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ORIGINAL PAPER

Field evaluation of center pivot irrigation system's performance under the River Nile State conditions, Sudan

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Abstract: The study aimed to evaluate the performance of center pivot irrigation systems in River Nile state, Sudan. Four locations were selected randomly to represent the using of center pivot irrigation technology in the state. The hydraulic characteristics, namely coefficient of uniformity (CU), distribution uniformity (DU), and application efficiency (AE) were evaluated. Additionally, the rate of spreading the new technology over the surface irrigation was evaluated. The obtained results were compared with that of Northern and Khartoum states under different span traveling speeds (30, 70, and 100%). The results showed that, the spreading percentage of center pivot systems reached 36%, while it was covered 64% under surface irrigation systems. Center pivot irrigation systems in the River Nile State gave the lowest hydraulic performance (80, 68, and 62% for CU, DU, and AE, respectively) in comparison to center pivot systems of the Northern and Khartoum states. Furthermore, 70 and 30% span traveling speeds showed higher performance than 100% span traveling speed. It is concluded that, the problems of design, operation and poor management are the main causes of the low performance of center pivot irrigation systems under the River Nile conditions. Therefore, center pivot irrigation systems should be managed and evaluated under field conditions immediately after design and during use.

Keywords: Center pivot, irrigation systems performance, span speed.

Introduction

Water scarcity is a vital problem faces the whole world and threatens food security (Makhlof et al., 2021). Therefore, the effective and sustainable use of water for agricultural production has become a global priority of vital importance, requiring urgent and immediate solutions

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(Bhattacharya, 2014). Recent studies indicated that water resources always lost due to the low irrigation efficiency and applying more water to crops than needed (Al-Ghobari, 2010; Mulu and Alamirew, 2012). Therefore, improving irrigation efficiency is the short way to save water and conserve water resources (Younesi et al., 2015). On the other hand, poor water management and lack of optimal application of the irrigation, lead to decrease crop productivity (Silva et al., 2012; Toledo et al., 2020).

The problem is renewed every year and much research and investments have been done to develop more refined techniques and practices to apply water accurately to the crop according to their requirements and then improving efficiency. Under this circumstance, the use of pressurized irrigation systems can be an option of enhancing the efficiency of water consumption (Bhattacharya, 2014). The application of improved and/or modernized irrigation methods and techniques is expanding rapidly in Sudan as a result of increasing demand for highest irrigation efficiency, as to save large quantities of water.

Center pivot irrigation systems is the best choice for agricultural production, because of its low labor and maintenance requirements, convenience, flexibility, high performance and easy operation. When properly designed and operated, and equipped with high efficiency water applicators, a center pivot system can conserve three precious resources-water, energy and time. According to Makki et al. (2011), center pivot irrigation system was recently introduced in limited areas in Sudan. It consists of a single sprinkler lateral supported by series of towers. The towers are self-propelled so that the lateral of the system rotates around a pivot point in the center of the irrigated area. Time for the system to revolve through a complete circle could range from a few hours to many days. Thus, the water application rate must increase with the distance from the pivot to deliver even application (Rogers et al., 2017; Rizvi et al., 2020).

Knowledge of the uniformity parameters of an irrigation system is essential for attainable precision irrigation management (Larue and Evans, 2012). The common measures of water application uniformity are coefficient of uniformity (CU), distribution uniformity (DU), and application efficiency (AE). The CU is index of the degree of uniformity obtainable for any sprinkler system under given condition, and it has been adopted as one of the criteria defined to express uniformity. The coefficient is computed from field observation of the depth of water caught in open cans placed at regular intervals within a sprinkled area. DU is a measure used to indicate how water uniformly applied by center pivot irrigation system using a catch cans test, and is usually defined as the ratio of the average of the lowest 25% of recorded depths to the average depth of the whole distributions. The DU of center pivot system depends on both the system characteristics and on managerial decisions (Pereira et al., 2002).

AE is an estimate of amount of water used to increase soil moisture up to the needed level, out of the applied amount to the field (Biswas, 2015). Moreover, application losses of water to inefficient application range between 28 to 50% (Sharma and Sharma, 2007). Presently there is a little information on the performance of the center pivot system in the projects adopting it.

Owners are using few general guidelines for the operation and management of the system. Factors like efficiency, application rates and uniformity of distribution are not yet properly investigated (Alsayim, 2021). Therefore, this study aimed to evaluate the performance of center pivot irrigation systems in River Nile State, Sudan, especially for the hydraulic characteristics, namely CU, DU, and AE. Additionally, the spreading of center pivot systems over surface irrigation was evaluated. Then a comparison was made with the performance of center pivot in River Nile with that used in Northern and Khartoum states.

Material and Methods

Characterization of the study

This study was conducted to investigate the performance of center pivot irrigation systems in River Nile State during winter season 2019/2020, including two steps. In the first step, soil samples were collected in four locations of River Nile State (irrigated areas by center pivot system). The soil physical and chemical properties were analyzed according to the Laboratory of the University of Khartoum. The dominant soil is sand clay loam, which characterized by pH values varying from 7.46 to 8.38, no evidence of salinity or sodicity, and the levels of macro and micronutrients are low.

The climate is semi-desert with summer rain and warm winter, with annual mean rainfall 57.7 mm, falling mainly in July and August, reaching a smaller amount in September. Mean annual temperature is 30^{o}C (Alsayim and Saeed, 2011).

In the second step, were randomly selected irrigation projects from the three states (Khartoum, River Nile, and Northern) to the performance evaluation of center pivot systems. For this, data from different sources (previous studies, Ministries of Agriculture records, personal contact, remote sensing and GPS) were collected. The common specifications of the center pivot irrigation systems dominantly used in River Nile State are shown in Table 1.

The field performance evaluations

The procedure for evaluating the performance of center pivot irrigation systems was based on the American Society of Agricultural and Biological Engineers (ASABE, 2007), in four randomly selected locations. Catch-cans test was used to evaluate the actual application depth. Under each system there were two straight lines perpendicular to the direction of travel of the machine. Each line consists of 55-60 catch-cans which were identical in size and shape. The catch-cans were located uniformly by 5 m distance from each. Then after the amounts of water captured in the catch-cans were measured volumetrically by measuring cylinders and then converted into depths by dividing the captured amounts into the catch-can by cross sectional area. The performance indicators evaluated were: actual average application depth (D), average low-quarter depth (Ds), coefficient of uniformity (CU, Equation 1), distribution uniformity (DU, Equation 2), and application efficiency (AE, Equation 3). The operating pressure was measured at 2 to 3 selected sprinklers in each tower using the Pitot tube pressure gauge. Moreover, the behavior of the same sprinklers was done by using a known volume container and the time required to fill the container.

Table 1: Specifications of the center pivot irrigation systems used in River Nile State

Term	Specifications
Pivot point pipe diameter	219 mm
Sprinkler line pipe diameter	168 mm
Number of spans	7
Span length	54.8 m
Number of sprinklers per span	19
Sprinkler pressure	0.69 bar
Span traveling speed	50%
Pump type	Centrifugal
Pump discharge	360 $m^3 h^{-1}$
Covered area per center pivot	46.2 ha

Coefficient of uniformity (CU)

The most popular method specified for CU calculation was proposed by Heermann and Hein (1968).

$$CU(\%) = 100\left[1 - \frac{\sum_{i=1}^{n}(Si[Di - \bar{D}])}{\sum_{i=1}^{n} SiDi}\right] \quad (1)$$

Where:

Di – applied water depth for one collector position;

$\overline{D}$ – average applied water depth for all collectors; and,
Si – distance to equally spaced collectors.

Distribution uniformity (DU)

It was computed using the equation as recommended by Michael (1978).

$$DU(\%) = \frac{Ds}{\overline{D}} \times 100 \quad (2)$$

Where:
Ds – average low-quarter depth caught in cans; and,
$\overline{D}$ – average depth of water accumulated in all cans.

Application efficiency (AE)

Is defined as the volume of water applied divided by the volume of water exiting in the sprinkler emitter, according to equation described by Mohammed and Ahmed (2022).

$$AE(\%) = 100 \left[\frac{M \times Ap}{Vs}\right] \quad (3)$$

Where:
Ap – plot area (m²);
M – average applied depth (mm); and,
Vs – volume exiting from sprinkler during CU test (m³).

Statistical analysis

The statistical analysis was performed using SPSS package 21.

Results and Discussion

Center pivot irrigation systems has played and will continue to play a critical role in agricultural development in the whole Sudan and River Nile state in particularly. It was introduced recently in Sudan; put it found its way to spread in Khartoum, River Nile and Northern states compared with other states (Abdelbagi, 2017). Therefore, the study designed to reflect the performance of center pivot irrigation systems in the River Nile State, and then the comparison was made with Khartoum and Northern states. As shown in Figure 1, the performance parameters were studied and evaluated in four locations under the River Nile State conditions. From these results, the lowest obtained values of CU and DU were less than the minimum values recommended for center pivot irrigation systems, according to Keller and Bliesner (2000). The CU for center pivot irrigation systems with low operating pressure ranges from 85 to 90% depending on the climate prevailing during the evaluation process, while for DU values are as follows: DU ≥ 85 is excellent, 75 ≤ DU < 85 is very good, 70 ≤ DU < 75 is good, 65 < DU < 70 is fair, and DU ≤ 65 is poor.

It is well documented that the DU value indicates the degree of uniformity of water distribution over the irrigated area in the lower quarter (25%) and thus it reflects the amount of technical and administrative problems related to the distribution of water to irrigated area. The lower value of DU indicates an increase in water losses as well as problems in maintenance of the irrigation system. Whenever the value of DU decreases, it gives an indication that there is a non-uniform application of water which will result in areas of under-watering as well as areas of over-watering. On the other hand, the AE values were in the range of 62.0 to 71.3% (Figure 1) which is similar to the findings of Sharma and Sharma (2007), who stated that the application losses of water to inefficient application range between 28 to 50%.

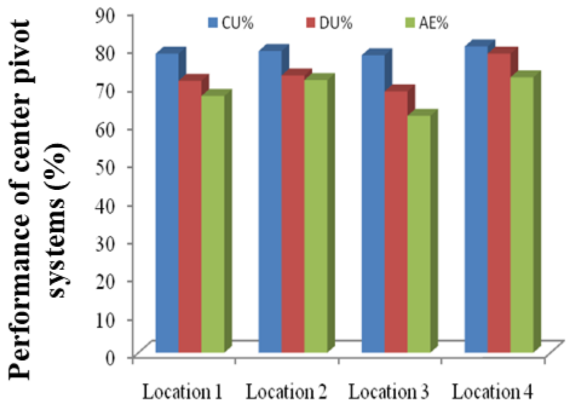

Figure 1: Performance of center pivot irrigation systems in four locations of the River Nile State conditions.

Figure 2 indicated that the spreading of center pivot irrigation system as a new technology against the traditional method (surface irrigation) used in River Nile state. The results explained that the center pivot irrigation system covered about 36%, while surface irrigation withdrawal to 64% from the total cultivated area.

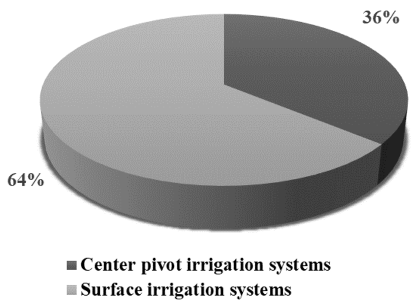

Figure 2: Spreading percentage of center pivot systems compared to surface irrigation in the River Nile state.

The current result showed that adopting of the new technology is increasing day by day, and this may be due that center pivot system distributes water uniformly compared with surface irrigation, which resulted in high productivity, because poor distribution uniformity reduces yield due to water stress, these findings supported by that of Dechmi et al. (2003), who stated that the uniformity of irrigation system directly affects the system's application efficiency and crop yield.

As shown in Tables 2, the comparison was made for evaluating the performance of center pivot irrigation systems under different span traveling speeds (30, 70, and 100%) between the River Nile, Northern and Khartoum states.

Table 2: Comparison of irrigation systems performance in different locations

Location	**Span speed**		
	100%	**70%**	**30%**
Coefficient of uniformity (CU)			
Northern State	90.9a	94.7a	94.8a
Omdoum-Khartoum State	85.3c	88.1b	81.9b
West Omdurman-Khartoum State	88.0b	86.3c	83.5b
River Nile State	78.1d	80.3d	79.6c
LSD	1.70	1.60	2.80
Distribution uniformity (DU)			
Northern State	88.0a	91.9a	92.1a
Omdoum-Khartoum State	83.1c	85.1b	78.1c
West Omdurman-Khartoum State	80.0b	80.7c	80.9b
River Nile State	68.5d	78.4d	73.3d
LSD	2.40	2.10	2.70
Application efficiency (AE)			
Northern State	86.5a	87.4a	87.5a
Omdoum-Khartoum State	86.2a	85.6a	84.6a
West Omdurman-Khartoum State	85.6b	85.1a	84.3a
River Nile State	62.0c	71.3b	70.5b
LSD	0.98	3.50	4.00

LSD – least significant difference; means followed by the same letter in the same column are not significantly difference at $P \leq 0.05$.

The uniformity parameters were significantly affected ($P \leq 0.05$) by the different locations and span traveling speeds. Based on this result, the Northern State recorded the highest mean values of CU, DU, and AE, regardless of span traveling speed, while the River Nile showed the lowest values. On the other hand, the span speed 70 and 30% showed similar performance and higher than that recorded with traveling speed 100%. These results may be due to suitable soil type and management system that followed in Northern state. Moreover, the current results are in the line of Al-Ghobari and Dewidar (2021), who stated that the variation in coefficient of uniformity may be attributed to the improper setup of the system. On the other hand, the obtained result agreed with the finding of Hamid (2013), who stated that center pivot irrigation system recorded a highest value of CU under span traveling speeds 30 and 70% in comparison with traveling speed 100%.

Conclusions

Due to the problems related to design, operation and management, the center pivot irrigation system performance under the River Nile State conditions was fell below the recommended values as compared to Northern and Khartoum states. Therefore, the best management practices for irrigation system should be adopted and followed. In addition, center pivot irrigation system should be evaluated under field conditions, immediately after design and during use.

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