Bakht Al-RudaUniversity Quarterly Refereed Scientific Journal, Issue (35) Volume (3) December 2022; [UBJSR: ISSN [1858-6139]: (Online)
http://www.juornal-bakhtalruda.bid/22/
Arab ImpactFactor(1.12)

Evaluation and Operation of Central pivot Irrigation System to Grow Wheat crop at New Hamdab and Dongola locations at Northern Sudan

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Acceptance Date: 1/10/2022 Publication Date:30/12/2022

Abstract

A two separately field experiments were conducted at Northern Sudan. The first one was conducted during season 2017/18 in New Hamdab location and the second was conducted during season 2018/2019 in Dongola location. The objective of this study was to evaluate center pivot irrigation system at New Hamdab Scheme and Dongla research station in order to determined the optimum operation if propose to grow wheat crop. Coefficient uniformity (CU), distribution uniformity (DU) and mean water application depth of catch cans at timer setting 100% at New Hamdab and at different timer setting 50%, 75% and 100% at Dongola were determined . Wheat crop water requirement was estimated for initial, development, mid and late season stage using the previous review data of K_c and normal climatic data. Then the optimum operation of these irrigation systems was determined. The results stated that at New Hamdab; the system work with CU of 80% and DU of 69% which were acceptable for both CU and DU within the range of a fair. The optimum timer setting is 100% operating every 2days at all crop stages except in mid season stage which operating every day. At Dongola; The system work with CU of (83, 84 and 85%) and DU (75, 70 and 74%) at the different timer setting of (100, 75 and 50%) respectively which were acceptable for CU within the range of good at timer setting 50% and fair at timer setting 100% and 75%, and acceptable for DU within the range of very good at timer setting 100% and good at timer setting 75% and 50%. The optimum timer setting is operating every day at all crop stages at timer 100% except in mid season stage which operating at timer setting 50%.

Key words: Irrigation systems .Central Pivot . Distribution Uniformity . Timer setting .

Introduction

Water scarcity is a vital problem faces the whole world and threatens food security (Frona*et al.*, 2019; Yassir*et al.*, 2020; Makhlof*et al.*, 2021; and Hassan *et al.*, 2022). In general irrigation is one of the most important factors, which affect the crop yield (Ageeb, 1993). Central pivot irrigation system is the one of the most important modern irrigation system in this area. There is a great expansion in using this type of systems (Asim, 2018). In Northern Sudan there are many units of this irrigation system which had been implemented by Merowi dam implementation unit and the investors. One unit can service a large area (45 ha). The area will increase or decrease according to the pivot length. When designing sprinkler irrigation systems, it is important to provide as uniform of water application as possible. A non-uniform application will result in areas of under-watering as well as areas of over-watering. This will result in reduced yields and decreased system efficiency. The uniformity of the sprinkler nozzle package design is determined by package design. It is affected by the operating conditions, and environmental factors, especially wind. The discharge rate of the emitters along the pipeline is not the same along the line, but varies from lower values near the center to higher ones towards the outer end by the use of small and large nozzles along the line accordingly and sometimes variable spacing. Good overlapping is essential. Obtaining suitable application rate patterns is dependent on following the manufacturer's nozzle size and pressure range recommendations. Performance indicators showed that central pivots were performing relatively well as uniformity coefficients (*CU* – coefficient of uniformity and *DU* – distribution uniformity) for the systems were within acceptable standards above the base values of 85% for *CU* and 75% for *DU* (Msibi*et al.* 2014).Classes of *CU* are as follows: $CU \geq 90$ – excellent, $85 \leq CU < 90$ –good, $80 \leq CU < 85$ – fair, $CU < 80$ – poor. Classes of DU are as follows $DU \geq 85$ excellent, $75 \leq DU < 85$ – very good, $70 \leq DU < 75$ – good, $65 < DU < 70$ – fair, $DU \leq 65$ – poor.

Study Objective

The objective of this study was to evaluate central pivot irrigation system at New Hamdab Scheme and Dongla Research Station in order to determine the optimum operation if propose to grow wheat crop.

Material and Methods

A two separately field experiments were conducted at Northern Sudan. The first one was conducted during season 2017/2018 in New Hamdab location and the second was conducted during season 2018/2019 at Dongola location. The New Hamdab location is characterized by a non–saline, non– sodic soils with coarse textured sandy loam at the top 0–40 cm and 65% and 18%, sand and clay respectively. It is classified as TypicHaplocambids, fine loamy, mixed, hyperthermic and super active. It is correlated to Kelly soil series (Table1). The Dongola Research Station Farm location; in General its Soil pH ranges between 7.6 and 8.4 and the texture of this soil is loamy in the upper layer 0-30 cm and sandy loam at the depth of 30-60 cm (Table 2 & 3).

Table (1) New Hamdab location Soil physical and chemical properties.

Characters	Soil depth				
	0-20 cm	20-40 cm	40-45 cm	45-85 cm	85-125 cm
CS (%)	52	52	55	55	52
FS (%)	14	13	14	15	12
Si (%)	18	12	15	8	13
C (%)	16	13	16	23	23
Bulk density (g cm^{-3})	1.73	1.49	1.86	1.85	1.71
Porosity (%)	35	44	30	30	35
Wilting point (%)	8.9	9.2	9.0	8.5	8.9
Field Capacity (%)	17.8	18.3	18.3	17.0	17.9
Saturation (%)	36	36	36	41	62
$CaCo_3$ (%)	2.4	2.4	2.0	6.6	19.2
CEC ((Cmol +)kg^{-1} soil	13	10	12	17	18
EC (dsm^{-1})	0.45	0.86	0.55	1.08	1.47
PH paste	7.9	7.9	7.8	8.0	7.6

Where: CS = Coarse sand, FS = Fine sand, Si = silt, C = Clay, ECe = Electric conductivity, CEC = Cation exchange capacity and ESP = Exchangeable sodium percentage.Source: (Abbas and Elfatih, 2017).

Table (2) Dongola location chemical properties.

Depth (cm)	EC (meq/l)	Na (meq/l)	Ca+Mg (meq/l)	SAR (meq/l)	ESP (%)	pH (Paste)	pH (1.5)
0-30	6.45	47.7	17.8	16.2	18.7	7.6	8.4

Source:(Erneo, 2007)

Tabble (3) Dongola location soil texture.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
0-30	50	35	15	Loam
30-60	60	26	14	Sandy Loam

Source:(Erneo, 2007)

Acatch cans of 14 cm diameter were spaced 3 m apart in 3 rows extending from the pivot centre straight out to the circle edge. The first row was placed at angle of 30^0 from the pivot so no water should be entering the cans until the pivot is at full pressure and speed. This cans was use to collect the applied irrigation water and then measuring the water collected using measuring cylinder. The operation was repeated 3 times at timer 100% at New Hamda location and at different timer (100, 75 and 50%) at Dongolalocation . While the last tower running, a tow point were tagged and the distance between them was determined and the time for the tower to run this distance was recorded.The coefficient uniformity (CU) was calculated using Christiansen equation as described by Heermann and Hein (1968) and expressed by El Nahry*et al.*, (2011) and Basheer*et al.*, (2015)as follow;

$$CU = [1- \sum(x_i - \bar{x})/n*\bar{x}]*100$$

Where;

CU = coefficient uniformity (%)

X_i = water depth in can

$\bar{x}$ = mean water depth

n = number of cans

The distribution uniformity (DU) was calculated using the following equation as described by Michael (1978) and suggested by ASABE(2007);

$$DU = dn/\bar{x}$$

Where;

DU = distribution uniformity (%)

dn = men water depth of least quarter

$\bar{x}$ = over all mean water depth

The crop water requirement of wheat crop was estimated for initial, development, mid and late season stage using the previous review data K_c and normal climatic data (**Adam,2014**). After that to determine the optimum operation of this irrigation system; the data which resulted from the performance evaluation were used to apply exactly the applied water of the crop water requirement at each stage.

Results Discusion

Table (4) Coefficient uniformity (CU) ,Distribution uniformity (DU)and mean water application depth of catch cans at timer setting 100%.

Catch cans (No)	W.App depth (mm)	Catch cans (No)	W.App depth (mm)	Catch cans (No)	W.App depth (mm)
1	1.2	25	8.6	49	8.5
2	2.2	26	10.6	50	8.6
3	4.7	27	7.8	51	20.3
4	3.5	28	7.3	52	7.8
5	3.1	29	6.4	53	7.2
6	4.2	30	7.6	54	8.7
7	6.2	31	9.2	55	5.8
8	9.9	32	8.1	56	7.6
9	6.7	33	9.1	57	8.5
10	8.3	34	9.6	58	7
11	6.1	35	10.1	59	7.8
12	7.4	36	8.8	60	8.8
13	7.7	37	9.9	61	7.7
14	7.9	38	9.3	62	5.9
15	6.3	39	7.4	63	8
16	4.8	40	6.4	64	10
17	9	41	6.9	65	7.8
18	6.5	42	8.6	66	6.0
19	6.7	43	7.9	67	7.3
20	8.8	44	8.2	68	9
21	8.9	45	8.2	69	8.7
22	7.3	46	8.3	70	8.2
23	8.1	47	7.5	71	8.1
24	7.2	48	8.5	72	8.1
				73	11.1
Mean	7.5				
CU (%)	80				
Classes	Fair				
DU (%)	69				
Classes	Fair				

Performance evaluation of the central pivot irrigation system at New Hamadab location season 2017/2018:The results in Table 4. indicated that the system work with coefficient uniformity CU of 85% and DU of 69% within the acceptable range of fair for both at timer setting 100% and The application water depth at catch cans varies from (1.2 to 11.1 mm) with total mean of 7.5 mm at timer 100% .

Table (5) Time per revolution (hr) water application depth (mm) at different timer setting.

Timer setting (%)	Time/revolution (hr)	Mean w.app. depth (mm)
100	13	7.5
90	14.4	8.3
80	16.3	9.4
70	18.6	10.7
65	20	11.5
60	21.7	12.5
55	23.6	13.6
50	26	15.0
45	28.9	16.7
40	32.5	18.8
35	37.1	21.4
30	43	25.0
25	52	30.0
20	65	37.0

The results in Table 5.indicated that the higher timer setting obtain lower mean water application depth with lower time per revolution. On the other hand the lower timer setting obtains higher mean water application depth with higher time per revolution. The time per revolution it range between (13 to 65 hr) and the mean water application depth it ranges between (7.5 to 37.0 mm).

Table (6) Wheat crop water requirement and the Optimum timer setting at different crop stages.

Crop Stage	Initial	development	Mid	Late	Total
Days	20	40	40	20	120
K_c	0.5	0.75	1.15	0.5	
ET_o	6.4	5.1	6.4	7.8	
ET_c (mm/day)	3.2	3.8	7.4	3.9	
Optimum timer (%)	100 (2 days)	100 (2days)	100 (1 day)	100 (2 days)	

The results in Table 6. according to the estimation wheat crop water requirement from the previous review data and under this unit condition, the optimum timer setting was 100% operating at all crop stages every 2 days except at mid season which operating every day.

Table (7) Coefficient uniformity (CU) ,Distribution uniformity (DU)and mean water application depth of catch cans at timer setting 100%, 75% and 50%.

Catch cans (No)	Water application depth (mm) of catch cans		
	Timer 100%	Timer 75%	Timer 50%
1	3.07	6.49	9.01
2	4.64	7.11	11.87
3	4.77	6.15	11.09
4	4.20	6.24	10.27
5	4.03	5.11	8.10
6	3.99	4.94	7.89
7	3.29	4.07	6.15
8	3.03	3.86	6.72
9	2.69	3.81	5.72
10	2.69	3.86	6.76
11	2.64	3.38	5.33
12	2.38	3.68	5.59
13	2.38	5.55	6.76
14	5.98	7.11	8.32
15	4.51	6.93	9.09
16	3.99	7.19	7.97
17	3.51	5.76	8.49
18	3.64	5.85	9.14
19	4.12	6.07	8.84
20	3.73	5.89	9.01
21	3.81	6.02	8.41
22	3.34	5.55	8.67
23	3.89	5.19	9.36
24	3.55	5.46	8.67
25	3.42	5.50	8.97
26	3.16	5.46	8.06
27	3.38	5.29	7.54
28	3.03	3.99	6.11
Mean	3.60	5.341	8.14
CU (%)	83	84	85
Classes	Fair	Fair	Good
DU (%)	75	70	74
Classes	Very good	Good	Good

Performance evaluation of the central pivot system at Dongola location during season 2018/2019: The results in Table 7. indicated that the The system work with CU of (83, 84 and 85%) and DU (75, 70 and 74%) at the different timer setting of (100, 75 and 50%) respectively which were acceptable for CU within the range of good at timer setting 50% and fair at timer setting 100% and 75%, and acceptable for DU within the range of very good at timer setting 100% and good at timer setting 75% and 50%. This may be due to the fact that the low timer setting always resulted in more uniform distribution. The application water depth at catch cans varies from (2.38 to 5.98 mm) with total mean of 3.60 mm at timer 100% and from (3.38 to 7.19 mm) with total mean of 5.41 mm at timer 75% not only but also from (5.33 to 11.87 mm) with total mean of 8.14 mm at timer 50% , this variation may be due to factor of wind speed.

Table (8) Time per revolution (hr) and water application depth (mm) at different timer setting.

Timer setting (%)	Time/revolution (hr)	Mean w.app. depth (mm)
100	2.29	3.6
95	2.41	3.79
90	2.55	4.0
85	2.70	4.24
80	2.87	4.5
75	3.06	4.8
70	3.27	5.14
65	3.53	5.54
60	3.82	6.0
55	4.17	6.55
50	4.58	7.2
45	5.09	8.0
40	5.73	9.0
35	6.45	10.29
30	7.64	12.0
25	9.17	14.4
20	11.46	18.0
15	15.28	24.0
12	19.10	30.0
9	25.47	40.0
6	38.20	60.0
3	76.41	120.0

The results in Table 8.indicated that the higher timer setting obtain low mean water application depth with lower time per revolution. On the other hand the lower timer setting obtains higher mean water application depth with higher time per revolution. The time per revolution it range between (2.29 to 76.41 hr) and the mean water application depth it ranges between (3.6 to 120 mm).

Table (9) Wheat crop water requirement and the Optimum timer setting at different crop stages.

Crop Stage	Initial	development	Mid	Late	Total
Days	20	40	40	20	120
K_c	0.5	0.75	1.15	0.5	
ET_o	6.4	5.1	6.4	7.8	
ET_c (mm/day)	3.2	3.8	7.4	3.9	
Optimum timer (%)	100	94	48.9	92	
Proximately	100 (1 day)	95-100 (1 day)	50 (1 day)	90-100 (1 day)	

The results in Table 9. according to the estimation of wheat crop water requirement from the previous review data under this unit condition, the optimum timer setting were (100), (95 to 100), (50) and (90 to 100) operating every day at initial, atage development, mid and late season stage respectively. Beside the consideration of irrigation at sowing date should be at low timer about 50 to 75% due to the need of enough water to germinate the seeds.

Conclusion

1. For New hamdab: The system work with acceptable distribution uniformity within the range of fair for both CU and DU.

2. The system optimum timer setting is 100% operating every 2days at all crop stages except at mid season stage which operating every day.

3.For Dongola:Thesystem work with acceptable for CU within the range of good at timer setting 50% and fair at timer setting 100% and 75%, and acceptable for DU within the range of very good at timer setting 100% and good at timer setting 75% and 50%.

4.The system optimum timer setting is operating every day at all crop stages at timer 100% except at mid season stage which operating at timer setting 50%.

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