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Technical Performance Evaluation of Center Pivot Sprinkler Irrigation Systems in the Atbara River Region, Sudan

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Abstract

The study was conducted during winter season 2019/2020, under desert high terrace soil in the eastern bank of the Atbara River. The growing adoption of modern irrigation systems, especially center pivot irrigation systems, requires the necessity of knowing the efficient use during operation, and thus identifying the characteristics of water distribution under these systems. The experimental units consist of four center pivot sprinkler irrigation systems. The climate is semi-desert with warm winters. The result for evapotranspiration using Penman-Monteith ranged from 5.69 to 6.26 mm/day for November and December, then alfalfa crop (*Medicago sativa*) consumptive use was 6.14 to 6.89 mm/day, respectively. The results for sprinkler (nozzles) configuration represented 27.4, 35.8, 50.3 and 38.0% of the total sprinklers were installed without spray nozzles for the systems 1, 2, 3 and 4, respectively. The uniformity coefficients (CU) were 87.1, 80.0, 84.1, and 83.4% at a rotational speed of 50% for the irrigation systems 1, 2, 3 and 4, respectively. Distribution uniformity (DU) values were ranged from 68.7 to 75.3%. Application efficiency (AE) ranged from 93.2 to 98.3% and the potential efficiency of low quarter (PELQ) values ranged from 64.8 to 72.2%. The results showed that, hydraulic performance of CU, DU and PELQ for the centre pivot systems were affected by the different management practices gave an indication of non-compliance with the design specifications regarding the arrangement and distribution of sprinklers which leads to an unacceptable irrigation scheduling.

Keywords

Centre Pivot System, Irrigation, Technical Performance Evaluation

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1. Introduction

The increasing need to produce crops due to the growing population is the main reason for the increasing expansion of irrigation uses around the world. The crop needs water for optimal growth and for high productivity. Over the past few years, elaborate farming systems and specific management of crop production have become popular. In many cases, soil analysis and crop productivity have shown that water is the main variable affecting crop growth. Poor distribution uniformity reduces yields due to water stress. Dechmi *et al*. [1] and El-Ansary *et al*. [2] concluded that the uniformity coefficient of sprinkler irrigation system directly affects the system's application efficiency and crop yield as well.

Some studies have shown that the use of water resources is not optimized due to the low irrigation efficiency, which leads to increasing water losses and applying more water to crops than needed [3, 4]. In other cases, as a result of poor water management and lack of optimal application of irrigation, an amount of water applied does not meet the requirements of irrigation, hence the productivity of the crop decreases [5].

The application of improved irrigation methods and

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techniques is expanding rapidly in Sudan as a result of increasing demand for food production. Center pivot is one of the best options for agricultural production, because of its low labor and maintenance requirements, convenience, flexibility, high performance and easy operation.

The wrong installation of sprinklers or pressure regulators and failure to follow up on maintenance procedures leads to poor distribution of irrigation water. Irrigation system operators are accustomed to adding too much water to avoid the problem of irregular application. According to Harrison and Perry [6], 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.

Smaller wetted diameters of sprinkler reduce the uniformity of application and increase the potential for runoff. Martin *et al*. [7] mentioned that the sprinkler wetted diameter depends on the height of the sprinkler above the surface of application when the droplets maintain a horizontal velocity. They conducted experiments when the Spinner device was 1.07 m above the soil which caused the sprinkler to drop into the corn canopy.

As the center pivot moves through the field, the wheels can create ruts in the wet soil. These ruts cause machine bogging, stopping and make field rough. A method to reduce these problems is to use boom backs which are designed to extend the sprinklers behind the wheels and most use part-circle sprinklers [7].

Field assessment methods to evaluate the performance of irrigation systems have attracted the attention of researchers because of their ability to discover technical errors and clarify the places of defect and its accuracy in finding deviations from design specifications. Owners as well as operators are using few general guidelines for the system operation and management. The field assessment is a quantitative and qualitative analysis of the system components. The performance evaluation of irrigation system based on measurements and indicators taken in the field under normal operating conditions. Hence the objective of this study is to conduct a technical field assessment to evaluate the performance of a group of center pivot irrigation systems in the Atbara River region and to identify hydraulic characteristics and performance indicators for the systems under field conditions.

2. Materials and Methods

The study was conducted in the eastern bank of Atbara River, River Nile state under desert high terrace soil. Soil physical and chemical properties for the experimental site was analyzed at University of Khartoum laboratory. The soils are dominantly sandy clay loam not affected by salinity and sodicity.

The climate of the experimental field is semi-desert with summer rains and warm winters, with annual mean rainfall 57.7 mm falling mainly in July and August with less amounts in September. Mean annual temperature is 30.0°C, the average maximum temperature in the hottest months (April – June) is 43.2°C, while the minimum temperature in the same period is 28°C, and the average minimum temperature during winter (Dec-Feb.) is 14.2°C; while the average maximum temperature in the same period is 29.8°C [8].

The experimental field consists of four center pivot sprinkler irrigation systems. The systems produced by Valley company, consisted of a pivot point; 219 mm pipe diameter, seven spans 168 mm pipe diameter with an overhang, tower structure, drop pipes with I. Wobbler Senninger sprinkler with a pressure regulator of 0.69 bar (10 psi), electrical centrifugal pump and fertilizer unit. The center pivot systems derived its water via an earth canal from the Atbara river.

Crop evapotranspiration (calculated using Penman Monteith equation) and crop (Alfalfa) consumptive use were calculated using the following equation proposed by Alsayim and Saeed [9]:

$$\mathrm{ETc} = \mathrm{Kc} \times \mathrm{ETo}$$

Where: ETc = crop (Alfalfa) consumptive use, mm/day, ETo = reference evapotranspiration, mm/day, Kc = crop coefficient.

Field evaluations were made on the four center pivot systems (1, 2, 3 and 4) during winter season 2019/2020, where some performance indicators; such as uniformity coefficient (CU), distribution uniformity (DU), application efficiency (AE) and potential efficiency of low quarter (PELQ) were evaluated. The most popular method specified for coefficient of uniformity CU calculation was proposed by the American Society of Agricultural and Biological Engineers ASABE [10] to evaluate the uniformity of water application as follows:

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

Where, CU is coefficient of uniformity, n is the number of collectors used in the data analysis, I is a number assigned to identify a particular collector beginning with i=1 for the collector located nearest the pivot point and ending with i = n for the most remote collector from the pivot point, Di is the applied water depth for one collector position, $\overline{\mathrm{D}}$ is the average applied water depth for all collectors and Si is the distance to equally spaced collectors. The distribution of uniformity DU of the systems was computed by using the following formula as recommended by Harrison and Perry [6];

$$DU = \frac{Ds}{\overline{D}} \times 100$$

where:

DU = Distribution uniformity (%), Ds = average low-quarter depth caught in cans, $\overline{D}$ = average depth of water accumulated in all cans. The average application depth was determined by dividing the pumped volume by the application area [11]:

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

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 [5]:

$$AE = 100 \times \left[\frac{M \times Ap}{Vs}\right]$$

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

The potential efficiency of low quarter (PELQ) is indicator of how irrigation was applied and how water is distributed. It indicates the possible existence of such problems. The PELQ is measured using the following equation according to Abedinpour [12]:

$$PELQ = \left[\frac{Ds}{B}\right] \times 100$$

where: Ds = average low quarter depth, B = average depth of water applied when management allowed depletion just satisfied.

The procedure for evaluating the performance of the center pivot irrigation systems was based on the ASABE standard [10]. Catch-cans arranged in two straight lines perpendicular to the direction of travel were used to evaluate actual application depth. Each line consists of 55-60 catch-cans which were identical in size and shape, separated uniformly by 5 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 performance indicators evaluated were: average application depth (AgD), coefficient of uniformity (CU), distribution uniformity (DU), application efficiency (AE) and potential efficiency of low quarter (PELQ). A Microsoft Excel spread sheet program was used for processing to compute all the above indicators.

The operating pressure of 2 - 3 sprinklers in each tower was measured using pitot tube pressure gauge. Furthermore, the behaviour of the same sprinklers was measured using a known volume container and determining the number of seconds required to fill the container.

The systems discharge were estimated using the method recommended by the ASABE, [10] which depends on the average water depth measured and the depth of the water evaporated during field evaluation and the total time required to complete a full cycle.

3. Results and Discussion

The result for evapotranspiration calculating using Penman-Monteith equation was range from 5.69 to 6.26 mm/day, then alfalfa consumptive use will be 6.14 to 6.89 mm/day for November and December, respectively. These results agree with Alsayim and Saeed, [9] who found ETc was 8.1 mm/day at peak consumptive use. The estimated discharges were found to be 261.28, 320.19, 324.79, and 287.74 m^3/h for irrigation systems 1, 2, 3 and 4, respectively. According to the pump specifications, the pump discharge was 360 m^3/h compared to the measured discharges perceived that 15-30% of the available discharge is not utilized (Figure 1). Technical administrative conditions with low expertise lead to reduction in irrigated area by 13.7 hectare for each system.

Sprinkler (nozzles) configuration represent that 36 sprinklers (27.4%), 47 (35.8%), 66 (50.3%) and 49 (38%) at the second half of the sprinkler line were installed without spray nozzles for the systems 1, 2, 3 and 4, respectively. This signifies, largest area of the field provides an application depth that does not adequate the crop water requirement, therefore irregularity in the distribution of water negatively affects the growth and production of the crop. The sprinklers discharge depends on the spray nozzle size and operating pressure, so it is necessary to place the spray nozzle in its correct position in relation to the sprinkler line ensure that the water distribution is homogeneous and thus provide the appropriate soil moisture for each plant. Manufacturers have made each spray nozzle with specific size and color to facilitate the distribution of spray nozzles.

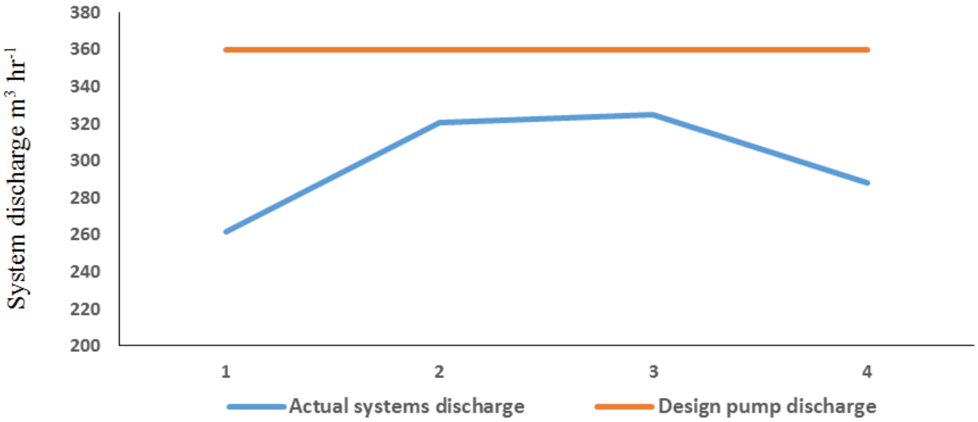

Figure 1. Variation in system discharge for the systems 1, 2, 3 and 4.

A variation in terms of the height of the sprinklers from the soil surface was observed which was found ranged from 0.07 to 1.4 meters. This difference may be due to random replacement of drop pipes. The height of the sprinkler above the ground has a direct impact on the diameter of the wetted diameter. If the sprinkler is installed at a specified height within the crop canopy, the wetted diameter will be small compared to another sprinkler that was installed above the crop canopy, and thus affects the uniformity of the water distribution [3]. Also, it was found that the sprinklers near the wheels' track applied water in a full circle, which causes wetness and accumulation of water on the wheels' tracks. The correct way to ensure the wheels' track is dry by using sprinklers near the wheels applied water with semi-circular application or using back tubes [7].

Sprinklers discharge and operating pressure along the sprinkler line were measured to compare the characteristics of actual discharge with the design specifications. 2 - 3 sprinklers were chosen in each span in order to identify the extent of variation or consistency between the sprinkler behaviour with the calculated design specification. Figure 2 shows the measured discharge compared to the calculated values. It was recorded that the irrigation systems 1, 3, and 4 gave discharge more than required, while the system No. 2 gave fewer discharge. The discrepancy in discharge may be caused by improper arrangement of the sprinklers during maintenance and consequently to install spray nozzles in a misplaced location or not to commit to installing spray nozzles according to the specific size of each site or there is a blockage in some of them. This difference in the sprinklers discharge followed by difference in depth of the water applied which affects the uniformity of water distribution, growth and productivity of the crop.

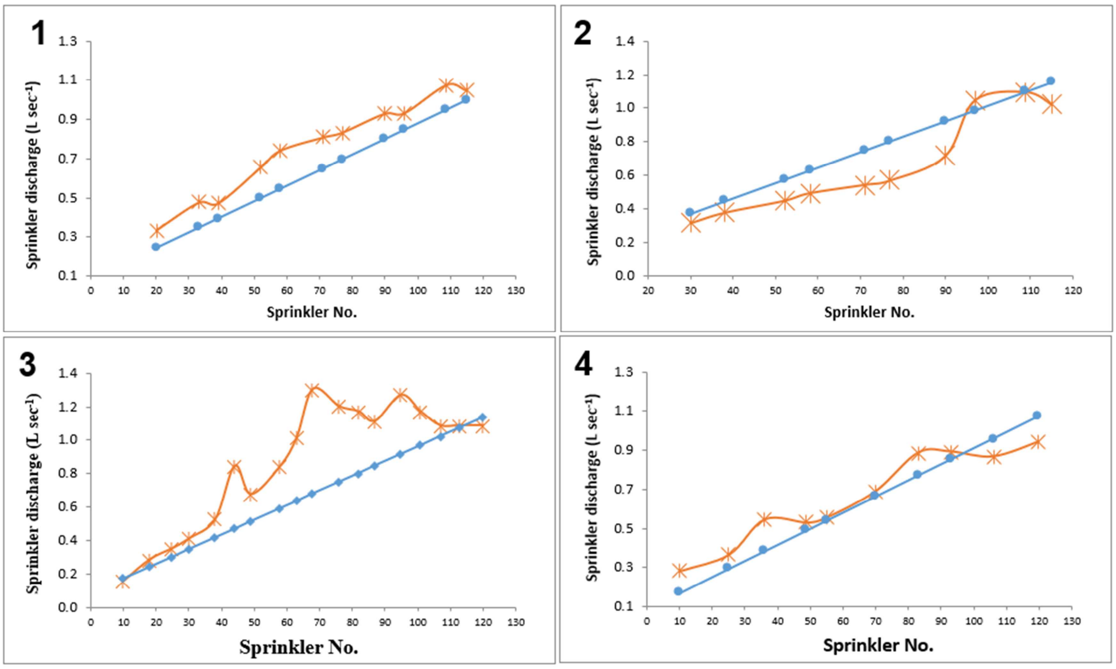

Figure 2. Sprinkler discharge measured and design discharge for the systems 1, 2, 3 and 4.

Figure 3 shows the average depth applied along the sprinkler line ranged between 9.61 to 12.3 mm, and the depth in the lower quarter ranged 6.84 - 9.26 mm. It was observed a clear variation in the application depth along the sprinkler line of each system. The center pivot irrigation system No. (1) is considered the best one in terms of distributing irrigation water along the sprinkler line, two thirds of the sprinkler line, outside part received depths close to the average application depth. While the center pivot system No. (2), more than 70% of the sprinkler line (the first 280 meters of the sprinkler line) was irrigated by the amount of water less than the average application depth, while the last third had been distributing water in a good way. In irrigation system No. (3), the first 260 meters of the sprinkler line received an average of a very differentiated application depth (higher and less than the average application depth) while the last third part received less water. The irrigated area, system No. (4) received application depth different in quantities along the sprinkler line, and it can be observed that the part in the center of the irrigated area received irrigation water less than the average application depth, while the outside part considered a better condition as it received application depths close to the average depth.

The difference in the mean application depths and the average depths in the lower quarter leads to the irregular distribution of water from the sprinklers along the sprinkler line (irrigated area), therefore some areas have higher water quantities than others. This affects the growth and productivity of the crop, especially during the period of maximum water requirement. Representing Figure 3 it was possible to determine the areas that got extra or less depths and thus know the sprinklers that need to be reviewed, maintained or replaced along the sprinkler line. Therefore, it is highly recommended to conduct field evaluation of center pivot systems at the beginning of each season, which helps owners, engineers and operators to make proper decisions.

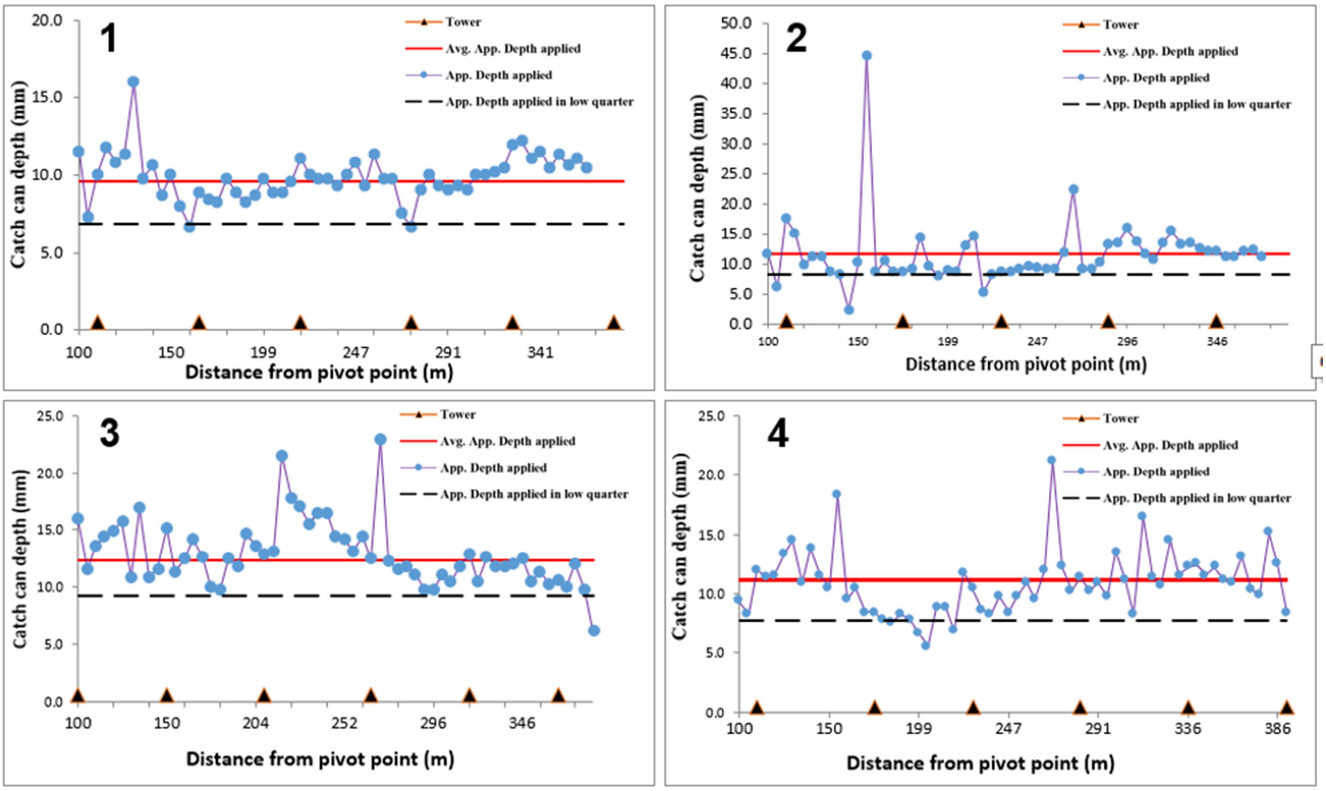

Figure 3. Distribution of application depths, average application depths and average application depths in low quarter along the sprinkler line for the center pivot systems 1, 2, 3 and 4.

Figure 3 gave graphical representations of the actual systems hydraulic indicators. It was found that the CU values were 87.1, 80.0, 84.1, and 83.4% at a rotational speed of 50% for the center pivot irrigation systems 1, 2, 3 and 4, respectively. From these results, we observed that the uniformity coefficient of the three irrigation systems 2, 3, and 4 were less than the minimum value recommended for center pivot irrigation systems. The uniformity coefficient CU for center pivot irrigation systems with low operating pressure ranges from 85% to 90% depending on the climate prevailing during the evaluation process [13].

Failure in distribution of spray nozzles and incorrect placed of sprinkler height above the soil surface were the reason for decrease in the values of the uniformity coefficients. It was found that a large number of sprinklers installed without a spray nozzle and thus resulted in an irregular distribution of irrigation water over the irrigated area as well the distribution of the sprayers along the sprinkler line did not take into account the design specifications of the manufacturer. So, in order to improve the performance of the center pivot systems, some corrective measures for trouble shooting need to be considered [14].

The uniformity coefficient for the lowest quarter DUs were found to be 71.2, 69.2, 75.3, and 68.7% for center pivot irrigation systems No. 1, 2, 3, and 4, respectively (Table 1). The DUs values indicated the degree of uniformity of water distribution over the irrigated area in the lower quarter (25%) and thus reflects the amount of technical and administrative problems related to the distribution of water to irrigated area [15]. The lower the value of DU, indicates an increase in water losses as well as problems in maintenance of the irrigation system. Whenever the values of DU decreases, it gave an indication that there are areas in the irrigated area did not received the amount of irrigation water as required and maybe the areas had irrigation more than required. From Figure 3 it can be seen that the average application depth in the lowest quarter was away from the average application depth (the line in red). We notice that the system No. (3) gave a higher DU value (75.3%), while irrigation system No. (4) gave a lower value of DU (68.7%).

The application efficiency (AE) was found 93.2, 93.5, 96.0, and 98.3% for center irrigation systems evaluated 1, 2, 3 and 4, respectively (Table 1). The values of the application efficiency were high for irrigation systems under evaluation. These results were found similar to the findings of Rajan *et al.*, [16], who reported that the application efficiency of low energy center pivot systems will be greater than 90%. The value of the application efficiency gave an indication of the amount of water losses during the time of its flow from the pumping unit until it reaches the surface of the soil. These losses may be caused by leakage from the main sprinkler line, the points of contact between the pipes, the descending pipes (carrying spray nozzles), water losses by wind drift and evaporation resulting from the high temperature. Because the field evaluation for the four systems took place during the morning period (low temperature) and at an acceptable wind speed, irrigation losses were few, in addition to the sprinkler line is free of defects and holes.

Table 1 shows the values of potential efficiency of low quarter (PELQ). PELQ values were found ranged from 64.8 to 72.2%. The value of PELQ gave an indication of how irrigation was applied and how water is distributed, so it is an indication of the quality of irrigation management. The low values of PELQ means there are problems with the irrigation system design and/or administrative problems in the field irrigation process. These problems appear in the form of an increase in irrigation time and the application depth over the required, thereby increasing water losses by evaporation, surface runoff and deep leakage. The estimated PELQ values gave an indication of non-compliance with the design specifications regarding the arrangement and distribution of sprinklers (administrative problems) which leads to an unacceptable irrigation scheduling that operators resort to avoid these problems.

Table 1. Hydraulic performance of center pivot irrigation system.

	Center pivot system NO. 1	**Center pivot system NO. 2**	**Center pivot system NO. 3**	**Center pivot system NO. 4**
Average application depth (mm)	9.61	11.82	12.30	11.17
Average application depth in low quarter (mm)	6.84	8.18	9.26	7.79
Uniformity coefficient CU%	87.1	80.0	84.1	83.4
Uniformity coefficient for the lowest quarter DU%	71.2	69.2	75.3	68.7
Application efficiency AE%	93.2	93.5	96.0	98.3
Potential efficiency of low quarter PELQ%	66.4	64.8	72.2	68.7

4. Conclusions

Agriculture is one of the primary means of livelihood in Sudan, and it depends on water resources such as rain, rivers and agricultural lands, whose severity has deteriorated due to climate change, unguided use and other factors. Because the agricultural sector is the largest water-consuming sector, this requires the need to rationalize water use. The growing adoption of modern irrigation systems, especially center pivot irrigation systems, requires the necessity of knowing the efficient use during operation, and thus identifying the characteristics of water distribution under these systems and irrigated areas. This is in addition to identifying the problems and obstacles facing investors, farmers, technicians and operators, and the result is the rewarding economic return for the investor and farmers.

5. Recommendations

1. Commitment to the operating manual of the manufacturer and to conform to the design specifications.
2. Conducting a field assessment at the beginning of each season.

3. Regular periodic maintenance of the moving parts and Rehabilitation of the wheels' track.
4. Review the sprinklers and monitor their performance during and after irrigation to ensure the performance of the sprinkler, operating pressure, and the necessity of ascertaining the sprinkler nozzle and the length of drop pipe and replace them when necessary.
5. Working on and stopping the irrigation system, in the same place from the field, and it is advisable to do so near the service road to facilitate monitoring, inspection and maintenance.
6. Maintenance works and parts change must be recorded in special records, with any notes that may be useful in the future.
7. Provide each irrigation system with a pressure gauge and a flowmeter in the pivot point to ensure optimum performance.
8. A cleaning process for the sprinkler line must be carried out from impurities, clay, and others.

References

[1] Dechmi, F., Playan, E., Faci, J. and Tejero, M. (2003). Analysis of an Irrigation District in Northeastern Spain. I: Characterization and Water Use Assessment. Agriculture Water Manag., 61: 75–92.

[2] El-Ansary, M. Y., El-Gindy, A. M., Awad, M. A. and Wasif, E. (2003). Evaluation of the Alternate Sets Management of Sprinkler Irrigation. The 11th Annual Conference of Misr Society of Agricultural Engineering, 15-16 October, Egypt, 20: 236 - 250.

[3] Al-Ghobari, H. M. (2010). The Performance of the Center Pivot Irrigation Systems under Riyadh Region Conditions in Saudi Arabia. Journal of the Saudi Society of Agricultural Sciences, 9 (2): 55-68.

[4] Alamirew T., (2012). Evaluation coefficient of uniformity for center pivot sprinkler irrigation. trans. Global Journal of Biology, Agriculture and Health Sciences (G. J. B. A. H. S) Vol. 1 (1) PP. 17-21.

[5] 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.

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

[7] Martin D., Kranz W., Smith T., Irmak S., Burr C. and Yoder R. (2017). Center Pivot Irrigation Management Handbook. Department of Biological Systems Engineering, University of Nebraska-Lincoln, Nebraska Extension.

[8] Alsayim H. E., El-Mahdi A. A. and Nayel M. H. (2013). Water - use Efficiency of Two Wheat Cultivars (*Triticum aestivum* L.) under Tropical High Terrace Soil Conditions, Asian Journal of Agriculture and Food Science, Volume 01– Issue 05.

[9] 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), 103 – 122.

[10] American Society of Agricultural & Biological Engineers, 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. Amer. Soc. Agric. Engr., St. Joseph, MI. Pp. 1033-1039.

[11] Almasraf S., Jury J. and Miller S. (2011). Field Evaluation of Center Pivot Sprinkler Irrigation Systems. Ann. report, MI: Department of Biosystems and Agricultural Engineering Michigan State University.

[12] Abedinpour M. (2017). Field evaluation of center pivot sprinkler irrigation system in the North-East of Iran. Journal of Water and Land Development. No. 34: 3–9.

[13] Keller, J. and Bliesner, R. D. (1990). Sprinkle and Trickle Irrigation. van Nostrand Reinhold. New York. Pp. 86-97.

[14] Alsayim H. E. and Saeed A. B. (2016). Field Performance Evaluation of Center Pivot Sprinkler Irrigation System, Shendi University Journal, Vol. (15), 39-60.

[15] Al-Ghobari H. M. and El Marazky M. S. (2018). Field assessment of water losses and performance of center pivot irrigation systems under Riyadh area conditions. Journal of King Saud University 27 (1): 27-35.

[16] Rajan, N.; Maas, S.; Kellison, R.; Dollar, M.; Cui, S.; Sharma, S. and Attia, A. (2015). Emitter uniformity and application efficiency for center-pivot irrigation systems. *Irrigation and Drainage*, 64: 353–361.