Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

A Developed Simple Spreadsheet for Center Pivot Irrigation System Design

Yasser E. Arafa[1]
Agricultural Engineering Department,
Faculty of Agriculture,
Ain Shams University, Egypt

Khaled A. Shalabi [2]
On-Farm Irrigation Engineering Dept.,
Agricultural Engineering Research Institute,
ARC, Egypt

***Abstract* - Centre pivot irrigation system is a promising and precise system, for increasing the utilization efficiency of unit water. However, Egyptian agricultural-water uses policies for reclaiming and cultivation 1.5 million feddan (625000 ha) had stated center pivot irrigation system as a major irrigation system. Hence, a developed simple-spread sheet module for center pivot irrigation system design has been developed and validated. However, the developed spread-sheet is based on different design criteria, as, crop type, weather data, and soil characteristics. The module comprises five sub-models for: (a) main sub-model; (b) data entry sub-model; (c) weather sub-model; (d) irrigation sub-model; and (e) results sub-model. The most important outputs include nozzle flow rate (m^3/h), application rate (mm/h), and throw diameter (m). These outputs (outputs of 9 scenarios) were compared with observed/manufactured data for the calibration and validation of the model.**

Results of this comparison show that differences in model accuracy owing to different variables affecting the design and management of the center pivot were not significant. The relationships between the observed/manufactured and simulated results have a good correlation with high value of coefficient of determination and the best models are as follows:

1- **Nozzle flow rate (m^3/h) was in scenario 5 with R^2 = 0.967 and explained by an exponential model: $Q_{SIM} = 0.1067e^{4.1131\,(Q_{obs})}$.**
2- **Throw diameter (m) was in scenario 1 with R^2 = 0.942 and explained by a power model: $Dw_{SIM} = 3.9064\,(Dw_{MFD})^{0.4361}$.**

Keywords: Modeling; Application rate; Nozzle flow rate; Throw diameter.

1. INTRODUCTION

Center pivot is a promising method of irrigation, became very popular in Egypt, in which water is dispersed through a long segmented arm that revolves a water source (deep well for example) and covers a circular area. A wide diffusion of the center pivot irrigation systems [8 and 15] is due to two reasons: (I) automation is built into the center pivot device allowing for irrigation with minimal labor input; and (II) center pivot systems can be one of the most efficient and uniform methods of applying irrigation water. Currently, an objective of irrigation planners is to obtain a high level of irrigation management as general and center pivot irrigation management in specific. Attempts to apply and manage center pivot irrigation systems have been started the 1960s. Reference [7] had developed center pivot irrigation model software for water and/or water-nitrate distribution analyses from center pivots. Reference [2] is developed a model for simulating of water application under center pivots, focusing on irrigation uniformity. A sophisticated software package for center pivot evaluation and design (CPED) was introduced by [9].

Generally, several attempts on design and watering management of center pivot irrigation systems based on different modeling techniques, had been considered. Reference [5] stated that modelling remains a valuable tool to address a variety of engineering problems (such as irrigation management), at the design, planning, and operations levels. Accordingly, the application of simulation models in irrigation water management reduces water and energy consumption which, leads to increase the efficiency of utilization of these resources [11].

In practical, there are many simulation models that have proved a great success in the design and management of pressurized irrigation systems such as: the SpacePro model [3], for the purpose of selecting nozzle size and spacing for a given application; the SIRIAS model for sprinkler droplet simulation [4]**;** the TRAVGUN model for sprinkler application depth [14].

Due to the design requirements of center pivot irrigation systems and attributed watering-management criteria, that needs a highly qualified data and designer’s background. Therefore, the aim of this study was to open a new era of spread-sheets modeling in design of center irrigation system under arid conditions.

2. MATERIAL AND METHODS

2.1. Modeling Conceptualization of the Developed Spreadsheet

The appropriate development of a simulation model begins with understanding and interpretation of the real system through one of the methods of system analysis. Thus the waterfall model is used in the model building which gives the possibility to programmers to follow phases of development of the program in a certain order, as presented in Fig. 1. However, database contains information such as station information, weather information, and crop water data information. Consequently, the mathematical model consists of five sub-modules was developed. A detailed description of the sub-modules could be summarized as following:

2.2. Main Sub-module:

Main sub-module is the way to interact with a computer using pictures and other visual elements displayed on a computer screen. This sub-module directs the running of the model by offering the user ability to select subsequent sub-modules and load the data files. It is the main entry point as well as the highest level of the program.

2.3. Data Entry Sub-module:

Design data entry sub-module controls the optimization procedure by performing the required calculations. This enables the user to enter and edit the basic project data to simulate one or more operating scenarios. The basic project input data include: irrigated area dimensions; type of water source; available discharge of water source; reference evapotranspiration ETo (whether entered manually by the user or retrieved from the database incorporated in the program for three cities); wind speed; soil characteristics retrieved from the database; and crop coefficient and root zone depth for each crop retrieved from the database.

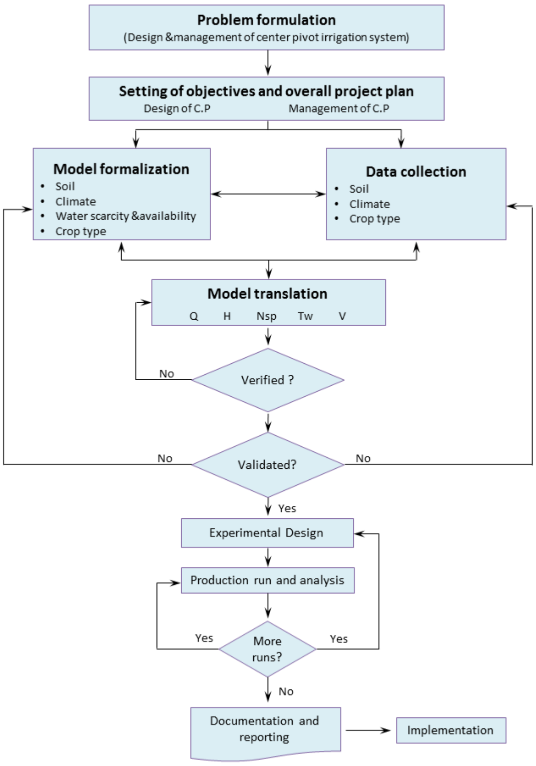


Fig. 1: Schematic flow-chart of the developed simple spread-sheet.

2.4. Sub-module Requirements of Center Pivot Irrigation System Design

Fig. 2 represents all related calculations to crop water requirements, irrigation requirements, and center pivot irrigation system design had been considered. However, these related parameters could be described as:

2.4.1.1. Center Pivot System Capacity (Qs, m^3/h)

Center pivot system capacity design followed the methodology recommended by [10] as follows:

$$Q_s = K \times A \times I_a / T_i \times T \tag{1}$$

Where:
K is conversion factor = 0.001;
A is total irrigated area, m²;
I_a irrigation requirement;
T is operating time, h/day
Ti irrigation interval

2.4.1.2. Center Pivot Hydraulic Analysis

Hydraulic of center pivot irrigation system includes determination of friction losses (H_f, m) along the sprinkler line, sprinklers operating pressure head (H_{sp}, m), nozzle size (d_{sp}, mm), nozzle discharge (Q_{sp}, m3/h) and Sprinkler throw diameter (D_w, m). The hydraulic characteristics design followed the approaches proposed by (10 and 1) as the following equations:

Friction head losses, m

$$H_f = 1.22\times 10^{12} \times f \times (R/100) \times (Q_s/C)^{1.852} \times D^{-4.87} \tag{2}$$

Where:
f: outlet friction coefficient (0.548)
R: pipe length, m
C: Roughness coefficient (for galvanized steel = 120)
D: pipe inside diameter, mm

Operating pressure head in the pivot point, m

$$H_v = H_e + 1.1H_f \pm \Delta H_z + H_{rg} + H_r \tag{3}$$

Where:
H_e: Pressure head required in the end of the sprinkler line, m
ΔH_z: Height difference between pivot and the end of lateral, m
H_{rg}: Head losses in pressure regulator, m
Hr: Height of Sprinkler, m
Sprinklers operating pressure head, m

$$H_{sp} = H_f\,(1-1.875\,(X-(2X^2/3)+(X^5/5))+H_e \tag{4}$$

$$X = r_{sp}/R \tag{5}$$

Nozzle size, mm

$$d_{sp} = 30.46 \times (Q_{sp}/P_{sp})^{1/2} \tag{6}$$

Nozzle discharge, m^3/h

$$Q_{sp} = (2\, r_{sp}\times S_s \times Q_s) / R^2 \tag{7}$$

Sprinkler throw diameter, m

$$D_w = 2.59 + 0.56\, d_{sp} + 0.023\, P_{sp} \tag{8}$$

Where: Psp is sprinkler operating pressure in kPa

2.4.1.3. Application rate (R_a, mm/h):

The application rate of sprinkler, as described in the following equation, depends on distance to sprinkler at lateral (r_{sp}, m), system capacity (Q_s, m^3/h), radius of center pivot (R, m) and throw diameter of sprinkler (D_w, m).

$$R_a = (2 \times 1000 \times r_{sp}\times Q_s) / (R^2 \times D_w) \tag{9}$$

2.4.2. Sub-module Output

One of the most important objectives of this study was creating good output sub-module that allows users generating and handling clear outputs easily. Reports of the output can be printed or saved in spreadsheets such as Microsoft Excel according to users' specific needs, as shown in Fig. 3 and Fig. 4.

2.4.3. Validation Case Study

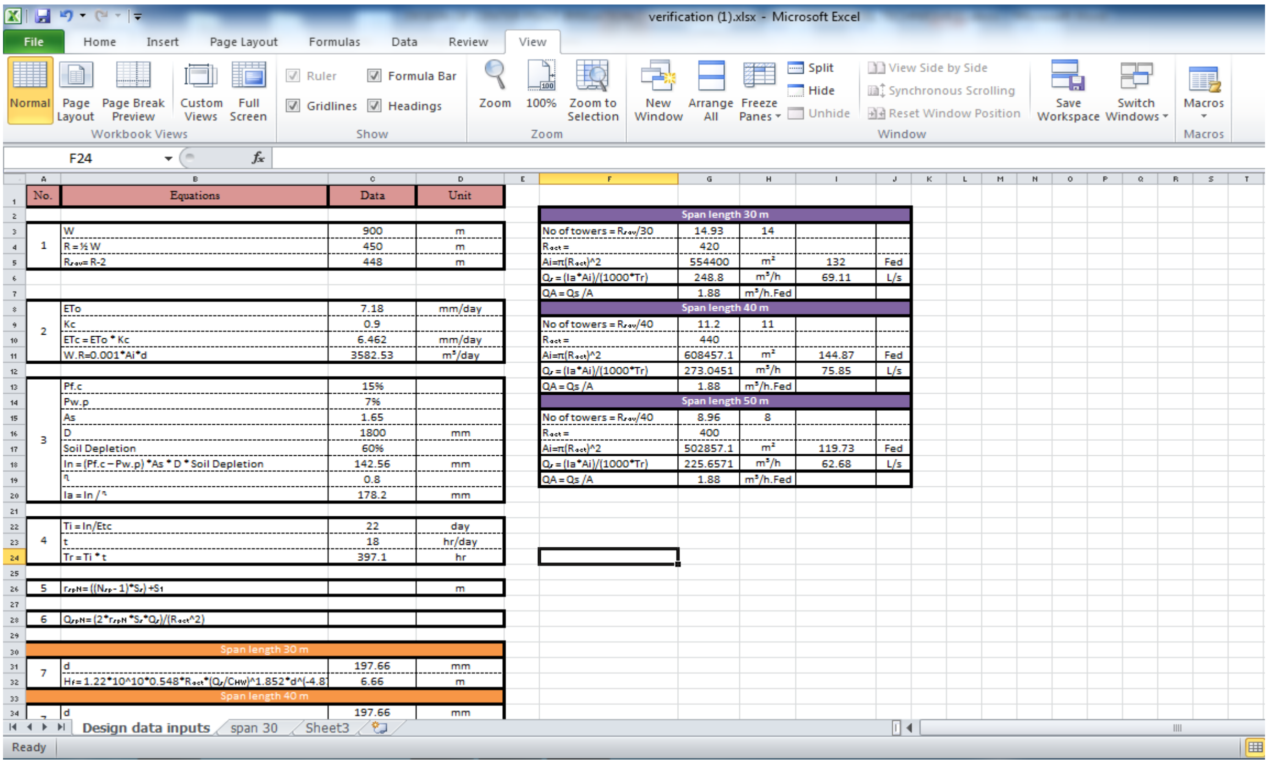
Field experiment on a single span center pivot irrigation system was used for validation process. The technical configuration of the evaluated center pivot irrigation system was: a span length of 56.7 m with flow rate of 4.2 m³/h. Sprinklers were manufactured by Nelson Irrigation Corporation with pressure regulators of 1.03 bars. The distance from the sprinkler to the ground surface was

1.8 m. Sprinklers throw diameter were varied in a range of 14 to 16 m from the beginning at the center pivot to the end of the center pivot radial line. Nozzle flow rate was measured for each nozzle along the radial line of the center pivot, meanwhile, the application rate (mm/h) and throw diameter (m) data of sprinklers were downloaded from the official web site of center pivot provider for the same center pivot model used in the experiment (Nelson Irrigation Corporation).

The analyzed output variables include Nozzle flow rate (m^3/h), application rate (mm/h), and throw diameter (m). All scenarios have two types of boundary conditions. Firstly, are related to soil-plant-water relationship, while the second are related to center pivot irrigation management. Data of boundary conditions and limitations of the different scenarios of the validation case studies are shown in Table (1).

2.4.4. *Statistical Analysis*

To achieve the objectives of the research, hypothesis testing was performed through the use of statistical analysis. Descriptive statistics, tests of normality, and test of homogeneity of variances were initially used for analyzing the data using IBM SPSS Statistics version 20.0. An analysis of variance between groups (ANOVA) for both simulated and observed/manufactured data was performed. Nozzle flow rate (m^3/h), application rate (mm/h), and throw diameter (m) were included in the statistical analysis and tested for statistically significant differences at 5% confidence level, [13, 6 and 12].



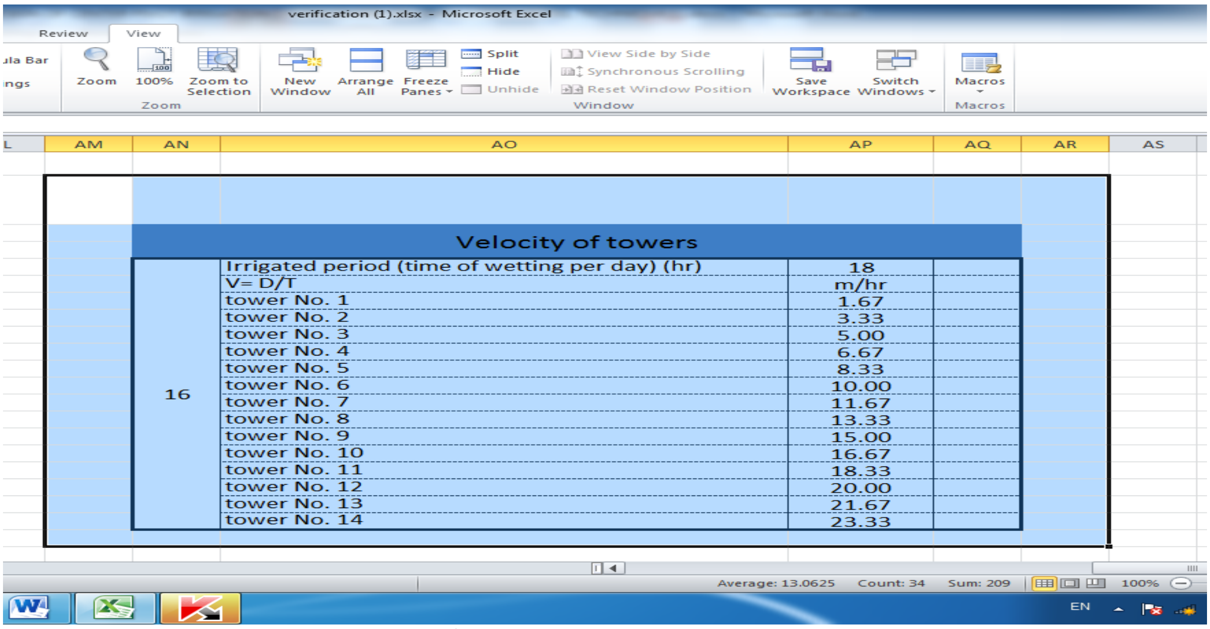
No.	Equations	Data	Unit
1	W	900	m
	R = ½ W	450	m
	R_{rav}= R-2	448	m
2	ETo	7.18	mm/day
	Kc	0.9	
	ETc = ETo * Kc	6.462	mm/day
	W.R=0.001*Ai*d	3582.53	m^3/day
3	Pf.c	15%	
	Pw.p	7%	
	As	1.65	
	D	1800	mm
	Soil Depletion	60%	
	In = (Pf.c – Pw.p) *As * D * Soil Depletion	142.56	mm
	η	0.8	
	Ia = In / η	178.2	mm
4	Ti = In/Etc	22	day
	t	18	hr/day
	Tr = Ti * t	397.1	hr
5	r_{rpN}= ((N_{rp} - 1)*S_r) +S_1		m
6	Q_{rpN}= (2*r_{rpN} *S_r*Q_r)/(R_{act}^2)		
Span length 30 m			
7	d	197.66	mm
	H_f= 1.22*10^10*0.548*R_{act}*(Q_r/C_{HW})^1.852*d^(-4.87	6.66	m
Span length 40 m			
7	d	197.66	mm

Span length 30 m				
No of towers = R_{rav}/30	14.93	14		
R_{act} =	420			
Ai=π(R_{act})^2	554400	m^2	132	Fed
Q_r = (Ia*Ai)/(1000*Tr)	248.8	m^3/h	69.11	L/s
QA = Qs /A	1.88	m^3/h.Fed		
Span length 40 m				
No of towers = R_{rav}/40	11.2	11		
R_{act} =	440			
Ai=π(R_{act})^2	608457.1	m^2	144.87	Fed
Q_r = (Ia*Ai)/(1000*Tr)	273.0451	m^3/h	75.85	L/s
QA = Qs /A	1.88	m^3/h.Fed		
Span length 50 m				
No of towers = R_{rav}/40	8.96	8		
R_{act} =	400			
Ai=π(R_{act})^2	502857.1	m^2	119.73	Fed
Q_r = (Ia*Ai)/(1000*Tr)	225.6571	m^3/h	62.68	L/s
QA = Qs /A	1.88	m^3/h.Fed		

Fig. 2: Input data and required design equations of center pivot irrigation system

TABLE 1: Boundary conditions of studied variables at different design scenarios.

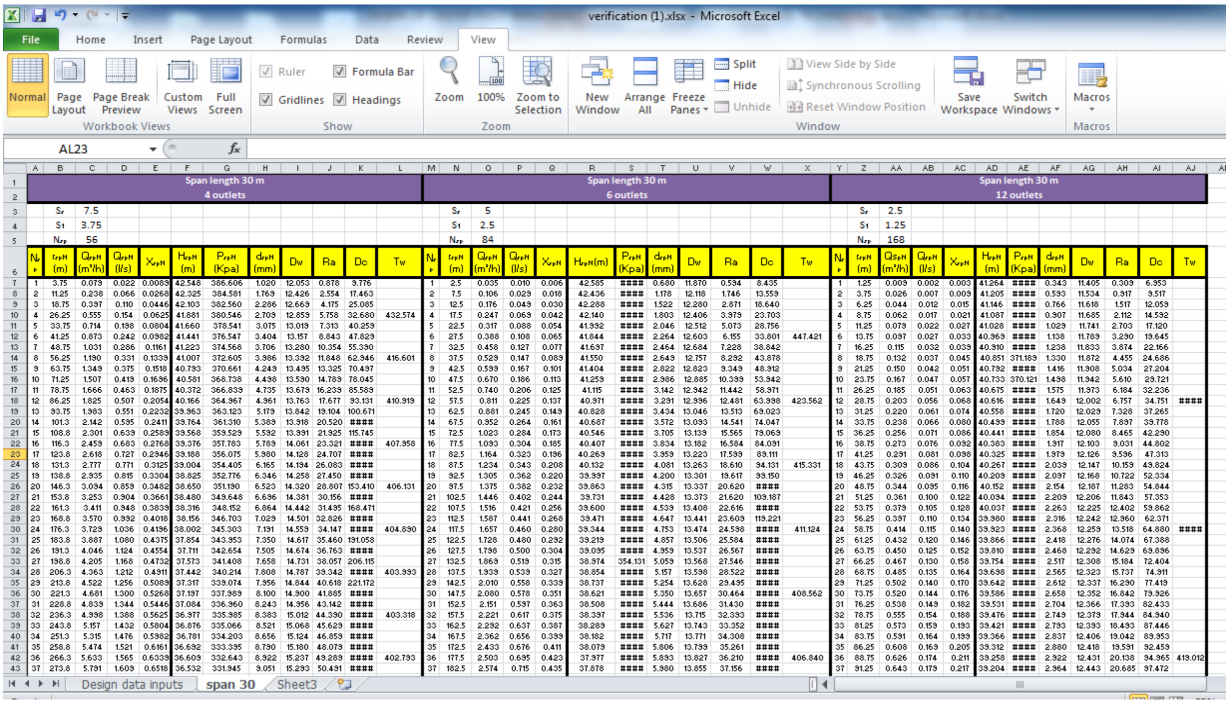
Scenario	Variable							
	Span length, m	Equivalent output length, m	No. of Sprinklers	Distance between sprinklers, m	Flow rate, m^3/h	Soil	Crop	ET_o, mm/day
Scenario.1	30	56.3	7	7.5	7	Sand	Alfalfa	8
Scenario.2	30	57.5	11	5	6.2	Sand	Alfalfa	8
Scenario.3	30	56.3	18	2.5	5.5	Sand	Alfalfa	8
Scenario.4	40	55	6	10	6.3	Sand	Alfalfa	8
Scenario.5	40	56.7	8	6.67	6.2	Sand	Alfalfa	8
Scenario.6	40	55	14	3.33	5.4	Sand	Alfalfa	8
Scenario.7	50	56.3	5	12.5	6.8	Sand	Alfalfa	8
Scenario.8	50	54.2	7	8.33	5.94	Sand	Alfalfa	8
Scenario.9	50	56.3	12	4.17	5.8	Sand	Alfalfa	8



	Velocity of towers	
16	Irrigated period (time of wetting per day) (hr)	18
	V= D/T	m/hr
	tower No. 1	1.67
	tower No. 2	3.33
	tower No. 3	5.00
	tower No. 4	6.67
	tower No. 5	8.33
	tower No. 6	10.00
	tower No. 7	11.67
	tower No. 8	13.33
	tower No. 9	15.00
	tower No. 10	16.67
	tower No. 11	18.33
	tower No. 12	20.00
	tower No. 13	21.67
	tower No. 14	23.33

Average: 13.0625 Count: 34 Sum: 209 100%

Fig. 3: Span velocity output data of center pivot irrigation system based on the developed spread-sheet



Span length 30 m
4 outlets

S_r 7.5
S_1 3.75
N_{rp} 56

N_{rp}	r_{rpN} (m)	Q_{rpN} (m³/h)	Q_{rpN} (l/s)	X_{rpN}	H_{rpN} (m)	P_{rpN} (Kpa)	d_{rpN} (mm)	Dw	Ra	Dc	Tw
1	3.75	0.079	0.022	0.0089	42.548	386.606	1.020	12.053	0.878	9.776	
2	11.25	0.238	0.066	0.0268	42.325	384.581	1.769	12.426	2.554	17.463	
3	18.75	0.397	0.110	0.0446	42.103	382.560	2.286	12.669	4.175	25.085	
4	26.25	0.555	0.154	0.0625	41.881	380.546	2.709	12.859	5.758	32.680	432.574
5	33.75	0.714	0.198	0.0804	41.660	378.541	3.075	13.019	7.313	40.259	
6	41.25	0.873	0.242	0.0982	41.441	376.547	3.404	13.157	8.843	47.829	
7	48.75	1.031	0.286	0.1161	41.223	374.568	3.706	13.280	10.354	55.390	
8	56.25	1.190	0.331	0.1339	41.007	372.605	3.986	13.392	11.848	62.946	416.601
9	63.75	1.349	0.375	0.1518	40.793	370.661	4.249	13.495	13.325	70.497	
10	71.25	1.507	0.419	0.1696	40.581	368.738	4.498	13.590	14.789	78.045	
11	78.75	1.666	0.463	0.1875	40.372	366.839	4.735	13.679	16.239	85.589	
12	86.25	1.825	0.507	0.2054	40.166	364.967	4.961	13.763	17.677	93.131	410.919
13	93.75	1.983	0.551	0.2232	39.963	363.123	5.179	13.842	19.104	100.671	
14	101.3	2.142	0.595	0.2411	39.764	361.310	5.389	13.918	20.520	####	
15	108.8	2.301	0.639	0.2589	39.568	359.529	5.592	13.991	21.925	115.745	
16	116.3	2.459	0.683	0.2768	39.376	357.783	5.789	14.061	23.321	####	407.958
17	123.8	2.618	0.727	0.2946	39.188	356.075	5.980	14.128	24.707	####	
18	131.3	2.777	0.771	0.3125	39.004	354.405	6.165	14.194	26.083	####	
19	138.8	2.935	0.815	0.3304	38.825	352.776	6.346	14.258	27.450	####	
20	146.3	3.094	0.859	0.3482	38.650	351.190	6.523	14.320	28.807	153.410	406.131
21	153.8	3.253	0.904	0.3661	38.480	349.648	6.696	14.381	30.156	####	
22	161.3	3.411	0.948	0.3839	38.316	348.152	6.864	14.442	31.495	168.471	
23	168.8	3.570	0.992	0.4018	38.156	346.703	7.029	14.501	32.826	####	
24	176.3	3.729	1.036	0.4196	38.002	345.303	7.191	14.559	34.147	####	404.890
25	183.8	3.887	1.080	0.4375	37.854	343.953	7.350	14.617	35.460	191.058	
26	191.3	4.046	1.124	0.4554	37.711	342.654	7.505	14.674	36.763	####	
27	198.8	4.205	1.168	0.4732	37.573	341.408	7.658	14.731	38.057	206.115	
28	206.3	4.363	1.212	0.4911	37.442	340.214	7.808	14.787	39.342	####	403.993
29	213.8	4.522	1.256	0.5089	37.317	339.074	7.956	14.844	40.618	221.172	
30	221.3	4.681	1.300	0.5268	37.197	337.989	8.100	14.900	41.885	####	
31	228.8	4.839	1.344	0.5446	37.084	336.960	8.243	14.956	43.142	####	
32	236.3	4.998	1.388	0.5625	36.977	335.985	8.383	15.012	44.390	####	403.318
33	243.8	5.157	1.432	0.5804	36.876	335.066	8.521	15.068	45.629	####	
34	251.3	5.315	1.476	0.5982	36.781	334.203	8.656	15.124	46.859	####	
35	258.8	5.474	1.521	0.6161	36.692	333.395	8.790	15.180	48.079	####	
36	266.3	5.633	1.565	0.6339	36.609	332.643	8.922	15.237	49.289	####	402.793
37	273.8	5.791	1.609	0.6518	36.532	331.945	9.051	15.293	50.491	####	

Span length 30 m
6 outlets

S_r 5
S_1 2.5
N_{rp} 84

N_{rp}	r_{rpN} (m)	Q_{rpN} (m³/h)	Q_{rpN} (l/s)	X_{rpN}	H_{rpN}(m)	P_{rpN} (Kpa)	d_{rpN} (mm)	Dw	Ra	Dc	Tw
1	2.5	0.035	0.010	0.006	42.585	####	0.680	11.870	0.594	8.435	
2	7.5	0.106	0.029	0.018	42.436	####	1.178	12.118	1.746	13.559	
3	12.5	0.176	0.049	0.030	42.288	####	1.522	12.280	2.871	18.640	
4	17.5	0.247	0.069	0.042	42.140	####	1.803	12.406	3.979	23.703	
5	22.5	0.317	0.088	0.054	41.992	####	2.046	12.512	5.073	28.756	
6	27.5	0.388	0.108	0.065	41.844	####	2.264	12.603	6.155	33.801	447.421
7	32.5	0.458	0.127	0.077	41.697	####	2.464	12.684	7.228	38.842	
8	37.5	0.529	0.147	0.089	41.550	####	2.649	12.757	8.292	43.878	
9	42.5	0.599	0.167	0.101	41.404	####	2.822	12.823	9.349	48.912	
10	47.5	0.670	0.186	0.113	41.259	####	2.986	12.885	10.399	53.942	
11	52.5	0.740	0.206	0.125	41.115	####	3.142	12.942	11.442	58.971	
12	57.5	0.811	0.225	0.137	40.971	####	3.291	12.996	12.481	63.998	423.562
13	62.5	0.881	0.245	0.149	40.828	####	3.434	13.046	13.513	69.023	
14	67.5	0.952	0.264	0.161	40.687	####	3.572	13.093	14.541	74.047	
15	72.5	1.023	0.284	0.173	40.546	####	3.705	13.139	15.565	79.069	
16	77.5	1.093	0.304	0.185	40.407	####	3.834	13.182	16.584	84.091	
17	82.5	1.164	0.323	0.196	40.269	####	3.959	13.223	17.599	89.111	
18	87.5	1.234	0.343	0.208	40.132	####	4.081	13.263	18.610	94.131	415.331
19	92.5	1.305	0.362	0.220	39.997	####	4.200	13.301	19.617	99.150	
20	97.5	1.375	0.382	0.232	39.863	####	4.315	13.337	20.620	####	
21	102.5	1.446	0.402	0.244	39.731	####	4.428	13.373	21.620	109.187	
22	107.5	1.516	0.421	0.256	39.600	####	4.539	13.408	22.616	####	
23	112.5	1.587	0.441	0.268	39.471	####	4.647	13.441	23.609	119.221	
24	117.5	1.657	0.460	0.280	39.344	####	4.753	13.474	24.598	####	411.124
25	122.5	1.728	0.480	0.292	39.219	####	4.857	13.506	25.584	####	
26	127.5	1.798	0.500	0.304	39.095	####	4.959	13.537	26.567	####	
27	132.5	1.869	0.519	0.315	38.974	354.131	5.059	13.568	27.546	####	
28	137.5	1.939	0.539	0.327	38.854	####	5.157	13.598	28.522	####	
29	142.5	2.010	0.558	0.339	38.737	####	5.254	13.628	29.495	####	
30	147.5	2.080	0.578	0.351	38.621	####	5.350	13.657	30.464	####	408.562
31	152.5	2.151	0.597	0.363	38.508	####	5.444	13.686	31.430	####	
32	157.5	2.221	0.617	0.375	38.397	####	5.536	13.715	32.393	####	
33	162.5	2.292	0.637	0.387	38.289	####	5.627	13.743	33.352	####	
34	167.5	2.362	0.656	0.399	38.182	####	5.717	13.771	34.308	####	
35	172.5	2.433	0.676	0.411	38.079	####	5.806	13.799	35.261	####	
36	177.5	2.503	0.695	0.423	37.977	####	5.893	13.827	36.210	####	406.840
37	182.5	2.574	0.715	0.435	37.878	####	5.980	13.855	37.156	####	

Span length 30 m
12 outlets

S_r 2.5
S_1 1.25
N_{rp} 168

N_{rp}	r_{rpN} (m)	Qs_{pN} (m³/h)	Q_{rpN} (l/s)	X_{rpN}	H_{rpN} (m)	P_{rpN} (Kpa)	d_{rpN} (mm)	Dw	Ra	Dc	Tw
1	1.25	0.009	0.002	0.003	41.264	####	0.343	11.405	0.309	6.953	
2	3.75	0.026	0.007	0.009	41.205	####	0.593	11.534	0.917	9.517	
3	6.25	0.044	0.012	0.015	41.146	####	0.766	11.618	1.517	12.059	
4	8.75	0.062	0.017	0.021	41.087	####	0.907	11.685	2.112	14.592	
5	11.25	0.079	0.022	0.027	41.028	####	1.029	11.741	2.703	17.120	
6	13.75	0.097	0.027	0.033	40.969	####	1.138	11.789	3.290	19.645	
7	16.25	0.115	0.032	0.039	40.910	####	1.238	11.833	3.874	22.166	
8	18.75	0.132	0.037	0.045	40.851	371.189	1.330	11.872	4.455	24.686	
9	21.25	0.150	0.042	0.051	40.792	####	1.416	11.908	5.034	27.204	
10	23.75	0.167	0.047	0.057	40.733	370.121	1.498	11.942	5.610	29.721	
11	26.25	0.185	0.051	0.063	40.675	####	1.575	11.973	6.184	32.236	
12	28.75	0.203	0.056	0.068	40.616	####	1.649	12.002	6.757	34.751	####
13	31.25	0.220	0.061	0.074	40.558	####	1.720	12.029	7.328	37.265	
14	33.75	0.238	0.066	0.080	40.499	####	1.788	12.055	7.897	39.778	
15	36.25	0.256	0.071	0.086	40.441	####	1.854	12.080	8.465	42.290	
16	38.75	0.273	0.076	0.092	40.383	####	1.917	12.103	9.031	44.802	
17	41.25	0.291	0.081	0.098	40.325	####	1.979	12.126	9.596	47.313	
18	43.75	0.309	0.086	0.104	40.267	####	2.039	12.147	10.159	49.824	
19	46.25	0.326	0.091	0.110	40.209	####	2.097	12.168	10.722	52.334	
20	48.75	0.344	0.095	0.116	40.152	####	2.154	12.187	11.283	54.844	
21	51.25	0.361	0.100	0.122	40.094	####	2.209	12.206	11.843	57.353	
22	53.75	0.379	0.105	0.128	40.037	####	2.263	12.225	12.402	59.862	
23	56.25	0.397	0.110	0.134	39.980	####	2.316	12.242	12.960	62.371	
24	58.75	0.414	0.115	0.140	39.923	####	2.368	12.259	13.518	64.880	####
25	61.25	0.432	0.120	0.146	39.866	####	2.418	12.276	14.074	67.388	
26	63.75	0.450	0.125	0.152	39.810	####	2.468	12.292	14.629	69.896	
27	66.25	0.467	0.130	0.158	39.754	####	2.517	12.308	15.184	72.404	
28	68.75	0.485	0.135	0.164	39.698	####	2.565	12.323	15.737	74.911	
29	71.25	0.502	0.140	0.170	39.642	####	2.612	12.337	16.290	77.419	
30	73.75	0.520	0.144	0.176	39.586	####	2.658	12.352	16.842	79.926	
31	76.25	0.538	0.149	0.182	39.531	####	2.704	12.366	17.393	82.433	
32	78.75	0.555	0.154	0.188	39.476	####	2.749	12.379	17.944	84.940	
33	81.25	0.573	0.159	0.193	39.421	####	2.793	12.393	18.493	87.446	
34	83.75	0.591	0.164	0.199	39.366	####	2.837	12.406	19.042	89.953	
35	86.25	0.608	0.169	0.205	39.312	####	2.880	12.418	19.591	92.459	
36	88.75	0.626	0.174	0.211	39.258	####	2.922	12.431	20.138	94.965	419.012
37	91.25	0.643	0.179	0.217	39.204	####	2.964	12.443	20.685	97.472	

Fig. 4: Technical characteristic's outputs data of center pivot irrigation system based on the developed spread-sheet

3. RESULTS AND DISCUSSION

3.1. Nozzle Flow Rate

Fig. 5 shows the average flow rate of the nozzle for different designed scenarios and observed data. Average nozzle flow rates do not differ significantly across scenarios and observed data at the $p<0.05$ level (sig. 0.211). However, the highest rate of convergence was in scenarios 2, 3, 6, and 9. With a deeper analysis of this comparison, there is a notable declination of the mean of nozzle flow rate in scenarios 3 and 6 by 36.17%, 17.02%, respectively, While the mean of nozzle flow rate has a slight increasing in scenarios 2 and 9 by 19.15%, 4.26%, respectively. On the contrary, there is a diverging the mean of nozzle flow rate in scenarios 5 and 8 by a large margin of 65.96%, 80.85%, respectively. Scenarios 1, 4, and 7 have abnormal results from the mean of nozzle flow rate that are increasing by more than 90%.

On the other hands, unlike the Nozzle flow rate and application flow rate, there is a significant difference between means of throw diameter of the scenarios and manufactured data at the $p<0.05$ level (sig. 0.012).

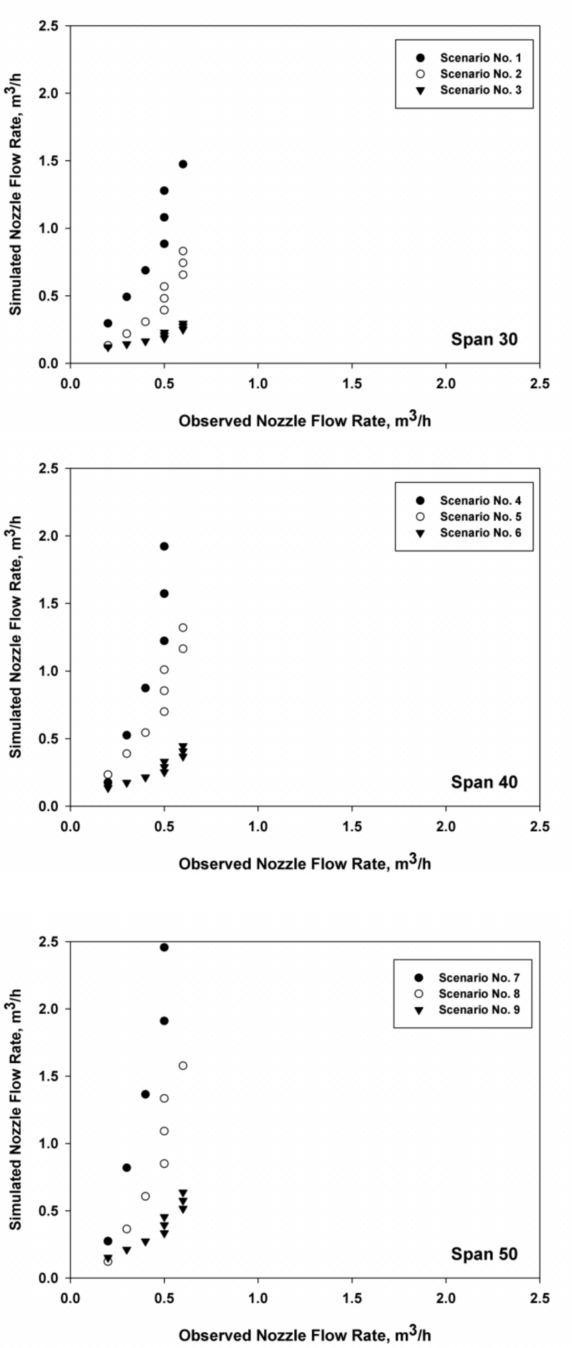


Fig. 5: Average versus estimated nozzles flow rate under different center pivot irrigation system span lengths (30, 40 and 50 m).

3.2. Application rate

Fig. 6 indicated that, the absence of any significant difference between means of the scenarios and manufactured data at the $p<0.05$ level (sig. 0.905). By comparing these curves, we found that the highest rate of convergence between simulated and manufactured data was in scenarios 4, 7, and 8 with an increasing percentage of 5.83%, 7.50%, and 4.17 respectively, then scenarios 1, 2, and 5 by 22.64%, 21.53%, and 20.83 respectively. Whereas, the farthest mean of water application rate was in scenario 3 by 34.44%.

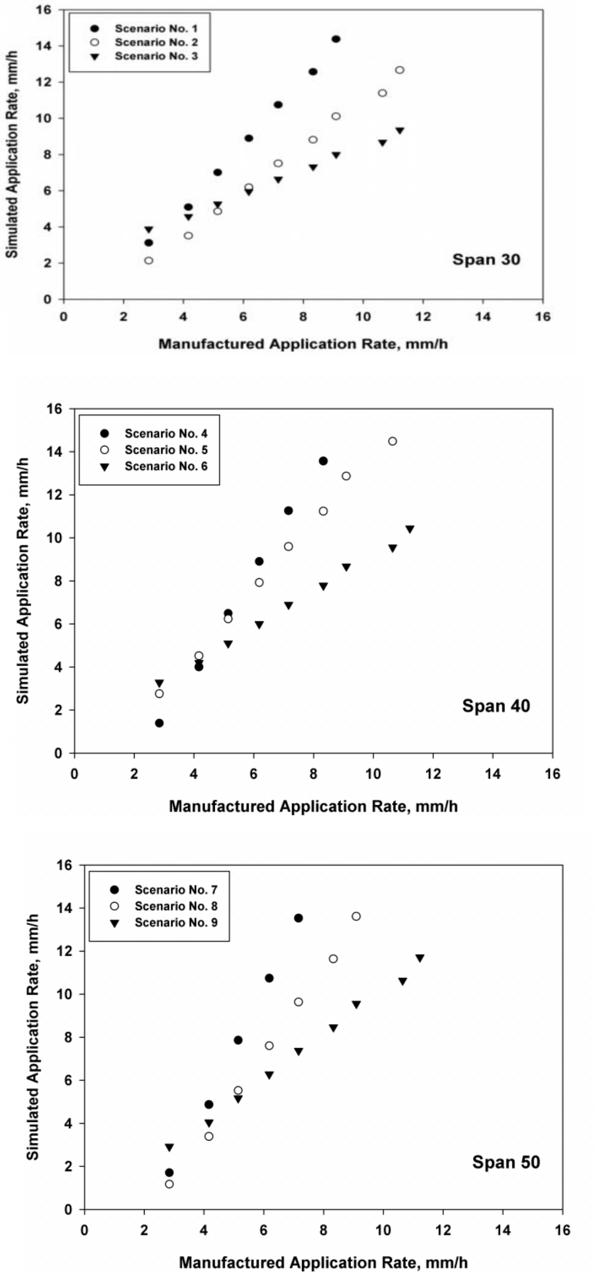
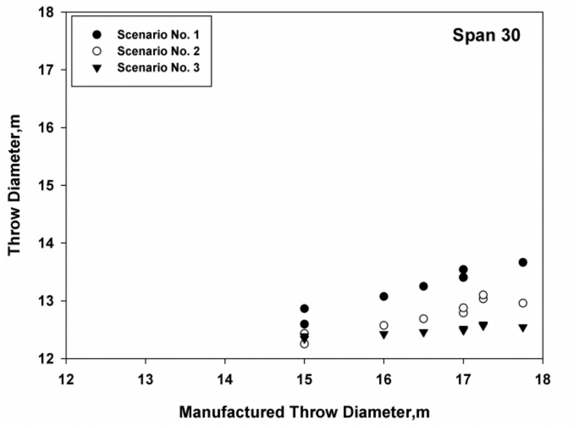


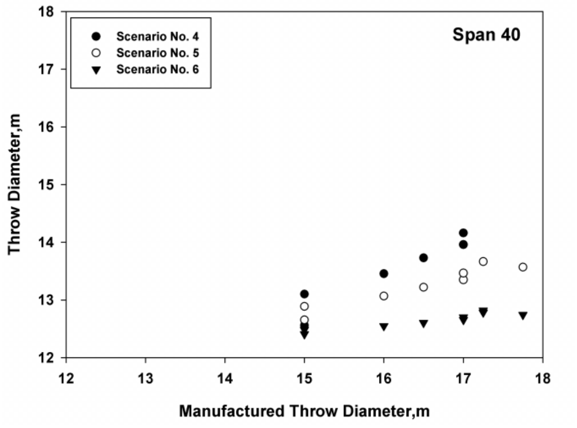
Fig. 6: Average versus estimated application rate under different center pivot irrigation system span lengths (30, 40 and 50 m).

3.3. Throw diameter

Fig. 7 shows the mean throw diameter for different scenarios and manufactured data. Therefore, the post-hoc comparison was applied using the multiple comparisons (Tamhane test) to test the difference between each pair of means. Results of Tamhane test indicate that the mean of scenarios 2, 3, 6, and 9 were significantly different with the manufactured data.

However, scenarios 1, 4, 5, 7, and 8 did not significantly differ from the manufactured throw diameter.





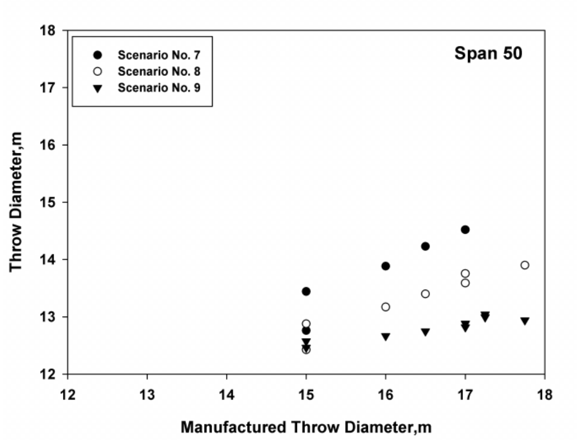


Fig. 7: Average versus estimated nozzles throw diameter under different pivot span lengths.

3.4. Validations of the developed simple spread-sheet

Regression analysis is done in order to estimate the relation between the independent variable (observed/manufactured) and the dependent variable (simulated). R^2 is the proportion of the total variation in predicted values that can be accounted by the relationship with measured or manufactured values. R^2 values near to 1 indicate that the data points fall in a well-defined equation, as shown in Table 2.

Table (2): The developed equations based on regression analysis under different design scenarios.

Scenario	Nozzle flow rate, m^3/h		Application rate, mm/h		Throw diameter, m	
	Model	R^2	Model	R^2	Model	R^2
1	$Q_{SIM} = 0.1383e^{4.0428 (Q_{obs})}$	0.960	$Ra_{SIM} = 1.798 (Ra_{MFD}) - 2.194$	0.998	$Dw_{SIM} = 3.9064 (Dw_{MFD})^{0.4361}$	0.942
2	$Q_{SIM} = 0.0574e^{4.2448 (Q_{obs})}$	0.966	$Ra_{SIM} = 1.2472 (Ra_{MFD}) - 1.5135$	0.997	$Dw_{SIM} = 4.8482 (Dw_{MFD})^{0.3447}$	0.888
3	$Q_{SIM} = 0.0754e^{2.0831 (Q_{obs})}$	0.936	$Ra_{SIM} = 0.649 (Ra_{MFD}) + 1.962$	0.997	$Dw_{SIM} = 9.3966 (Dw_{MFD})^{0.1013}$	0.870
4	$Q_{SIM} = 0.0537e^{6.803 (Q_{obs})}$	0.948	$Ra_{SIM} = 2.2664 (Ra_{MFD}) - 5.1754$	0.999	$Dw_{SIM} = 1.7812 (Dw_{MFD})^{0.7291}$	0.898
5	$Q_{SIM} = 0.1067e^{4.1131 (Q_{obs})}$	0.967	$Ra_{SIM} = 1.5587 (Ra_{MFD}) - 1.7341$	0.997	$Dw_{SIM} = 4.302 (Dw_{MFD})^{0.4015}$	0.917
6	$Q_{SIM} = 0.075e^{2.7614 (Q_{obs})}$	0.949	$Ra_{SIM} = 0.8492 (Ra_{MFD}) + 0.771$	0.997	$Dw_{SIM} = 7.9064 (Dw_{MFD})^{0.1673}$	0.877
7	$Q_{SIM} = 0.0911e^{6.4923 (Q_{obs})}$	0.948	$Ra_{SIM} = 2.7596 (Ra_{MFD}) - 6.3291$	0.999	$Dw_{SIM} = 1.3446 (Dw_{MFD})^{0.8409}$	0.868
8	$Q_{SIM} = 0.0441e^{6.2973 (Q_{obs})}$	0.944	$Ra_{SIM} = 1.9854 (Ra_{MFD}) - 4.6628$	0.998	$Dw_{SIM} = 2.6007 (Dw_{MFD})^{0.5846}$	0.918
9	$Q_{SIM} = 0.0761e^{3.325 (Q_{obs})}$	0.957	$Ra_{SIM} = 1.0428 (Ra_{MFD}) - 0.1537$	0.997	$Dw_{SIM} = 6.609 (Dw_{MFD})^{0.2355}$	0.883

Table (2): The developed equations based on regression analysis under different design scenarios.

However, results obtained from the regression analysis with R^2 are indicated that there are three groups of models that could explain the relation between the observed/manufactured data and simulated data. Firstly, exponential models that interpret the relationship between the observed and simulated for nozzle flow rate (m^3/h). The best model that explains the relationship between observed and simulated for Nozzle flow rate (m^3/h) among scenarios was obtained from the scenario no. 5 with $R^2 = 0.967$. Secondly, linear models that interpret the relationship between manufactured and simulated application rate (mm/h) with a very high R^2 (more than 0.99) for all scenarios. Finally, power models that interpret the relationship between manufactured and simulated throw diameter (m). The best model that could explain the relationship between manufactured and simulated for throw diameter (m) among scenarios was obtained from the scenario no. 1 with $R^2 = 0.942$.

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