Effect of Using Different Span Sizes on Irrigation Performance of Center Pivot Irrigation Systems

Eid S. F. M.[1] Khaled Shalabi[1] Tarek Salem[1]
On Farm Irrigation and Drainage,
Agricultural Engineering Research Institute,
ARC, Dokky, Giza, Egypt

***Abstract* – The effective features of center pivot performance are well documented but few studies have been conducted to evaluate the effect of using different span sizes on irrigation performance of center pivot irrigation systems. The aims of this research are to investigate the possibility of saving energy using a different span sizes of center pivot irrigation system when irrigates 63ha of irrigated land, determine the relationship between energy savings and the annual operating cost of the center pivot and its pump and figure out the payback period versus the extra investment required when using bigger span sizes. To achieve the targets of this research, nine (9) configurations of center pivot with different spans sizes of 6-5/8" and 8-5/8", have been hydraulically tested. The obtained results showed that 77% of the total area of 63.3 hectares is irrigated by the last four spans and the overhang while the first four spans is irrigated only23% of the total area., 90% of the cumulative friction loss occurred in the first five spans when the 6-5/8" pipe size spans are configured the center pivot. The lowest cumulative friction loss of 0.8 bar is occurred when using 7 spans 8-5/8" pipe size and last two spans as 6-5/8". 33% of the annual operating cost is saved at the same configuration. Payback period is obtained as one year in case using five spans 8-5/8" pipe size while increased to two years in case using seven spans of 8-5/8" pipe size.**

Keywords: Center Pivot, Energy Cost, Annual Operating Cost, Payback period.

1. INTRODUCTION

A center pivot irrigation system consists of number of spans that rotate around the central pivot point, where water is supplied to the spans under pressure. All spans are equipped with either fixed or dynamic sprinklers that spaced and sized to supply uniform depth of water in the irrigated field.

Rising energy prices, especially when combined with falling water tables, can increase the operating cost of the irrigation to uneconomical levels. Hence, there is a need to figure out the ideal span sizes that should be used when configure the center pivot to irrigate a specific irrigated area

There are many important factors which can be used to determine whether a center pivot irrigation system is properly designed. Among these factors are; Energy use, Application depth, Application uniformity, Instantaneous application rate and Application efficiency. The effective features of center pivot sprinklers such as wetted diameter, application rate pattern shape, drop size and distribution uniformity have been reported in the scientific literatures (Kincaid D. C., 1996); (Faci, 2001); (DeBoer, 2001); (Sourell, 2003); (Playa'n, 2004) and (Kincaid D. , 2005). An improvement in the design of a center pivot irrigation system will require the improvement of one or more of these factors. Many researchers (von Bernuth, 1983); (Solomon, K. and M. Kodoma. , 1978); (Heermann, D. F. and P. R. Hein. , 1968) have studied and developed methods which could improve the performance of center pivot irrigation systems with regard to energy use, application rate, and/or application uniformity.

The aims of this research are to investigate the possibility of saving energy using a different span sizes of center pivot irrigation system when irrigates 63ha of irrigated land, determine the relationship between energy savings and the annual operating cost of the center pivot and its pump and figure out the payback period versus the extra investment required when using bigger span sizes.

2. MATERIALS AND METHODS

A Center pivot with radius of 450 meter to irrigate 150 Feddan (63 hectares). The flow rate delivered to the pivot was 350 m^3/hr, so the application rate per unit of area was 5.51 m^3/hr.

Different center pivot configurations of span sizes and lengths as shown in Table (1) are used in this study to configure one center pivot with radius of 450 meter to achieve the study targets as follows:

Table 1: Center Pivot Configuration Scenarios

Configuration Scenarios	Number of Span with 168mm pipe Outside diameter	Span Length with 168mm pipe Outside diameter, m	Number of Span with 219mm pipe Outside diameter	Span Length with 219mm pipe Outside diameter, m	Overhang Length, m
Configuration 1	8	56.1	0	0	0
Configuration 2	7	56.1	1	51.5	6.2
Configuration 3	6	56.1	2	51.5	12.1
Configuration 4	5	56.1	3	51.5	17.7
Configuration 5	4	56.1	4	51.5	24
Configuration 6	4	56.1	5	51.5	0
Configuration 7	3	56.1	6	51.5	0
Configuration 8	2	56.1	7	51.5	0
Configuration 9	1	0	8	51.5	0

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1. Center pivot consists of eight (8) spans of 56 meters length with 6-5/8” pipe size plus 2 meters length overhang,
2. Center pivot consists of one (1) span of 50 meters length with 8-5/8” pipe size, seven (7) spans of 56 meters length with 6-5/8” pipe and 6 meters length overhang,
3. Center pivot consists of two (2) spans of 50 meters length with 8-5/8” pipe size, six (6) spans of 56 meters length with 6-5/8” pipe and 12 meters length overhang,
4. Center pivot consists of three (3) span of 50 meters length with 8-5/8” pipe size, four (4) spans of 56 meters with 6-5/8” pipe and 18 meters overhang,
5. Center pivot consists of four spans of 50 meters length with 8-5/8” pipe size, four (4) spans of 56 meters with 6-5/8” pipe and 24 meters length overhang,
6. Center pivot consists of five spans of 50 meters length with 8-5/8” pipe size, three (3) spans of 56 meters with 6-5/8” pipe and 24 meters overhang,
7. Center pivot consists of six spans of 50 meter with 8-5/8” pipe size, three (3) spans of 56 meters with 6-5/8” pipe and no overhang,
8. Center pivot consists of seven spans of 50 meter with 8-5/8” pipe size, two (2) spans of 56 meters with 6-5/8” pipe and no overhang,
9. Center pivot consists of eight spans of 50 meter with 8-5/8” pipe size, two (1) span of 56 meters with 6-5/8” pipe and no overhang,

The well and its pump were located outside the irrigated area 500 meters away of the center pivot point. A mainline of 500 meters length and 10” pipe size is used to deliver the water from the pump to the center pivot point as shown in Fig. (1).

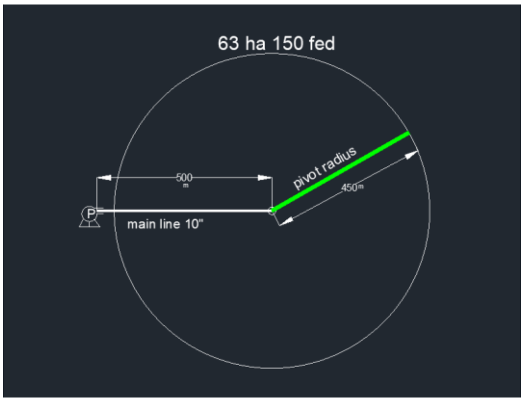

Fig (1): Center pivot with 450 meters radius and its mainline – 10” to the well and its pump.

To achieve the first target of this study regarding investigating the possibility of saving energy using a different span sizes of center pivot irrigation system, the end pressure of the center pivot is adjusted to be (1) bar and the pivot point pressure is calculated considering the friction losses inside the spans of every center pivot configuration of the above mentioned nine scenarios plus the friction losses occurred inside the mainline which deliver the water from the pump to the center pivot using Hazen Williams equation.

Hazen Williams equation in SI units (John D. Valiantzas, 2007):

$$H_{f\ per\ 100} = 2.4\,X 10^{8}\,\left(\frac{100}{C}\right)^{1.85}\left(\frac{Q^{1.852}}{D^{4.87}}\right) \quad \text{……… (1)}$$

where
$H_{f\ per\ 100}$ = head loss due to pipe friction per 100m of pipe (m/100m)
Q = flow rate, l/s;
D = pipe inside diameter, mm and
C = Hazen-Williams factor, dimensionless
For center pivot system where there is no end gun at the end of the system, the total friction head loss along the center pivot lateral is calculated as follow, (Richard G. Allen, Jack Keller, Derrel Martin, 2011):

$$H_f = \frac{H_{f\ per\ 100}\ L_h\ F_p}{100}$$

Hf = head loss due to pipe friction along the center pivot lateral, m
$H_{f\ per\ 100}$ = head loss due to pipe friction per 100m of pipe (m/100m)
Fp = friction adjustment factor for center pivot laterals to compensate for reduced discharge along the pipe of length, dimensionless
L_h = the equivalent hydraulic length of a center pivot lateral, m

For center pivot laterals, Fp ranges from 0.55 for 270 outlets to 0.560 for system having only 40 outlets. Thus, for almost all standard pivots a value of Fp = 0.555 will give results that accurate to within +/-1%

Average application rate is computed using the following formula (John D. Valiantzas, 2007):

$$I_a = 2\ X\ 1000\ X\ L_s\ X\ Q_p\ X\ \left(L_p + R_g\right)\ {}^{2} X\ L_d \quad \text{…….. (2)}$$

where
Ia = average application rate (mm/hr.);
Ls = distance to sprinkler (m);
Qp= pivot flow rate (m^3 /hr);
Lp = length of pivot (m);
Rg = end gun radius (m) and
Ld = sprinkler throw diameter (m).

Depth of water applied by the center pivot at a specific forward speed of the last tower is calculated as follow (John D. Valiantzas, 2007):
$D = Q_p$ x T_r x 318.3 $(Lp + Rg)^2$ ……………… (3)

Where
D = depth of water applied (mm);
Qp= pivot flowrate (m3 /hr);
Tr = hours per revolution (hrs.);
Lp = pivot length (m) and

Rg= end gun radius (m)

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A new sprinkler chart is created per each configuration of the nine proposed scenarios for this study to reveal the calculated pressure at the pivot point, the nozzle size in every outlet of each span based on number of spans, flow rate, end pressure, flow rate per each outlet along all towers and the overhang.

The outlet spacing in all spans have been selected to 1.486 meters between adjacent outlets. Sprinklers' clearance was 1.5 meter above the ground.

Table (1) reveals the applicate depth per revolution versus different forward speed of the last span of all different center pivot configurations:

Table 2: Water Applicate depth per revolution at all different scenarios

FULL CIRCLE		
Timer %	Hrs/Rev	mm/Rev
100	11.6	6.4
80	14.4	8.0
70	16.5	9.1
60	19.3	10.6
50	23.1	12.7
40	28.9	15.9
30	38.5	21.2
20	57.8	31.8
15	77.0	42.4
10	115.5	63.6
8	144.4	79.5
6	192.5	106.0
5	231.0	127.2

The annual energy requirement for an irrigation delivery system depends on annual irrigation requirements and the power needed to pump the water. In order to determine the relationship between energy savings and the annual operating cost of the center pivot and its pump, the required horse power at the pump is calculated for each center pivot configuration based on the pivot point pressure plus the friction loses of the mainline. All of the pump characteristics curves are related to the discharge. The efficiency at any given discharge gives the relationship between the useful energy transferred from the pump to the water to the energy input needed to drive the pump or water power (WP). The power output, or water power, WP is calculated using the following equation (John D. Valiantzas, 2007):

$$P_p = \frac{Q_{in}\,h_p}{102 n_e} \quad \text{……………………… (4)}$$

P_p = power required by the pump, kW
H = total operating head, m
Qs = design discharge of the irrigation systems, l/s
Ep = the overall pump efficiency, %

The total head of the pump can be calculated using Bernoulli's equation, given as:

$$h_s + h_p = H_{in} + Z_{in} + \frac{V_{in}^{2}}{2g} + h_{fs} \quad \text{…….. (5)}$$

where h_s is the total head at the source (m), which may coincide with the elevation head (Zs) of the water table; H in is the pressure head at the inlet point of the delivery system (m); Z in is the elevation head at the inlet point of the delivery system (m); $V_{in}^2/(2\,g)$ is the velocity head (m) at the inlet of the delivery system, which can be considered negligible for pressurized systems (Scaloppi, E. J., and R. G. Allen, 1993) and h_{fs} is the sum of the total friction head loss from the source to the inlet point of the delivery system (m).

The total friction loss in a center pivot lateral having two sizes of pipe is setup using the following equation as (Richard G. Allen, Jack Keller, Derrel Martin, 2011):

$$H_f = K_{dual}\, H_{f\ smaller} \quad \text{………………… (6)}$$

$H_{f\ smaller}$ = total pipe-friction loss along the lateral when comprised only for the smaller pipe, m

K_{dual} = friction reduction factor as a function of the fraction of center pivot lateral that is comprised of the larger pipe (denoted as r/L).

$$K_{dual} = 1 + \left[\left(\frac{D_{smaller}}{D_{larger}}\right)^{4.87} - 1\right]\left(\frac{15}{8}\right)\left[\frac{r}{L_h} - \frac{2}{3}\left(\frac{r}{L_h}\right)^3 + \frac{1}{5}\left(\frac{r}{L_h}\right)^5\right] \quad \text{…… (7)}$$

D smaller = inside diameter of the smaller pipe used in the lateral, mm
D larger = inside diameter of the larger pipe used in the lateral, mm
r = length of larger pipe used in the lateral, m
L_h = total "hydraulic" length of the lateral, m

The total annual energy cost (C EN. T) of water supplied to the delivery system is given as:

$$C_{EN.T} = C_{fu} P_p O_t E_{ae} \quad \text{………………… (8)}$$

where C_{fu} is the fuel cost ($/kWh), O_t is the hours of annual operation of the pump (h), and E_{ae} is the equivalent annualized escalating energy cost factor, which is calculated as (Keller, J., and R. D. Bliesner, 1990)

In order to calculate the payback period versus the extra investment required when using bigger span sizes within the different center pivot configurations, annual operating hours is estimated to be 5000 hours, average fuel consumption is estimated as (0.186 l/hr) to calculate the annual operating cost in each scenario of center pivot configuration and compare it with the extra required investment.

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3. Results & Discussion

3.1 System Hydraulics

Hydraulic analysis per each center pivot configuration starting from the first configuration which has all spans as 6-5/8” pipe sizes up to the last configuration which has 8 spans 8-5/8” pipe sizes and one span 6-5/8” pipe size, has been made to figure out the covered area under each span in each configuration, required flow per each span, effective flow per each span, flow deviation information and pressure loos information per each span. The results are showed at tables from 3 to 11 as follow:

Table 3a: Configuration 1, Flow & Irrigated Information (All Spans are 6-5/8”)

Configuration 1, Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	57,4	1,0	5,4
2	56,1	3,0	16,5
3	56,1	5,0	27,3
4	56,1	7,0	38,2
5	56,1	8,9	49,0
6	56,1	10,9	61,5
7	56,1	12,9	70,2
8	56,1	14,9	81,9

Table 3b: Configuration 1, Flow & Deviation Information

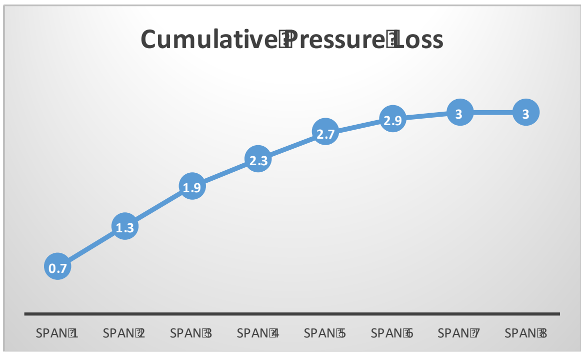
Configuration 1, Flow & Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
5,4	5,2	5,2	0,38
16,5	5,5	5,5	(-0,10)
27,4	5,5	5,5	0,31
38,2	5,5	5,5	(-0,01)
49,2	5,5	5,5	0,23
61,6	5,6	5,6	0,16
70,2	5,4	5,4	(-0,07)
81,9	5,5	5,5	(-0,06)

Table 3c: Configuration 1, Pressure Loss Information

Configuration 1, Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
153,21	150	57,4	0,7
153,21	150	113,5	1,3
153,21	150	169,6	1,9
153,21	150	225,7	2,3
153,21	150	281,8	2,7
153,21	150	337,8	2,9
153,21	150	393,9	3,0
153,21	150	450,0	3,0

The data showed in table 3c reveals the friction loss occurred in each span and the cumulative friction loss which occurred in all spans of the configuration 1, which was 3 bar (44psi). The total pressure required at the top of the pivot point in this case considering the one bar that should be available at the end of the center pivot will be 4 bar (58.8psi).

Fig (2): Cumulative pressure Loss in Configuration 1



As shown in Fig (2), 90% of the cumulative friction loss (2.7 bar) occurred when reached span number five in the configuration 1.

Table 4a: Configuration 2, Flow & Irrigated Information

Configuration 2, Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	51.5	0,8	4,2
2	56,1	2,8	15,3
3	56,1	4,8	26,1
4	56,1	6,8	37,0
5	56,1	8,7	47,8
6	56,1	10,7	58,7
7	56,1	12,7	70,6
8	56,1	14,7	80,9
O.H	6.2	1,7	9,4

Table 4b: Configuration 2, Flow & Deviation Information

Configuration 2, Flow Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
4,3	5,1	5,2	1,35
15,2	5,5	5,5	(-0,39)
26,1	5,5	5,5	0,05
37,1	5,5	5,5	0,24
47,7	5,5	5,5	(-0,26)
58,8	5,5	5,5	0,10
70,6	5,6	5,6	0,00
81,1	5,5	5,5	0,20
9,3	5,4	5.4	(-0,51)

Table 4c: Configuration 2, Pressure Loss Information

Configuration 2, Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
204,01	150	51,5	0,2
153,21	150	107,6	0,8
153,21	150	163,6	1,4
153,21	150	219,7	1,8
153,21	150	275,8	2,2
153,21	150	331,9	2,4
153,21	150	388,0	2.5
153,21	150	444,1	2,5
153,21	150	450,2	2,5

Table 4c showed the cumulative friction loss which decreased in the configuration 2 when inserting one span 8-5/8" pipe size instead of one span 6-5/8", from 3 bar (44psi) to 2.5 bar (36.75psi). Accordingly, the required pressure at the top of the center pivot in the configuration will be 3.5 bar. Fig (3) compared the friction loss occurred along the spans of configuration 1 and configuration 2.

Fig (3): Cumulative pressure Loss in Configuration 1 and 2

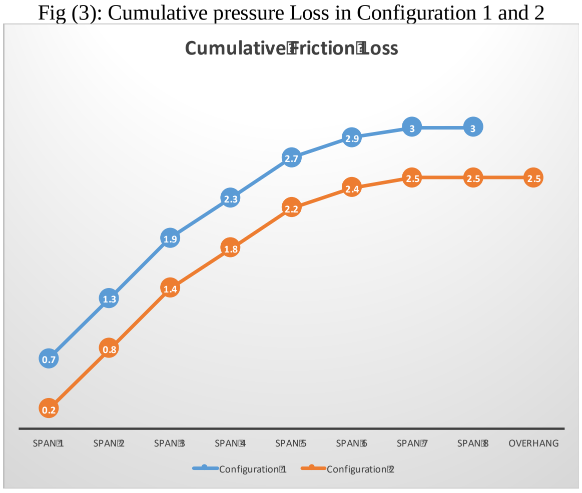


Table 5a: Configuration 3, Flow & Irrigated Information

Configuration 3. Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	51.5	0.8	4.3
2	50.1	2.4	13.2
3	56.1	4.6	25
4	56.1	6.5	35.8
5	56.1	8.5	46.7
6	56.1	10.5	57.6
7	56.1	12.5	68.4
8	56.1	14.5	80.7
O.H	12.1	3.4	18.4

When inserting 2 spans 8-5/8" pipe sizes in configuration 3, cumulative friction loss in all spans reduced from 2.5 bar (36.75psi) to 2.1 bar (30.87psi) and the required pressure at the top of the pivot point reduced as well from 3.5 bar to 3.1 bar. Fig (4) shows the friction loss distribution along the center pivot in configuration 3.

Table 5b: Configuration 3, Flow & Deviation Information

Configuration 3. Flow Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
4.3	5.1	5.2	1.35
13.2	5.5	5.5	0.09
25	5.5	5.5	0.14
35.8	5.5	5.5	(-0.05)
46.7	5.5	5.5	0.07
57.5	5.5	5.5	(-0.02)
67.1	5.5	5.4	(-1.92)
81.1	5.6	5.6	0.49
18.5	5.5	5.5	0.07

Table 5c: Configuration 3, Pressure Loss Information

Configuration 3. Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
204.01	150	51.5	0.2
204.01	150	101.6	0.3
153.21	150	157.7	0.9
153.21	150	213.8	1.3
153.21	150	269.9	1.7
153.21	150	326	1.9
153.21	150	382	2
153.21	150	438.1	2.1
153.21	150	450.2	2.1

Fig (4): Cumulative pressure Loss in Configuration 1, 2 and 3

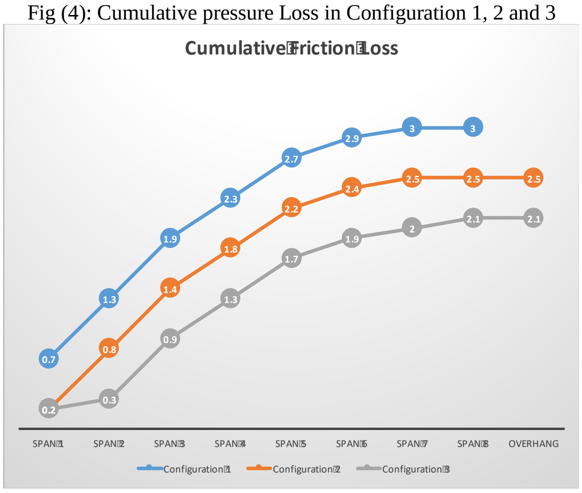


Table 6a: Configuration 4, Flow & Irrigated Information

Configuration 4. Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	51.5	0.8	4.3
2	50.1	2.4	13.2
3	50.1	4	21.8
4	56.1	6.3	34.7
5	56.1	8.3	45.5
6	56.1	10.3	56.4
7	56.1	12.3	68.2
8	56.1	14.2	77.5
O.H	17.7	4.9	28.5

Table 6b: Configuration 4, Flow & Deviation Information

Configuration 4. Flow Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
4.3	5.1	5.1	0.11
13.2	5.5	5.5	0.08
21.8	5.5	5.5	0
34.7	5.5	5.5	(-0.03)
45.5	5.5	5.5	(-0.03)
56.3	5.5	5.5	(-0.10)
68.3	5.6	5.6	0.14
77.5	5.4	5.4	(-0.01)
28.5	5.8	5.8	0.15

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Table 5c: Configuration 4, Pressure Loss Information

Configuration 4. Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
204.01	150	51.5	0.2
204.01	150	101.6	0.3
204.01	150	151.8	0.4
153.21	150	207.8	0.9
153.21	150	263.9	1.3
153.21	150	320	1.5
153.21	150	376.1	1.7
153.21	150	432.2	1.7
153.21	150	449.9	1.8

In configuration 4, number of 8-5/8” spans are increased to be three spans in the beginning of the center pivot, consequently the cumulative friction loss is reduced to 1.8 bar (26.46 psi). This value of friction loss is increased to 2.8 bar at the top of the pivot point of center pivot when considering the 1 bar at the end of the center pivot. Fig (5) shows the friction loss distribution along the center pivot in configuration 4.

Fig (5): Cumulative pressure Loss in Configuration 1, 2, 3 and 4

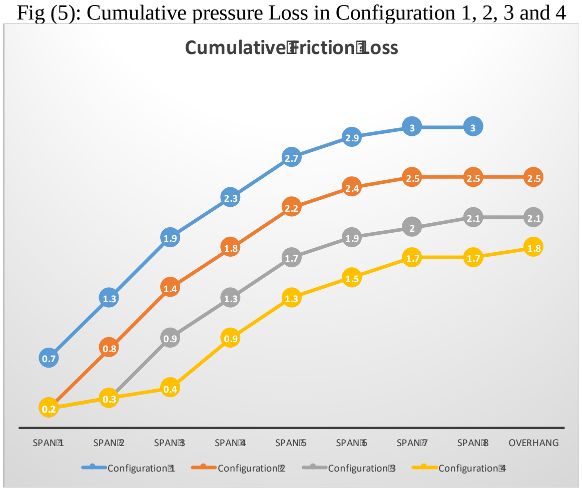


Table 7a: Configuration 5, Flow & Irrigated Information

Configuration 5. Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	51.5	0.8	4.3
2	50.1	2.4	13.2
3	50.1	4	21.8
4	50.1	5.6	30.5
5	56.1	8.1	44.4
6	56.1	10.1	55.2
7	56.1	12.1	67.9
8	56.1	14	76.6
O.H	24	6.6	36.2

Due to having four spans of 8-5/8” pipe size in the beginning of the center pivot instead of 6-5/8” pipe size, the cumulative friction loss is decreased to be 1.5 bar (22.05 psi) compared to 1.8 bar (26.46 psi) in configuration 4. Fig (6) shows the friction loss distribution along the center pivot in configuration 1 to 5.

Fig (6): Cumulative pressure Loss in Configuration 1, 2, 3, 4 and 5

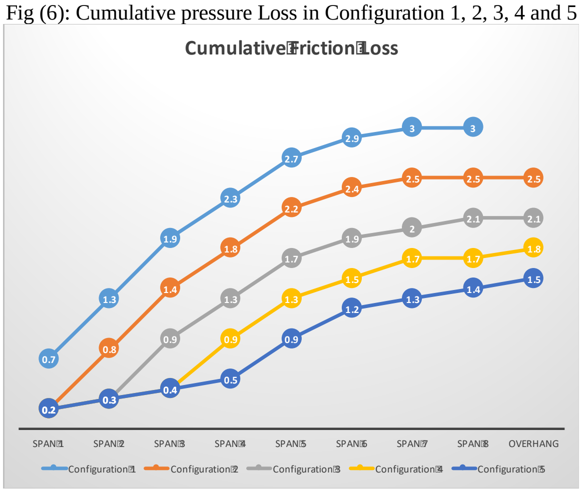


Table 7b: Configuration 5, Flow & Deviation Information

Configuration 5. Flow Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
4.3	5.1	5.1	1.35
13.2	5.5	5.5	0.09
21.8	5.5	5.5	0
30.4	5.5	5.5	(-0.21)
44.6	5.5	5.5	0.38
55.3	5.5	5.5	0.04
67.9	5.6	5.6	0.02
76.4	5.5	5.4	(-0.35)
36.2	5.5	5.5	0.09

Table 7c: Configuration 5, Pressure Loss Information

Configuration 5. Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
204.01	150	51.5	0.2
204.01	150	101.6	0.3
204.01	150	151.8	0.4
204.01	150	201.9	0.5
153.21	150	258	0.9
153.21	150	314.1	1.2
153.21	150	370.2	1.3
153.21	150	426.2	1.4
153.21	150	450.2	1.5

Table 8a: Configuration 6, Flow & Irrigated Information

Configuration 6. Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	51.5	0.8	4.3
2	50.1	2.4	13.2
3	50.1	4	21.8
4	50.1	5.6	30.4
5	50.1	7.2	39
6	50.1	8.7	47.6
7	50.1	10.3	55.5
8	50.1	11.9	64.7
9	50.1	13.5	73.4

In this configuration scenario which has five spans 8-5/8" pipe size in the beginning of the center pivot, its cumulative friction loss is decreased to the level of

Table 8b: Configuration 6, Flow & Deviation Information

Configuration 6. Flow Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
4.3	5.1	5.1	(-1.63)
13.2	5.5	5.5	0.09
21.9	5.5	5.5	0.2
30.3	5.5	5.4	(-0.35)
39	5.5	5.5	(-0.01)
47.6	5.5	5.4	(-0.08)
55.4	5.4	5.4	(-0.13)
64.8	5.4	5.4	0.08
73.6	5.5	5.5	0.08

Table 8c: Configuration 6, Pressure Loss Information

Configuration 6. Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
204.01	150	51.5	0.2
204.01	150	101.6	0.3
204.01	150	151.8	0.4
204.01	150	201.9	0.5
204.01	150	252	0.6
153.21	150	302.2	0.9
153.21	150	352.3	1
153.21	150	402.5	1.1
153.21	150	452.6	1.1

1.1 bar (16.7 psi) compared to 1.5 bar (22.05 psi) in configuration 5. Fig (7) shows the friction loss distribution along the center pivot in configuration 6.

Fig (7): Cumulative pressure Loss in Configuration from 1 to 6

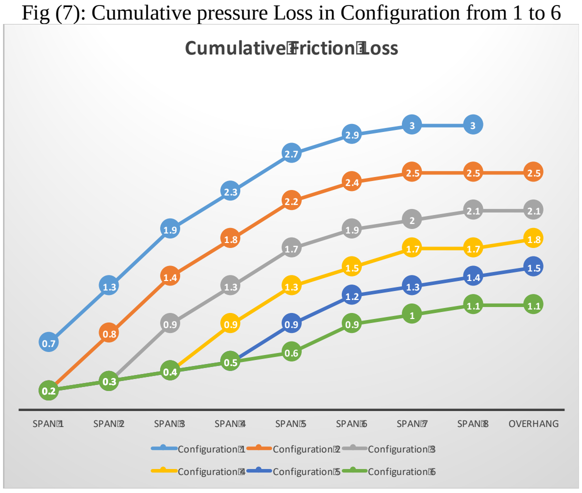


Table 9a: Configuration 7, Flow & Irrigated Information

Configuration 7. Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	51.5	0.8	4.1
2	50.1	2.4	13
3	50.1	4	21.6
4	50.1	5.6	30.2
5	50.1	7.2	38.8
6	50.1	8.7	47.4
7	50.1	10.3	56.9
8	50.1	11.9	64.7
9	50.1	13.5	73.4

Table 9b: Configuration 7, Flow & Deviation Information

Configuration 7. Flow Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
4.1	4.9	5	0.52
13	5.4	5.4	0.02
21.5	5.4	5.4	(-0.14)
30	5.4	5.4	(-0.45)
38.8	5.4	5.4	0.09
47.4	5.4	5.4	(-0.03)
56.6	5.5	5.5	(-0.39)
64.8	5.4	5.4	0.15
73.6	5.4	5.5	0.06

Table 9c: Configuration 7, Pressure Loss Information

Configuration 7. Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
204.01	150	51.5	0.2
204.01	150	101.6	0.3
204.01	150	151.8	0.4
204.01	150	201.9	0.5
204.01	150	252	0.6
204.01	150	302.2	0.7
153.21	150	352.3	0.8
153.21	150	402.5	0.9
153.21	150	452.6	0.9

Increasing number of spans 8-5/8" to six spans instead of six spans in the beginning of the center pivot was the direct reason behind reducing the cumulative friction loss in this configuration to the level of 0.9 bar (13.23 psi) compared to 1.1 bar (16.7 psi) in the configuration 6. Fig (8) shows the friction loss distribution along the center pivot in configuration 7.

Fig (8): Cumulative pressure Loss in Configuration from 1 to 7.

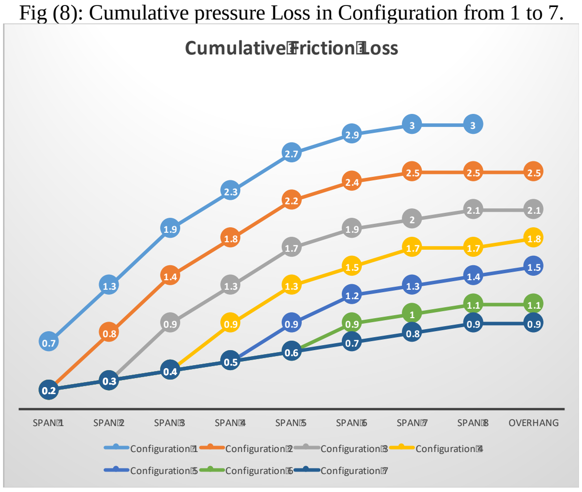


Table 10a: Configuration 8, Flow & Irrigated Information

Configuration 8. Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	51.5	0.8	4.1
2	50.1	2.4	13
3	50.1	4	21.6
4	50.1	5.6	30.2
5	50.1	7.2	38.8
6	50.1	8.7	47.4
7	50.1	10.3	56
8	50.1	11.9	65.6
9	50.1	13.5	73.4

Table 10b: Configuration 8, Flow & Deviation Information

Configuration 8. Flow Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
4.1	4.9	5	0.52
13	5.4	5.4	0.02
21.5	5.4	5.4	(-0.14)
30	5.4	5.4	(-0.45)
38.8	5.4	5.4	0.09
47.4	5.4	5.4	(-0.03)
56	5.4	5.4	(-0.03)
65.7	5.5	5.5	0.1
73.4	5.4	5.5	0.06

Table 10c: Configuration 8, Pressure Loss Information

Configuration 8. Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
204.01	150	51.5	0.2
204.01	150	101.6	0.3
204.01	150	151.8	0.4
204.01	150	201.9	0.5
204.01	150	252	0.6
204.01	150	302.2	0.7
204.01	150	352.3	0.7
153.21	150	402.5	0.8
153.21	150	452.6	0.8

Increasing number of spans 8-5/8" to seven spans instead of six spans in the beginning of the center pivot was the direct reason behind reducing the cumulative friction loss in this configuration to the level of 0.8 bar (11.76 psi) compared to 1.1 bar (13.23 psi) in the configuration. 7. Fig (9) shows the friction loss distribution along the center pivot spans in the configurations from 1 to 8.

Fig (9): Cumulative pressure Loss in Configuration from 1 to 8.

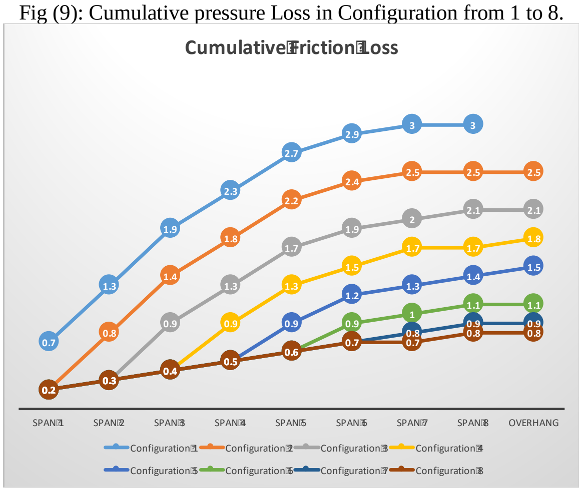


Table 11a: Configuration 9, Flow & Irrigated Information

Configuration 9. Flow & Irrigated Area Information			
Span #	Span Length (m)	covered area (ha)	Required Flow (m3/hr)
1	51.5	0.8	4.1
2	50.1	2.4	13
3	50.1	4	21.6
4	50.1	5.6	30.2
5	50.1	7.2	38.8
6	50.1	8.7	47.4
7	50.1	10.3	56
8	50.1	11.9	65.6
9	50.1	13.5	73.4

Table 11b: Configuration 9, Flow & Deviation Information

Configuration 9. Flow Deviation Information			
Effective Flow (m3/hr)	Required m3/h/ha	Effective Flow (m3/h/ha)	Deviation
4.1	4.9	5	0.52
13	5.4	5.4	0.02
21.5	5.4	5.4	(-0.14)
30	5.4	5.4	(-0.45)
38.8	5.4	5.4	0.09
47.4	5.4	5.4	(-0.03)
56	5.4	5.4	(-0.03)
65.7	5.5	5.5	0.1
73.4	5.4	5.5	0.06

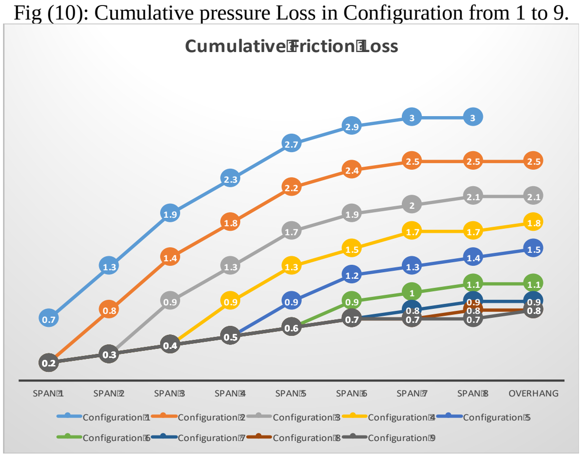
Table 11c: Configuration 9, Pressure Loss Information

Configuration 9. Pressure Loss Information			
Pipe I.D. (mm)	C-Factor	Distance from pivot point (m)	Cumulative pressure Loss (bar)
204.01	150	51.5	0.2
204.01	150	101.6	0.3
204.01	150	151.8	0.4
204.01	150	201.9	0.5
204.01	150	252	0.6
204.01	150	302.2	0.7
204.01	150	352.3	0.7
204.01	150	402.5	0.7
153.21	150	452.6	0.8

In this configuration, cumulative friction loss over all span remains the same 0.8 bar (11.76 psi) as in configuration 8. The total pressure required at the top of the pivot point of the center pivot in this case is 1.8 bar. Fig (10) shows the friction loss distribution along the center pivot in configuration 8.

As a conclusion based on the obtained results, the cumulative friction loss is stopped getting down due to inserting 8-5/8" span in the configuration 9 whereas the cumulative friction loss remained the same as it was at configuration 8. Consequently, the required pressure at the top of the pivot point were followed the same trend.

Fig (10): Cumulative pressure Loss in Configuration from 1 to 9.



3.2. Energy Cost

Energy cost of each configuration is calculated based on the required power in each case considering the friction loss occurred at the mainline which delivers the water from the pump to the pivot point of the center pivot. Required power in each configuration of the nine configurations proposed in this study is shown in table 12.

Table 12a: Energy cost in first three configurations

SYSTEM SPECS	ALL 6-5/8"	ONE TOWER 8 5/8"	TWO TOWER 8 5/8"
Pivot Pressure (bar)	4	3.5	3.1
Mainline 10" (500M) Friction Loss (bar)	2.58		
Pump Required Pressure (TDH) (psi)	6.6	6.1	5.7
Power Requirement (kw) PUMP@-75% Eff.	84.45	78.35	73.13
Aver. Fuel Consumption L/hr (.248)	21.16217	19.635	18.326
Fuel Consumption Cost in LE/year	396790.6	368156.3	343612.5
Fuel Consumption Cost Variance		28634.38	53178.13
Operating Cost Saving, %		7%	13%

Table 12b: Energy cost in configurations 4 to 6

SYSTEM SPECS	THREE TOWER 8 5/8"	FOUR TOWERS 8 5/8"	FIVE TOWERS 8 5/8"
Pivot Pressure (bar)	2.8	2.5	2.1
Mainline 10" (500M) Friction Loss (bar)	2.58		
Pump Required Pressure (TDH) (psi)	5.3	5.1	4.7
Power Requirement (kw) PUMP@-75% Eff.	68.78	65.92	61
Aver. Fuel Consumption L/hr (.248)	17.23517	16.3625	15.27167
Fuel Consumption Cost in LE/year	323159.4	306796.9	286343.8
Fuel Consumption Cost Variance	73631.25	89993.75	110446.9
Operating Cost Saving, %	18%	22%	28%

Table 12c: Energy cost in configurations 7 to 9

SYSTEM SPECS	Six TOWERS 8 5/8"	Seven TOWERS 8 5/8"	Eight TOWERS 8 5/8"
Pivot Pressure (bar)	1.9	1.8	1.8
Mainline 10" (500M) Friction Loss (bar)	2.58		
Pump Required Pressure (TDH) (psi)	4.4	4.3	4.3
Power Requirement (kw) PUMP@-75% Eff.	57	55.72	55.72
Aver. Fuel Consumption L/hr (.248)	14.399	13.96267	13.96267
Fuel Consumption Cost in LE/year	269981.3	261800	261800
Fuel Consumption Cost Variance	126809.4	134990.6	134990.6
Operating Cost Saving, %	32%	33%	33%

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Table 12a, b and c, showed the annual energy cost in Egyptian Pound for all nine configurations that proposed in this study. As data declared, the saving in the annual cost 7% in case using first span as 8-5/8” pipe size compared to all spans are 6-5/8”. This percentage of saving is increased to 13%, 18%, 22%, 28%, 32% and 33% when using two spans 8-5/8”, three spans 8-5/8”, four spans 8-5/8”, five spans 8-5/8”, six spans 8-5/8” and seven spans 8-5/8” respectively.

Energy saving percentage remains the same as 33% compared to all spans as 6-5/8”, in case using seven spans 8-5/8” or using eight spans 8-5/8”, because the cumulative friction loss in the last two configurations remained the same as mentioned in hydraulic analysis conclusion part.

As a result of this study, it will be recommended to use up to seven spans as 8-5/8” only as been used in configuration 8 to get the highest saving percentage of 33% compared to using all spans as 6-5/8” which will save the extra investment required when adding one extra span as 8-5/8” pipe size.

Fig (11) shows the annual operating cost in each configuration considering 5,000 annual operating hours with alfalfa crop.

Fig (11) The annual operating cost

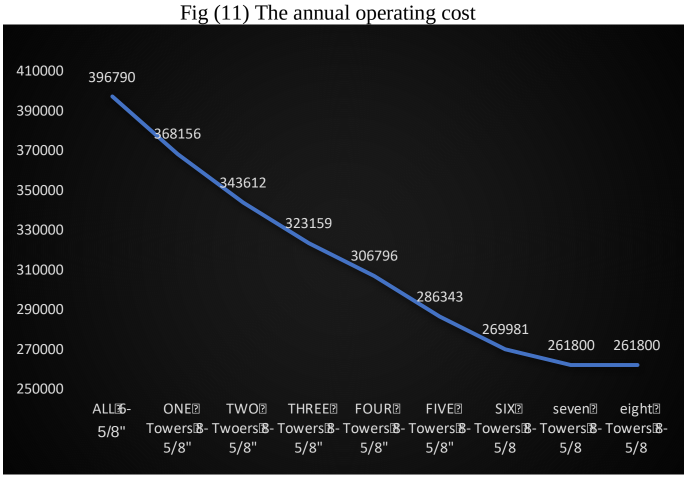
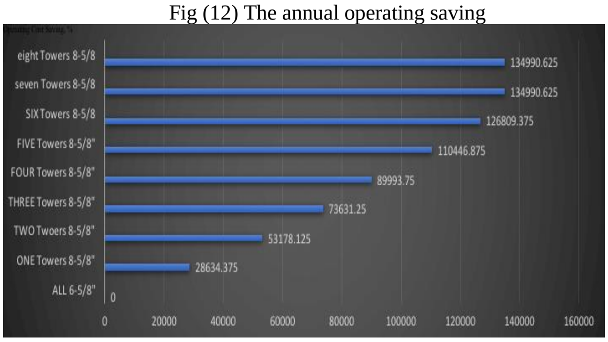


Fig (12) shows the annual operating saving in Egyptian Pound in each configuration of the nine under study compared to the first configuration which has all spans as 6-5/8” pipe size.

Fig (12) The annual operating saving



3.3. Payback Period

As per the data obtained from the manufacturers of the center pivot irrigation system regarding the extra investment required when inserting 8-5/8” span instead of 6-5/8” and reference to the saving percentages in the annual operating cost obtained in this study, the payback period is almost one year in case using five spans 8-5/8” and two years in case increased number of 8-5/8” spans to 7 spans.

1. CONCLUSIONS

Based on the obtained results, 77% of the total area of 63.3 hectares is irrigated by the last four spans and the overhang while the first four spans is irrigated only 23% of the total area.

Regarding the cumulative friction loss occurred, 90% of it occurred in the first five spans when the 6-5/8” pipe size spans are configured the center pivot.

The lowest cumulative friction loss of 0.8 bar is occurred at configuration 8 when using 7 spans 8-5/8” pipe size and last span as 6-5/8” plus overhang.

Cumulative pressure loss is stopped getting down at configuration 9 even after adding extra span has 8-5/8” pipe size.

Consequently, the lowest required pressure at the top of the pivot point was1.8 bar with configuration 8 when having 7 spans as 8-5/8” and the rest of the spans as 6-5/8” pipe size.

Regarding the energy cost, 33% saving of annual operating cost at configuration 8 when using seven spans 8-5/8” pipe size compared to configuration 1 which has all spans as 6-5/8” pipe size.

Payback period is obtained as one year in case configuration 6 which has five spans 8-5/8” pipe size while increased to two years in case configuration 8.

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