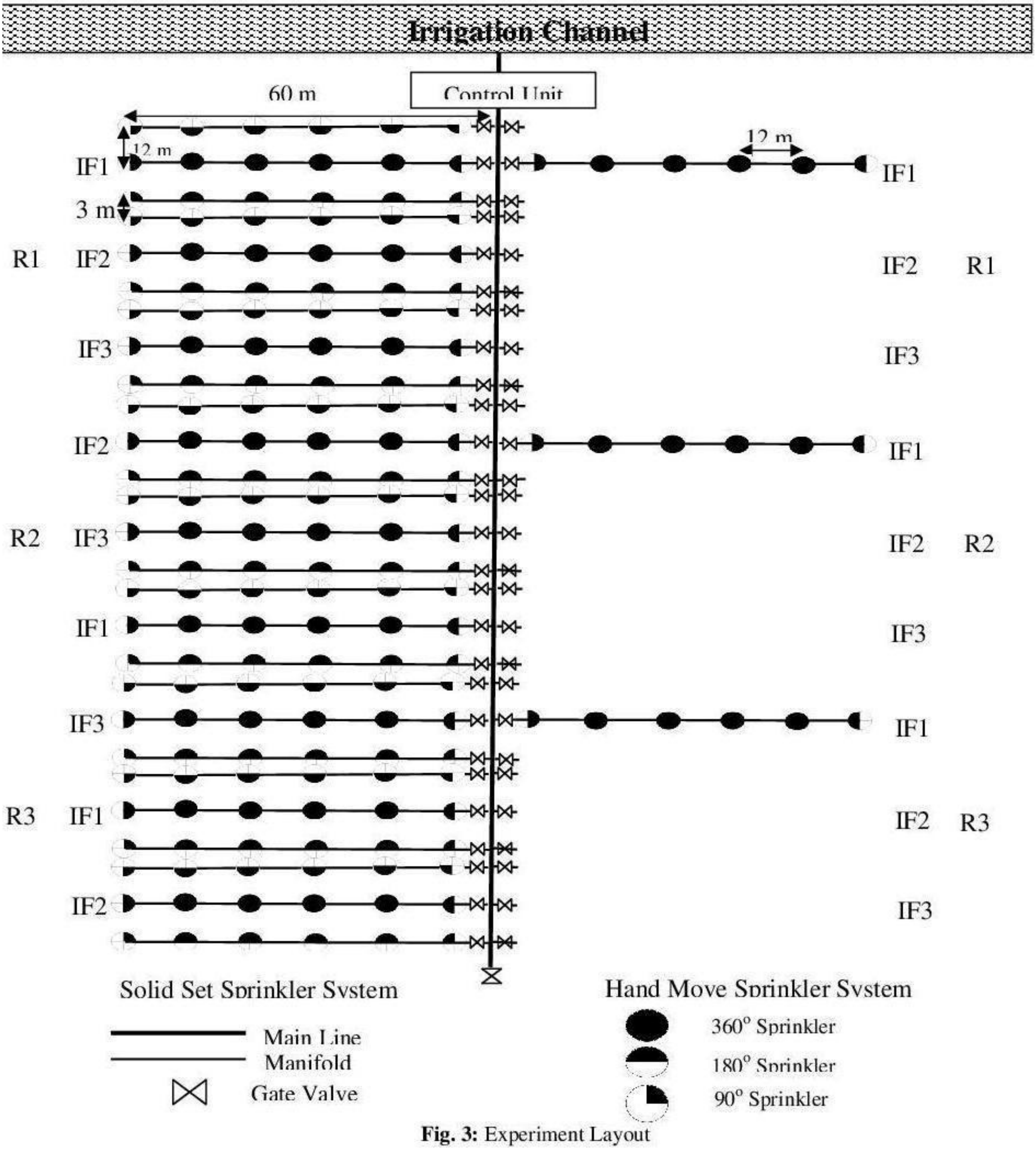

Fig. 3: Experiment Layout

4. CONCLUSION

Under solid set sprinkler irrigation system and irrigation frequency three times per week (IF_3) occurred best result of technical side and occurred also, maximum value of net return and there are significant differences.

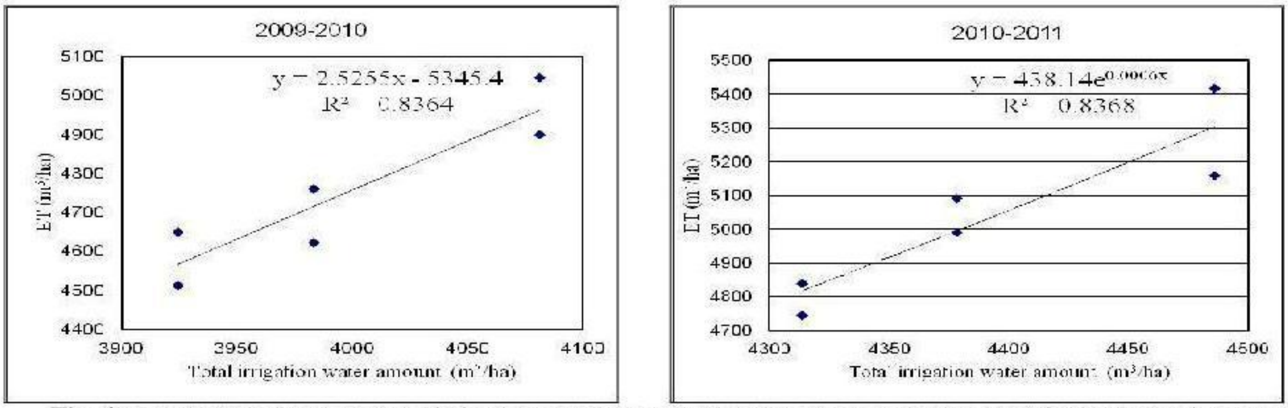

Fig. 4: Relationship between Total irrigation water amount (I) and evapotranspiration (ET) for both growing seasons

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