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Research paper

Field Evaluation of Center Pivot Sprinkler Irrigation Systems, Atbara Food Security Scheme

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ABSTRACT

This study aimed to evaluate the performance of three center pivot sprinkler irrigation systems; A, B and C in the high terrace soil of a farm near Atbara, River Nile State. Catch-can tests were carried out to determine the performance of irrigation applied with the center pivot sprinkler irrigation systems under field conditions. The coefficient of uniformity (CU), distribution uniformity (DU), and application efficiency (AE), as performance parameters, were determined. The Center Pivot irrigation Model (CPM) was used to determine the average application depth (AgD) as well as the performance parameters CU, DU and AE. Field evaluation results indicated that for the three systems, A, B and C the CUs were 77.7, 84.1 and 92.5%, respectively, the DUs were 49.1, 71.6, and 87.1%, respectively, and the AEs were 79.7, 92.1 and 92.9%, respectively. Generally, among the three systems, both B and C showed higher performance than A. Hence, the test of performance for a center pivot sprinkler irrigation system should be carried out each season.

Keywords: *Application efficiency, coefficient of uniformity, distribution uniformity, soil moisture content*

تقييم نظم الري بالرش المحوري بمشروع الأمن الغذائي عطبرة

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أجريت هذه الدراسة لتقييم أداء ثلاث نظم ري بالرش المحوري أ، ب و ج. نفذت هذه الدراسة بولاية نهر النيل جنوب مدينة عطبرة بمزرعة في أراضي التروس العليا. استخدمت علب القياس لتقييم أداء نظام الري بالرش المحوري تحت ظروف الحقل. المعاملات التي استخدمت لتقييم وتحليل الأداء شملت معامل الانتظامية (CU)، ومعامل انتظامية التوزيع (DU)، وكفاءة الإضافة (AE). البرنامج الحاسوبي "الري المحوري CPM" أستخدم لحساب معدل إضافة مياه الري (AgD) بالإضافة لحساب معاملات تقييم الأداء CU و DU و AE. نتائج التقييم الحقلي أوضحت أن معامل الانتظامية للثلاث نظم ري أ و ب و ج هي 77.7 ، 84.1 و 92.5 % على التوالي. من الناحية الأخرى، أوضحت النتائج أن معامل انتظامية التوزيع هي 49.1 ، 71.6 و 87.1 % وكفاءة الإضافة هى 79.7 و 92.1 ، 92.9 % للثلاث نظم ري أ، ب، وج على التوالي. من الناحية العامة أوضحت نتائج تقييم الأداء أن نظامي الري بالرش المحوري ب، وج كان أدائهما أفضل من أ عليه فإن دراسة كفاءة نظام الري المحوري يجب أن تطبق سنوياً.

Introduction

The role of irrigation development is to improve production and input efficiency in areas where the climate limits production potential. The global climate change and scarcity of water resources have further reduced the amount of water available for agriculture.

Irrigation systems improvements becomes very imperative because of the serious constraint faced by irrigators due to water scarcity and the ensuing competition for water by other higher-valued industrial concerns and urban uses. This trend is expected to continue due to improvements in water application efficiency and labor reduction associated with sprinkler irrigation systems (Ahaneku, 2010).

An ideal irrigation system should apply the correct amount of water, minimize the losses, and apply the water uniformly. Valin *et al*. (2012) stated that when the sprinkler irrigation system is properly designed and managed more than 90% of water applied can be utilized by the crop. Irrigation performance assessment will enable irrigation managers to measure and determine actual performance; identify which factors are responsible for less than ideal performance and determine the relative impact of these factors and how they might be addressed.

Center-pivot sprinkler irrigation systems have experienced a wide diffusion worldwide because of their advantages relative to other irrigation systems. Therefore, it is important to characterize the significance of several design and management factors affecting the efficiency and uniformity of these systems (Montero *et al*., 2003).

Since no irrigation system can apply water precisely to all areas of the field, it becomes necessary to estimate the uniformity of water application in order to assess the performance of the system. A non-uniform application will result in areas of under-watering as well as areas of over-watering. This will result in reduced yields as well as decreased system efficiency (Acar *et al.*, 2010). To help keep a center pivot irrigation system at peak efficiency, on-farm evaluations can be used to measure a system's average irrigation amount and identify uniformity problems that cannot be seen visually.

The uniformity of water application under a center pivot could be determined by setting out identical catch-cans along the length of the pivot, bringing the irrigation system up to proper operating pressure, and letting the system pass over them. The two most common methods of expressing uniformity are the coefficient of uniformity (CU) and distribution uniformity (DU).

The coefficient of uniformity (CU), proposed by Christiansen (1942) and modified by Heerman and Hein (1968), is the most popular uniformity coefficient used with center pivot catch-can data to include a term representing the distance from the center to the catch-can. It is recommended by the American Society of Agricultural and Biological Engineers (R2007) to evaluate the uniformity of water application as follows:

$$CU = 100\left[1.0 - \frac{\sum Ss\left|Ds - D\right|}{\sum DsSs}\right] \qquad (1)$$

Where, CU is the coefficient of uniformity, Ds is the applied water depth for one collector position, D is the average applied water depth for all collectors and Ss is the distance to equally spaced collectors.

The distribution uniformity (DU) was computed by dividing the average low quarter caught in the cans by average depth caught in all cans as applied by Harrison and Perry (2010):

$$\text{DU}=\left[\frac{\text{Average low quarter caught in the cans}}{\text{Average depth caught in all cans}}\right] \ldots\ldots..(2)$$

The average application depth was determined by dividing the pumped volume by the application area (Almasraf *et al.*, 2011):

$$\text{Average application depth (m)} \quad \frac{\text{time per revolution (Hrs)} \times \text{system flow rate } (\text{m}^3/\text{Hrs})}{\text{irrigated area } (\text{m}^2)} \ldots (3)$$

Rodrigues and Pereira (2009) reported that when the center pivot sprinkler irrigation system has low distribution uniformity, water productivity as well as economic efforts are low. Valin *et al.* (2012) stated that improving center pivot sprinkler irrigation systems design and management resulted in increasing water application uniformity, reducing energy used with lower pressure, and controlling negative environmental impacts such as excessive water and fertilizer operational losses.

Further, the application efficiency (AE) is an indicator of water that is lost during the process of supplying water to the field due to evaporation and wind drift losses. It is defined as the volume of water applied to the surface divided by the volume of water exiting in the sprinkler emitter (Rinders, 2001):

$$AE = 100 \times \left[\frac{M \times Ap}{Vs}\right] \dots\dots..(4)$$

Where, AE is the application efficiency (%), Ap is the plot area (m^2), M is the mean application depth (mm) and Vs is the volume exiting from sprinkler or emitter during CU test (m^3).

According to Harrison and Perry (2010), the basic interpretation of uniformity coefficients of center pivot irrigation systems is as follows: 90 to 100 % excellent; no changes required, 85 to 90% good; no changes required unless problem area is obvious, 80 to 85% fair; no improvement needed but system should be monitored closely and below 80% poor; where improvements needed. Rinders (2001) added that in every 1% drop in CU, crop yield might drop by 2%.

Performance evaluation may be carried out soon after the system's installation, and periodically repeated. Improvement of DU and well management of the irrigation system may lead to substantial savings in cost and the volume of water applied (Hill and Heaton, 2001).

Sprinkler irrigation systems, especially center pivot and linear move irrigation systems, have been recently introduced in limited area in Sudan, mostly in River Nile State.

The objective of this study was to evaluate the hydraulic performance of three center pivot sprinkler irrigation systems under River Nile State conditions.

Materials and Methods

This study was conducted at the Farm of Arab Company for Agricultural Production and Processing, River Nile State, at latitude 17º 48- N, longitude

34º 00- E and altitude 346.5 m above mean sea level. Field evaluations were made on three center pivot sprinkler irrigation systems (A, B and C) during winter season 2006/2007, where some performance indicators; such as uniformity coefficient (CU), distribution uniformity (DU), and application efficiency (AE), were evaluated.

Catch-cans test was used to evaluate the three systems performance. Under each system there were two straight lines perpendicular to the direction of travel of the machine. Each line consists of 44-52 catch-cans which were identical in size and shape. The catch-cans were located separated uniformly by 7 m. The amounts of water caught in the catch-cans were measured volumetrically by measuring cylinders and then converted into depths by dividing the amount caught into the catch-can by cross sectional area. The Center Pivot irrigation Model (CPM) developed by Alsayim and Saeed (2011) was used to determine the average application depth (AgD), coefficient of uniformity (CU), distribution uniformity (DU) and application efficiency (AE). The CPM model was developed using Microsoft Visual Basic 6.0 and was run in Windows. The program was interactive for designing a new system and/or for evaluation of an existing system.

The climate data were obtained from Sudan Meteorological Authority, Atbara station which is adjacent to the experimental field. It included the means of rainfall data, maximum and minimum temperatures, relative humidity, sunshine, wind speed at 2m height and evaporation rates. Monthly mean values for 30 years (1971– 2000) are presented in Table (1).

The physical properties of research cite soil was examined at Hudeiba Agricultural Research Station laboratories. The soil was high terrace soil classified as sandy clay loam. Samples for soil moisture content and corresponding bulk density were taken from each tower of the two systems (B and C) at two depths 0-20 cm and 20-40 cm, by using a cylinder with 4.8 cm diameter and 1 m height (Table 2).

The studied three center pivot irrigation systems obtained their water via an earth canal by pumping from the River Nile. The three systems consisted of eight towers with a total length of 419, 423 and 428 m for the three systems A, B and C, respectively.

Equidistant nozzles (1.9 m) of the type Inv Wobbler ¾M were used in each of the three systems. Water flow rates were measured by flowmeters and the pressure head at the pivot point was measured.

Results and Discussion

Coefficient of uniformity (CU)

The hydraulic performance indicators of the studied three center pivot sprinkler irrigation systems are shown in Figures (1, 2, 3 and 4). Among the three tested systems, C gave the highest coefficient of uniformity (92.5%), followed by B (84.1%) and A (77.7%). The lower value of CU for the third system was still under acceptable range. The CU values must be more than 80% as acceptable range (Harrison and Perry, 2010). Usually, in sprinkler irrigation systems, low CU values could be attributed to the inaccurate arrangement in nozzle size along the system beside not following the colure code recommended by manufacture.

Also, the low value of CU under center pivot system can be attributed to clogging of nozzles and/or nozzles being worn out as mentioned by Griffiths and Lecler (2001). However, the system operator justified that, the low CU values of system A is due to unavailability of spare parts in time.

Distribution uniformity (DU)

The distribution uniformity (DU) values for A, B and C systems as illustrated in Figures 1, 2, 3 and 4 were 49.1, 71.6 and 87.1%, respectively. These results could be considered reasonable except for system A as compared to 80% value recommended by Harrison and Perry (2010).

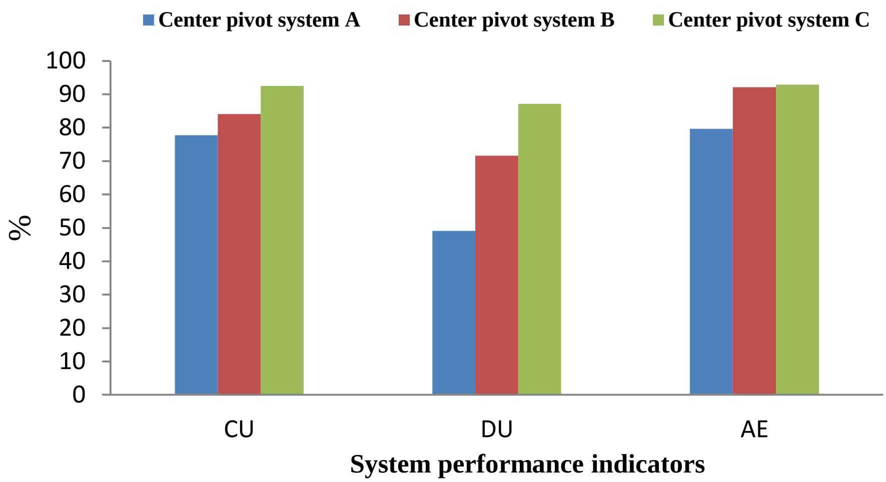
Table 1: Climatological normals (1971–2000), Atbara Station

Mon.	Air temperature in °C				Mean dry Temp.	Bright sunshine duration		Relative humidity %	Rain fall in mm				EVAP. pitch MM	Wind Mean Speed at 2 m $m\ s^{-1}$
	Maximum		Minimum						IN MMS	No. of rain days				
	MEAN	HST	MEAN	LST	IN °C	HRS	%	MEAN		>=0.1	>=1.0	>=10.0		
JAN	29.8	39.1	14.2	6.3	22.0	9.9	88	36	0.0	0.0	0.0	0.0	13.5	2.2
FEB	31.8	41.4	15.1	5.5	23.4	10.3	90	31	0.0	0.0	0.0	0.0	15.0	2.2
MAR	35.7	45.7	18.4	10.8	27.0	10.1	84	24	0.0	0.0	0.0	0.0	18.1	2.2
APR	40.0	46.3	22.1	15.0	31.1	10.6	85	23	0.4	0.2	0.1	0.0	20.1	1.9
MAY	42.6	47.5	26.5	18.9	34.5	9.8	75	23	3.2	0.7	0.5	0.1	20.4	1.6
JUN	43.2	48.0	28.0	21.6	35.6	8.6	65	22	1.0	0.3	0.2	0.0	20.7	1.6
JUL	41.2	47.7	27.3	19.5	34.3	8.7	65	32	15.1	1.4	1.3	0.4	19.0	1.9
AUG	40.6	46.5	26.9	19.5	33.8	8.6	67	37	26.5	2.2	2.0	0.9	18.0	1.9
SEP	41.6	47.6	27.4	20.0	34.5	8.6	71	32	8.6	1.1	1.0	0.3	18.5	1.9
OCT	39.7	44.5	25.2	16.0	32.5	9.8	83	31	3.0	0.5	0.5	0.1	17.4	1.6
NOV	34.9	40.7	20.1	11.7	27.5	10.2	90	36	0.0	0.0	0.0	0.0	14.7	1.9
DEC	31.1	38.5	16.0	6.5	23.6	9.7	88	40	0.0	0.0	0.0	0.0	13.2	1.9
Year	37.7	48.0	22.3	5.5	30.0	9.6	79	31	57.7	6.7	5.4	1.8	17.4	-

HST: Highest
LST: Lowest
Source: Sudan Meteorological Authority, Atbara Station

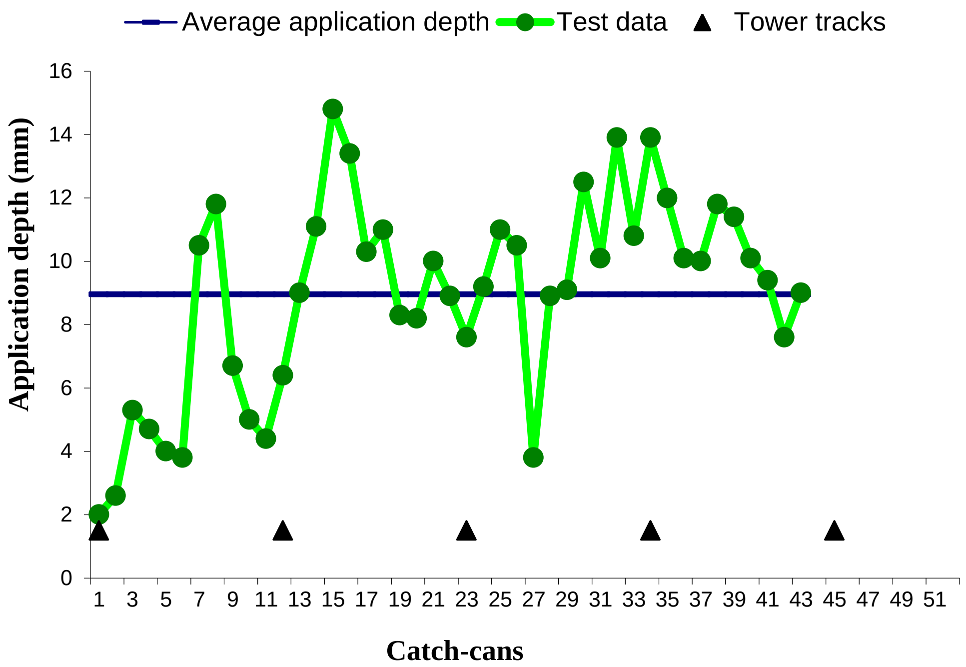
Table 2: Soil moisture content and bulk density for the two center pivot sprinkler irrigation systems B and C.

Tower No.	Depth (0-20 cm)				Depth (20-40 cm)			
	Center pivot sprinkler irrigation system **(B)**		Center pivot sprinkler irrigation system **(C)**		Center pivot sprinkler irrigation system **(B)**		Center pivot sprinkler irrigation system **(C)**	
	Moisture (%)	**Bulk Density (g/cm^3)**	**Moisture (%)**	**Bulk Density (g/cm^3)**	**Moisture (%)**	**Bulk Density (g/cm^3)**	**Moisture (%)**	**Bulk Density (g/cm^3)**
1	15.8	1.8	23.3	1.5	15.4	1.8	25.5	1.4
2	15.4	1.8	16.3	1.8	16.9	1.6	17.8	1.7
3	13.7	1.8	17.8	1.7	11.1	1.9	17.6	1.7
4	18.3	1.6	17.3	1.8	18.2	1.6	16.2	1.8
5	16.5	1.7	14.7	1.6	15.5	1.6	21.9	1.6
6	14.1	1.7	18.9	1.8	13.2	1.6	19.3	2
7	16.2	1.7	19.3	1.7	16.9	1.7	19.3	1.7
8	14.5	1.7	18.6	1.7	15.1	1.6	21.3	1.7
mean	**15.6**	**1.7**	**18.3**	**1.7**	**15.3**	**1.7**	**19.9**	**1.7**



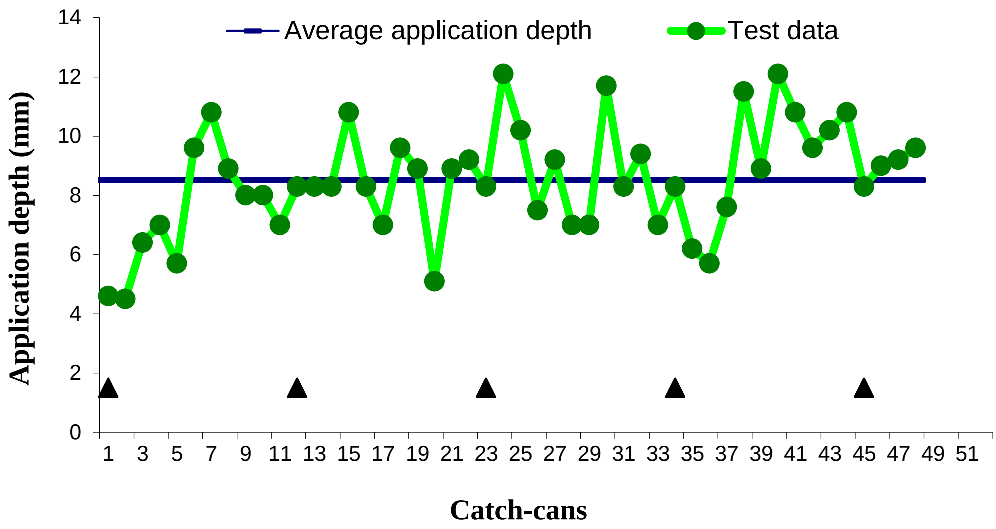
CU: Coefficient of uniformity, DU: Distribution uniformity and AE: Application efficiency

Figure 1: Hydraulic performance indicators for the three center pivot sprinkler irrigation systems



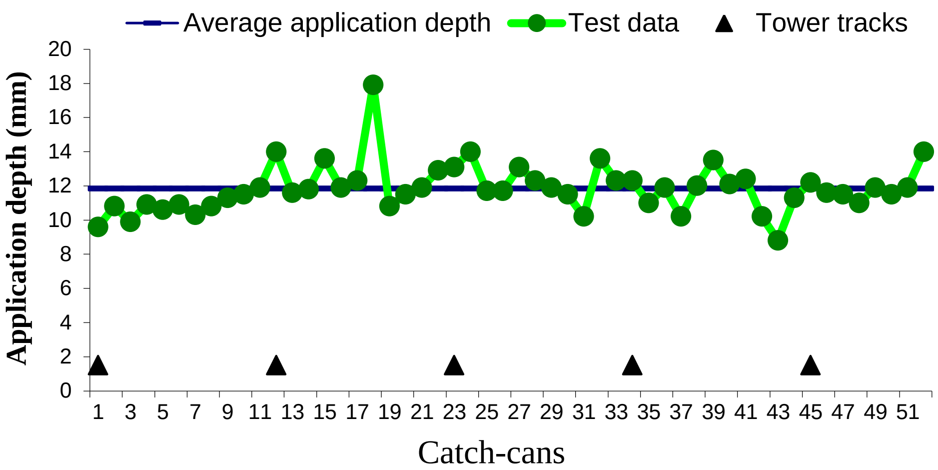
Coefficient of uniformity (CU) = 77.7 %, Distribution uniformity (DU) = 49.1 %
Application efficiency (AE) = 79.7 %

Figure 2: Uniformity test results for center pivot sprinkler irrigation system A



Coefficient of uniformity (CU) = 84.1 %, Distribution uniformity (DU) = 71.6 %
Application efficiency (AE) = 92.1 %

Figure 3: Uniformity test results for center pivot sprinkler irrigation system B



Coefficient of uniformity (CU) = 92.5 %, Distribution uniformity (DU) = 87.1 %
Application efficiency (AE) = 92.9 %

Figure 4: Uniformity test results for center pivot sprinkler irrigation system C

The low values of DU obtained may be attributed to improper replacing of the same nozzle size along the system according to operation manual. However, the uniformity of center pivot sprinkler irrigation systems is influenced by center pivot pressure, wind speed, nozzle wear, climatic condition and variation in pressure (Rinders, 2001).

Application efficiency (AE)

As shown in Figure (1) the application efficiency (AE) values obtained by the three systems are considered within the acceptable range (79.7 - 92.9%) proposed by Almasraf *et al.* (2011).

Concerning water losses, system A gave the highest value (20.3%). Correspondingly, Playa´n *et al.* (2005) reported that wind speed, as a meteorological variable, is more directly related to the sprinkler irrigation performance through its effects on the uniformity coefficient and wind drift and evaporation losses. However, Mustafa (2004) reported that the percentage of water losses for center pivot and linear move system under Sudan conditions ranges between 10 and 34.9%.

Soil moisture content

Table (2) shows the results of soil moisture content and corresponding soil bulk density for each tower for the systems B and C. The soil bulk density was 1.7 g cm^{-3} for both systems, which indicates that the two systems have the same soil type. Figure (5) represents the soil moisture content for the system B. The results showed clear variation in soil moisture content along sprinkler line (towers). This variation can be clarified by the variation of application depths caught by the catch-cans (Figure 3). On the other hand, the results of moisture content for system C showed slightly variation in soil moisture content along the sprinkler line (Figure 6) and this emphasis by high values of system performance indicators (CU=92.5% and DU=87.1%) (Figure 4).

Conclusions

In order to conserve water resources, close attention has to be paid to the performance of irrigation systems. Irrigation systems such as center pivot sprinkler irrigation systems should be evaluated on a regular basis to ensure that the systems are well maintained and are performing according to design. The distribution uniformity of a system must be as uniform as possible to ensure higher yields and efficient application of water.

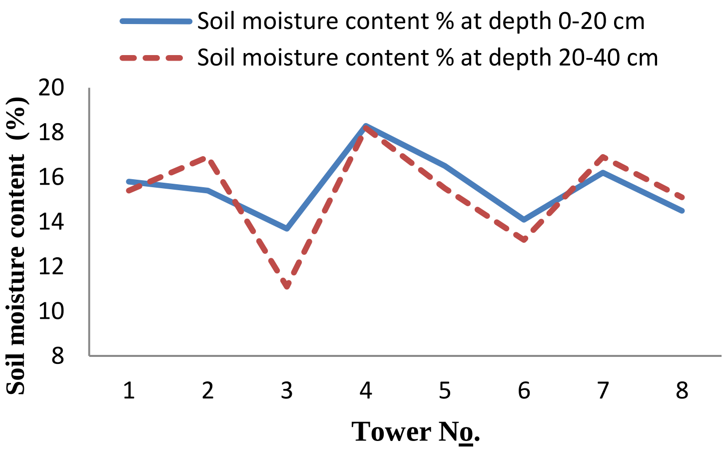


Figure 5: Soil moisture content for center pivot sprinkler irrigation system B

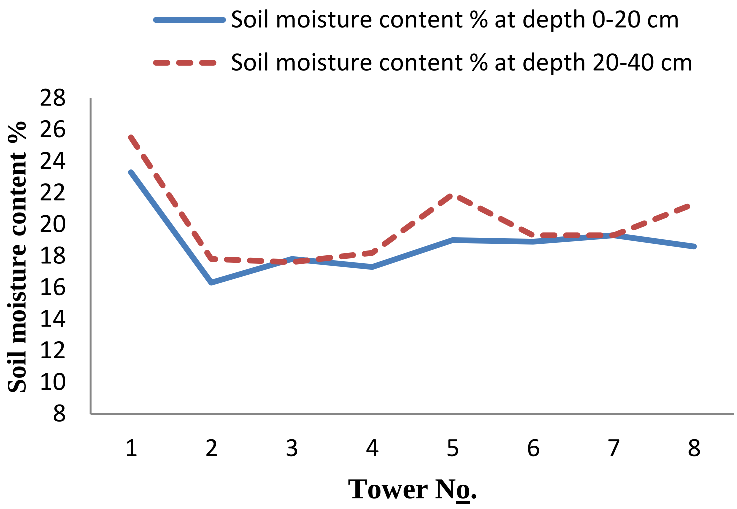


Figure 6: Soil moisture content for center pivot sprinkler irrigation system C

References

Acar, B.; Topak, R. and Direk, M. (2010). Impacts of pressurized irrigation technologies on efficient water resources uses in semi-arid climate of Konya Basin of Turkey. Int. J. of Sustainable Water and Environmental Systems, Vol. 1 (1), pp. 1 - 4.

Ahaneku, I. E. (2010). Performance evaluation of portable sprinkler irrigation system in Ilorin, Nigeria. Indian Journal of Science and Technology. Vol. 3 (7), pp. 853 - 857.

Almasraf, S.; Jury, J. and Miller, S. (2011). Field evaluation of center pivot sprinkler irrigation systems in Michigan. Department of Biosystems and Agricultural Engineering, Michigan State University.

Alsayim, H. E. and Saeed, A. B. (2011). A software tool for appropriate design of center pivot irrigation system. Sudan Journal of Agricultural Research. Vol. 17, pp. 103 - 122.

ASABE (2007). Test procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles. ANSI/ASAE S436.1 JUN1996. ASAE Standards, pp. 1033-1039.

Christiansen, J. E. (1942). Hydraulics of sprinkling systems for irrigation. Tran. Amer. Soc. Civ. Eng. 107: pp. 221-239.

Griffiths, B. and Lecler, N. (2001). Irrigation system evaluation. Proc S Afr Sug Technol Ass, 75: pp. 58-67.

Harrison, K. and Perry, C. (2010). Evaluating and interpreting application uniformity of center pivot irrigation systems. University of Georgia Cooperative Extension.

Heerman, D. F and Hein, P.R. (1968). Performance characteristics of self propelled center pivot sprinkler irrigation system. Transaction of the ASAE 11(1), pp.11-15.

Hill, R. W. and Heaton, K. (2001). Sprinklers, crop water use, and irrigation time, Beaver Country. Online Extension. usu. edu, ENGR/BIEWM/24.

Montero, J. M.; Valero, A. J. and Tarjuelo, J. M. (2003). Behavior of several kinds of emitters on water distribution with center pivot equipment. Montpellier, France: Workshop on Improved Irrigation Technologies and Methods: Research, Development and Testing. CIID CEI.

Mustafa, H. A. (2004). Evaluation of center pivot and linear move sprinkler irrigation system. M.Sc Thesis Dep. of Agric. Engineering, Faculty of Agricultural, University of Khartoum.

Playa´n, E.; Salvador, R.; Faci, J. M.; Zapata, N.; Martı´nez-Cob, A. and Sanchez, I. (2005). Day and night wind drift and evaporation losses in sprinkler solid-sets and moving laterals. Agricultural Water Management, 76(3), pp.139-159.

Rinders, F. B. (2001). Performance of irrigation systems and the impact on water use efficiency, ARC- Institute for Agricultural Engineering, private Bag X519 Silverton, 0127, South Africa.

Rodrigues, G. C. and Pereira, L. S. (2009). Assessing economic impacts of deficit irrigation as related to water productivity and water costs. Biosyst. Eng. 103 (4), pp. 536–551.

Valin, M. I.; Cameira, M. R.; Teodoro, P. R. and Pereira, L. S. (2012). DEPIVOT: A model for center-pivot design and evaluation. Computers and Electronics in Agriculture, 87: pp.159 –170.