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EVALUATION OF THE HYDRAULIC AND FIELD PERFORMANCE OF CENTER PIVOT IRRIGATION SYSTEMS IN A SEMI-ARID CLIMATE

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ABSTRACT

Aim of the study

This study aims to evaluate the hydraulic and field performance of central irrigation systems in a semi-arid climate to determine their efficiency and effectiveness in optimizing water use and crop yield in such conditions.

Materials and methods

The performance evaluation of the center pivot system involved placing two rows of catch-cans, spaced three meters apart and radiating outward from the pivot point, to measure the distribution and uniformity of irrigation. This setup helped in assessing the system's efficiency in delivering water.

Results and conclusions

In the Almutawar system, the average performance metrics for the 2022/2023 season were: CU = 77.8%, DU = 85.7%, SC = 1.2%, AE = 84.3%, and WL = 18%. For the 2023/2024 season, these metrics were: CU = 78.9%, DU = 85.6%, SC = 1.2%, AE = 84.9%, and WL = 18.3%. Similarly, in the Zimmatic system, the average results were: CU = 79.1%, DU = 87.5%, SC = 1.2%, AE = 87.4%, and WL = 17.0% for 2022/2023, and CU = 79.9%, DU = 85.8%, SC = 1.2%, AE = 88.2%, and WL = 15.9% for 2023/2024. ANOVA revealed that the differences in CU, DU, and AE across treatments were not statistically significant (P = 0.01), though a general trend suggesting improved performance in the 2023/2024 season was noted. The study found that the hydraulic function of the center pivot system varied with different steering modes, suggesting potential issues with design compliance and efficiency. Further investigation into these discrepancies could help in optimizing system performance.

Keywords: water supply, irrigation system, center pivot, Almutawar system, Zammatic system

INTRODUCTION

Water scarcity is a major global problem and threatens food security (Makhlof et al., 2021). For this reason, the efficient and sustainable use of water in agricultural production has become a significant global problem that requires an urgent solution (Bhattacharya, 2014). In many parts of the world, there is not enough rainfall to meet the water needs of crops. Therefore, water is used artificially such as irrigation. Currently, 15% to

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20% of the world's agricultural lands are irrigated, accounting for approximately 40% of total agricultural production (FAO, 2013). FAO (2002) estimates that 80% of the additional production required to meet future needs should come from increased productivity. Agriculture forms the backbone of many economies around the world, as it contributes significantly to gross domestic product (GDP) and provides food. The Food and Agricultural Organization (FAO) estimates that a 50% increase in irrigated food production by 2050 will require withdrawing 10% of water from agriculture while improving water efficiency (FAO, 2020). Irrigation plays an important role in solving key challenges such as food security and unpredictable rainfall. As stated by Keller and Bliesner (1990), irrigation is the method applying of water to the soil or plant in the amount and time needed. It is a tool for managing the impacts of agricultural production. Irrigation methods include surface irrigation, underground irrigation, and sprinkler systems. Sprinkler irrigation, for example, simulates natural rainfall by spraying water into the air and allowing it to fall evenly onto the ground (Garg, 2007). In this method, water is injected into the air and released evenly onto the ground at a velocity below ground level. The center pivot irrigation system is highly efficient, with efficiency rates increasing from approximately 60% to over 90%. This improvement is largely due to better water application methods and reduced evaporation losses, rather than a reduction in electricity consumption. This increase in efficiency is due to the reduction of electricity consumption, but mainly due to the fact that water is put into power plants and not released into the atmosphere. This method also consists of a central switch, but instead of cutting off too much energy, the pipes from the electricity are huge in the middle and a cage is attached to the bottom of each pipe, close to the ground, where water is placed poured plants. This means less water is lost through evaporation compared to traditional irrigation. More than 90% of the water used is used for crops and requires electricity (Harrison and Perry, 2007). Center pivot irrigation systems were invented 60 years ago with the main of reducing labor, increasing agricultural productivity, and improving water use. The center pivot consists of a lateral rotation around a fixed pivot point. The side supports above the field are a series of A-frame towers, with two wheels under each tower.

Sudan, with its rich natural resources, has significant agricultural potential. Efficient use of these resources is crucial for both domestic food security and export purposes. While Sudan's water resources mainly come from rainfall, the Nile River, seasonal streams, and groundwater, the Nile River and its tributaries are considered the main water resources for over 5 million people with reliable agriculture development areas and good amounts of water. The northern part receives less than 300 mm of rain per year, mainly due to the Nile River.

Alfalfa (*Medicago sativa L.*) grown in climates where daily temperatures exceed during the growing season. The optimum growth temperature is and growth is greatly reduced if the temperature is above and below. In hot weather, the efficiency of irrigation systems is higher compared to wet conditions. Crops such as alfalfa are grown seasonally, with the growing period varying depending on climate. After planting the seeds, it takes about 3 months for the plant to establish. Following seeding, the crop takes about 3 months to establish. The number of cuts varies depending on weather conditions and varies between 9 and 12 during the growing season. In addition, the yield obtained per unit area varies throughout the year depending on different climate. Alfalfa is considered a sustainable crop because of its ability to fix organic N2 in the atmosphere and reduce the scarcity of N fertilizer (Crews and Peoples, 2004). Most of the irrigation systems in Sudan are used to produces alfalfa for export. The increasing development of modern irrigation systems, especially pivot irrigation systems, requires knowledge of how to use them correctly during operation and therefore the need to know the characteristics of water distribution in that system and in the irrigation area. Mohammed (2010) mentioned, the centralized irrigation system in Sudan has expanded significantly in the last two decades as an automated and modern irrigation system. In fact, in 2010, there were 20,028 center pivots in the country, mainly used for irrigation purpose. Increasing demand for water resources in Sudan increases the need to improve and manage the irrigation system. To reduce energy costs in pumping irrigation water, researchers and farmers should evaluate the efficiency of irrigation system. Assessing irrigation system performance, including factors such as water dosage and balance, is crucial for identifying design and management issues that can impact energy costs and crop yield. This evaluation helps optimize system efficiency and sustainability. A characteristic feature of this methods is that the water velocity must increase latterly to create the same water depth, since the irrigated area increases latterly for each velocity length. This ratio can be increased as follows: constant droplet diameter with increasing nozzle diameter or constant diameter with gradually decreasing nozzle diameter. The evaluation included measuring pressures, system and nozzle flow rate, advance rate, length and thickness of water used. Both statistical methods (mean, standard deviation and correlation coefficient (Christiansen, 1942). This evaluation is particularly important for efficient and operational systems where parameters are considered as tools for system stability and performance. This article aims to evaluate the hydraulic and field performance of center pivot irrigation systems in a semi-arid climate. Specifically, it assesses the uniformity coefficient, distribution uniformity, scheduling coefficient, application efficiency, and water loss at various operational speeds (25%, 50%, 75%, and 100%).

MATERIALS AND METHODS

Experimental Site Description

1. **Location:** The surveys were carried out in the 2022/2023 and 2023/2024 harvest seasons within two farms of the West Omdurman Agricultural Scheme for Alfalfa Production in Sudan. This scheme is located on the west bank of the Nile, approximately 120 km from Omdurman district, at coordinates of longitude 32°:15 to 32°:20 East and latitude 15°:27 to 15°:33 North. 380 meters above mean sea level (MSL). For each pivot system, surveys were conducted on an area of 38.465 hectares.

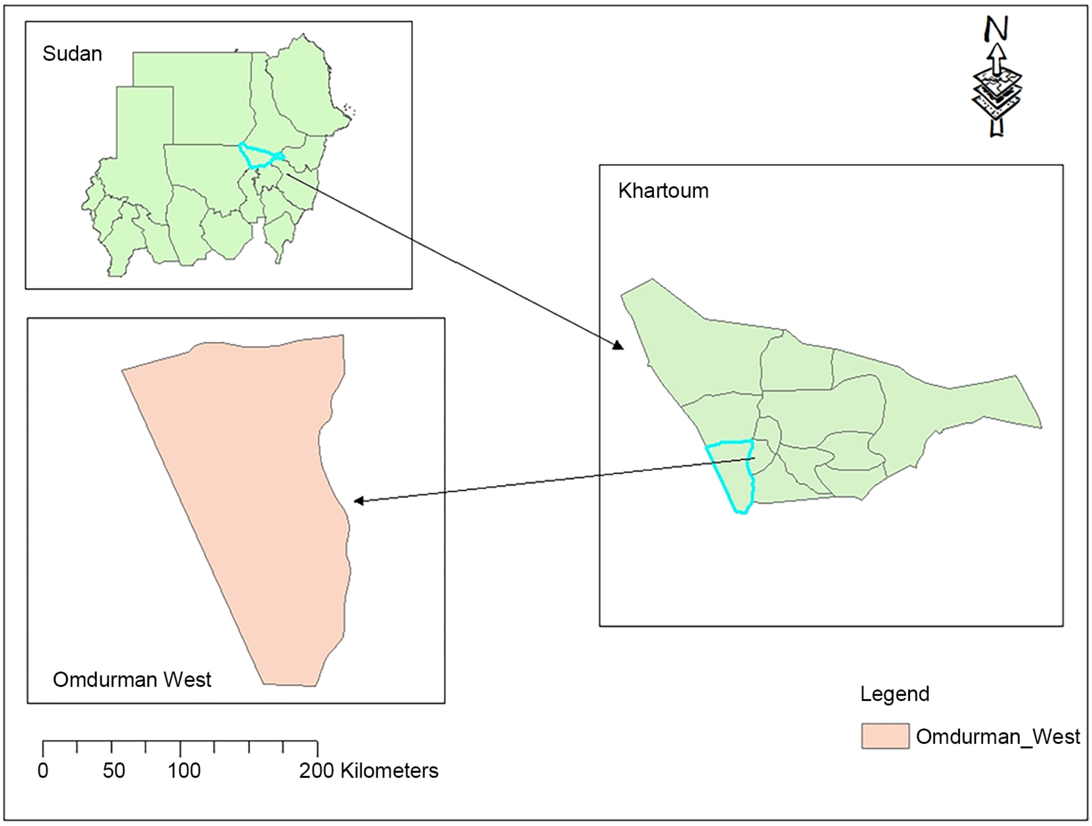

Fig. 1. Location map of the study area (source: Authors' own elaboration)

2. **Water Supply:** The water source in the irrigation system used to be groundwater; A center pivot system drew water from the well via submersible pumps. The center pivot irrigation system was powered by an internal combustion engine, which generated the electrical power necessary for the system's rotation.
3. **Climate:** In this region, which has a semi-desert climate, the average annual temperature is 30.5. In summer, the temperature rises rapidly, reaching 40 in April; In April and May the temperature sometimes reached 47 The temperature drops a little due to the rains that bring some rain in July and August, around 37–39, then at the end of the month between October and November. The rain increases slightly. The annual rainfall in this region is very low and reaches 120 mm, reaching a maximum of 50 mm in August. The sun shines with an average of 9.8% all year round, but sunshine hours are slightly shorter in summer. Wind speed is quite low from April to October, and starts to increase from November to March, with an average of 4.8 meters/hour per year.
4. **Soil:** The region is bordered by high or high mountains characterized by mountainous topography, except for the Merkhyite mountains and Jebel Aulia mountains in the extreme north and south of the region. This area is considered a semi-arid region characterized by little vegetation and sandy soil, which can be enhanced by seasonal irrigation and river banks.

Materials

1. Instruments used to measure water distribution:
   - Catch cans to collect water samples,
   - Graduated measuring cylinder in milliliters,
   - 30-meter tape measure tape; and possibly a short ruler,
   - A scientific calculator, pen, and paper tests.
2. Instruments used to measure water flow in sprinklers:
   - Container of known size (20 L bucket),
   - Stopwatch.
3. Instruments used to measure soil moisture:
   - An auger,
   - Sensitive balance,
   - Oven.

Method and Data Collection

1. **Experimental Design:** Two center pivot irrigation systems operating and rotating at four speeds (25%, 50%, 75%, and 100%) were randomly selected and validated to evaluate hydraulic performance: uniformity coefficient, distribution uniformity, and application efficiency. These treatments were designed in a randomized complete design (RCD) with four replicates. Analysis of variance (ANOVA) was used to compare CU, DU, and AE values for irrigation systems and standard center pivot irrigation using a one-way ANOVA. The variations among means were checked by the least significant difference (LSD).

Data Collection

1. **Metrological Data:** Search metrology data from Shambat Observatory Weather Station in Sudan and use the following daily data of: maximum and minimum temperatures, relative humidity, wind speed, sunshine, solar radiation, and precipitation for the two growing seasons of 2022/2023 and 2023/2024.
2. **Water Efficiency Measurement:** Test methods and procedures were conducted based on ASAE (1996) standard S436.1 and Merriam and Keller (1978). To evaluate the center pivot irrigation system, two rows of catch cans were placed three meters apart, extending radially outward from the pivot point. Water collected in each can be measured using a 500 ml graduated cylinder to assess distribution uniformity. A 30 m graduated tape measure was used to adjust the distance between the catch cans, and a 500 ml graduated cylinder was used to measure the water in each storage catch can.
3. **Water Flow Measurement:** Sprinklers' operating pressure was determined by selecting a nozzle for each position. The selected nozzle pressure was measured using a pressure gauge while the system was running. The discharge rate was also measured while the system was in operation by placing a 20-liter container 50 cm in height and 30 cm in diameter under the nozzle at each pivot point and taking the time required to fill, the stopwatch to check the time. The operating pressure and discharge rate of the nozzles were

measured to determine the performance level of the center pivot system compared to the recommended design specifications. The discharge rate was used to calculate the water uniformity coefficient, application efficiency, and application efficiency of low quarter. As explained by the Almond Board of California (2017) the discharge rate of the center pivot system can be calculated as follows:

$$\text{Sprinkler discharge Rate (r)} = \frac{\text{Volume of water measured in gallons}}{\text{Time taken in minutes}} \tag{1}$$

Where; discharge rate is measured in gallons per minutes

4. **Alfalfa Data:** Plant growth stages were used to determine the water needs of plants. This was achieved by recording planting dates and closely monitoring the growth stages of the alfalfa crop leading up to harvest. This was done using an observation method in which changes within a level are observed and recorded along with the number of days for each level.
5. **Crop Growth Stages:** Stages of plant growth were used in determining the water requirement of the crop. This was achieved by recording planting dates and carefully monitoring the stages of development up to the harvesting date for the alfalfa crop. This was done by observation method where the changes from one stage were observed and recorded together with the number of days per stage (Allen et al., 1998).
6. **Crop Coefficient (Kc):** This is the ratio of the crop to the reference, and shows the combination of effects of four main factors that distinguish the crop from the grass shown at i.e. plant height, cropland Albedo, canopy resistance, soil evaporation, especially soil exposure (Allen et al., 1998; FAO, 2008). When developing the crop coefficients for the growing season, different stages of crop development were taken into account; initial stage, development stage, and mid-season and late season stage: **Initial stage:** It begins to germinate and grow early when the soil surface is not covered or covered by the plant (less than 10% soil), **Crop development stage:** This starts at the end of the initial stage to the attainment of effective full groundcover (about 70-80% of the land), **Mid-stage:** This starts from attainment of effective full groundcover to time of start of maturing, and **Late stage:** It is the period starting from the end of the middle stage until the harvest season is completed (Allen et al., 1998).
7. **Crop Water Requirement:** This was achieved using the FAO-CROPWAT model using appropriate procedures defined by FAO in the Department of Water Development and Land (FAO, 2008). Data requirements included, for example, crop information including: planting and harvesting dates, growth stages, critical depletion, and yield response factors. The terrain includes: Total Available Water (TAW), maximum infiltration rate, maximum rooting depth, and initial soil moisture depletion, and finally climate data which required total monthly rainfall, effective rainfall, reference evapotranspiration (ET_o), and monthly average maximum and minimum temperature, wind speed, radiation, and sunlight. As reported by Allen et al. (1998) and FAO (2008), soil and crop data were collected from areas where specific monitored crops were grown. Crop coefficient values were obtained from previously published data K_c for early, mid and late growth phases of season (Allen et al., 1998).
8. **Reference Evapotranspiration (ET_o):** The CROPWAT program is a decision-marking tool developed by FAO's Land and Water Development Department (2010). The main functions are to calculate reference evapotranspiration, crop water needs and irrigation needs. This will promote the development of seasonal irrigation systems for water management and water supply, and enable evaluation of rain-fed production, drought impacts, and irrigation systems. To calculate crop yield from evapotranspiration, FAO uses the Penman-Monteith method for and its estimates are used for crop water requirements and irrigation schedule calculations. CROPWAT calculates irrigation water for different stages of crop development throughout the growing season on a daily or weekly basis or for a specific period as required by the irrigation system. It uses technology to

predict yields when all parameters of weather, soil, and crops are known. This method allows estimating and based on the estimation of yield potential. from the ratio of actual to potential yield. In this study, the CROPWAT program was used to estimate the water need of alfalfa. The calculation uses weather data such as maximum and minimum temperature, relative humidity, wind speed and sunshine hours. All data obtained were transformed to the format approved by CROPWAT 8.0 (Matthews and Stephens, 2002).

9. **Crop Evapotranspiration (*ET_c*):** This is the amount of water required by the plant during the growing season. This is usually determined by the crop correlation method, where different climatic effects are included in and crop characteristics in the crop coefficient. It is calculated as follows:

$$ET_c = ET_o \times K_c \tag{2}$$

Where: is Crop evapotranspiration, mm/day, ET_o is Reference evapotranspiration, mm/day and K_c is Crop coefficient constant.

Analysis of Hydraulic Performance

1. **Uniformity Coefficient (*CU*):** *CU* defines the alignment of the nozzles at a certain level to the centerline of the rotating system. Therefore, it indicates a balance in irrigation (Solomon and Jorgensen, 1992). One of the most common irrigation coefficients is the Christiansen uniformity coefficient (CU), expressed as a percentage. The coefficient of uniformity proposed by Christiansen (1942):

$$CU = \left[1 - \frac{\Sigma X}{mn}\right] \times 100 \tag{3}$$

Where: CU = Coefficient of uniformity (%), m = Average value of all observations average application depth (mm), n = Total number of observation points and x = Absolute numerical deviation of individual observation from the average application depth (mm).

2. **Uniformity Distribution (*DU*):** Uniformity of distribution was calculated using the equation given by Merriam and Keller (1978), as follows:

$$DU\ (\%) = \frac{\text{Mean low quarter caught in the cans}}{\text{Average depth caught in all cans}} \times 100 \tag{4}$$

3. **Scheduling Coefficient (*SC*):** Strategic planning has been created to determine critical areas in water use. It is the area with the least water consumption in the entire irrigated area (Solomon, 1988):

$$SC\ (\%) = \frac{1}{DU} \tag{5}$$

Where; DU = Distribution uniformity, (decimal)

4. **Application Efficiency (*AE*):** Application Efficiency (*AE*) according to Merriam et al. (1983), it is computed as follows:

$$\text{AE} = \frac{\text{Average depth of water collected in catch cans}}{\text{Average depth of water applied at nozzles}} \times \times 100 \tag{6}$$

5. **Water Loss (*WL*):** Water loss in the system is calculated by subtracting the average depth collected in cans from the average depth of application monitored by the flowmeter, as provided by Sabri (2007):

$$\text{Average depth of application} = \frac{\text{Volume applied (m}^3\text{)}}{\text{Area irrigated (m}^2\text{)}} \tag{7}$$

$$\text{Water loss} = \text{Average depth of application} - \text{– Average depth collected in cans} \tag{8}$$

$$\text{Water losses (\%)} = = \frac{\text{Water loss}}{\text{Average depth of application}} \times 100 \tag{9}$$

RESULTS AND DISCUSSION

Hydraulic Performance of Center Pivot Irrigation System

The Fig. 2, 3, 4 and 5 shows the results of uniformity coefficient, distribution coefficient, scheduling coefficient, application efficiency and water loss. The evaluation results of hydraulic performance demonstrate the ability of center pivot irrigation system to apply more uniformly and efficiently at different rotating speeds. Analysis of variance (ANOVA) on results showed that mean values of CU, DU and AE were not statistically significant (P = 0.01) across treatments, although a general trend was observed.

Uniformity Coefficient (CU)

The average results of the coefficient uniformity obtained for the pivot system in the first and second fields in two seasons are shown in Fig. 2, 3, 4 and 5. CU results were found in two systems: in the 2022/2023 season was 77.8% and 79.1%, while; in the 2023/2024 season was 78.9% and 79.9%. The results were similar to Ali (2012) with 79% in Arab Agricultural Production Company, 79% in El Bashir Jordanian Company, and 78% in Ras Al Wadi Alakhdar Project. Moreover, the results were lower than those of Ali (2002) who reported that the CU of the system in Sudan was between 78-85%, Ghorbani and Amini (2011) reported that CU in Iran is between 76–81%, Islam et al. (2017) reported a CU range of 87–92% in Pakistan, and Jonal et al. (2021) reported the CU of two systems in Ghana ranging from 80––87% and 76–84%. However, the results were higher than those reported by Mandor and El Sadig (2010) who found 75% in Sudan and Loung (2016) who found 72% CU in Sudan. As suggested by Henggeler and Vories (2009), Merriam et al (1983) and Zoldoske et al. (1994), the average of CU results obtained at these two pivot points was fair. Others, Evan et al. (1996), the lower values of uniformity coefficients obtained can also be attributed to the clogging of nozzles caused by sedimentation, trash or nozzles being worn out. Zoldoske et al. (1994) recommended, that 80% or less of the system requires an adjustment to the sprinkler package, a change to the default system and sprinkler pressure, and to conduct full maintenance of the whole system. It can easily be improved by checking sprinklers for plugged or enlarged nozzle size for the location on the irrigation system.

Distribution Coefficient (DU)

The average results of the uniform distribution obtained for the pivot system in the first and second fields in two seasons are shown in Fig. 2, 3, 4 and

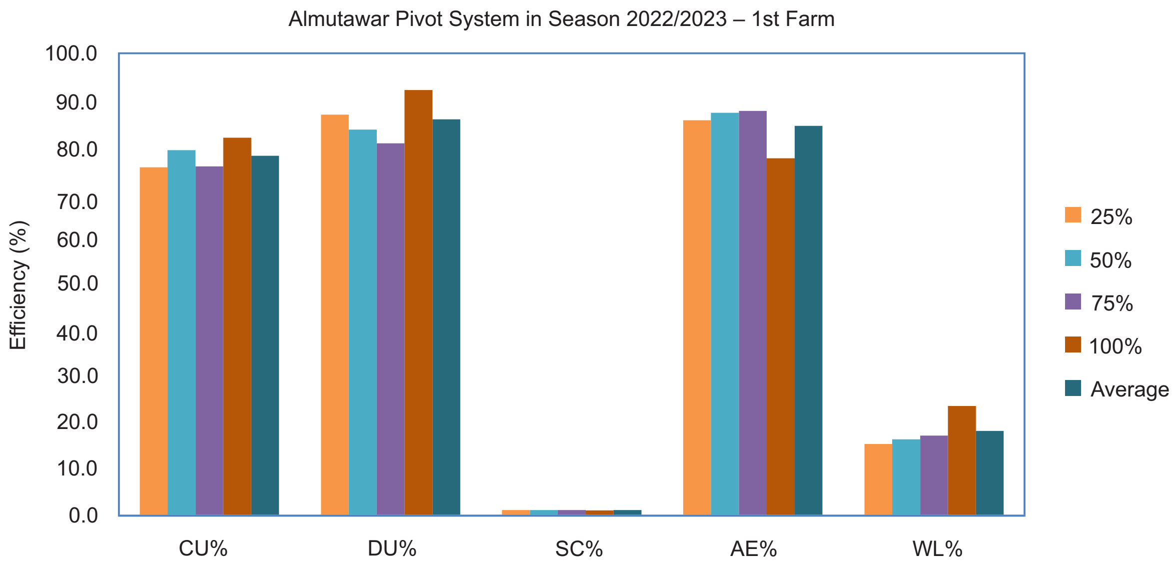

Fig. 2. Performance of pivot system at 1st farm (source: Authors' own elaboration)

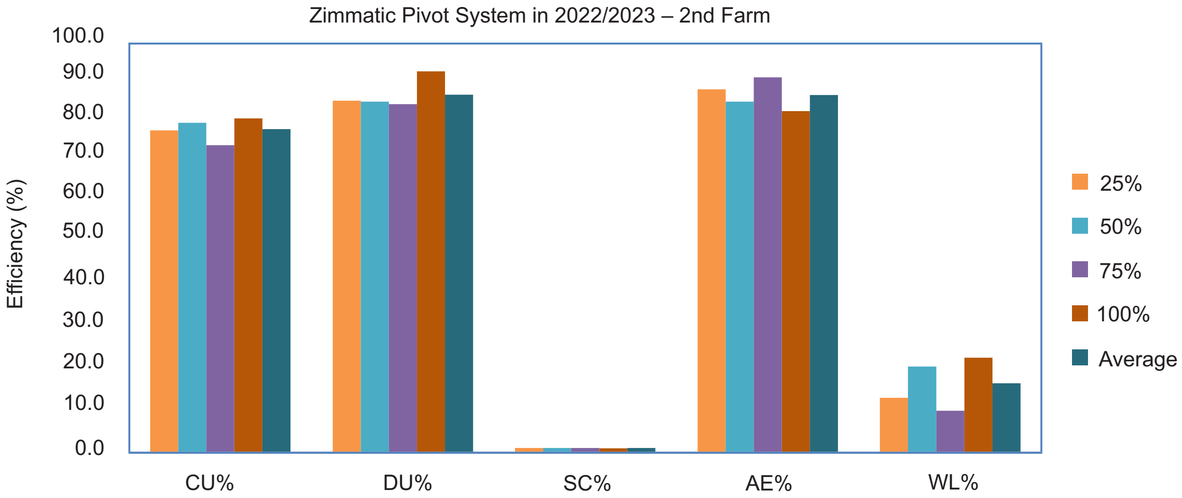

Fig. 3. Performance of pivot system at 2nd farm (source: Authors' own elaboration)

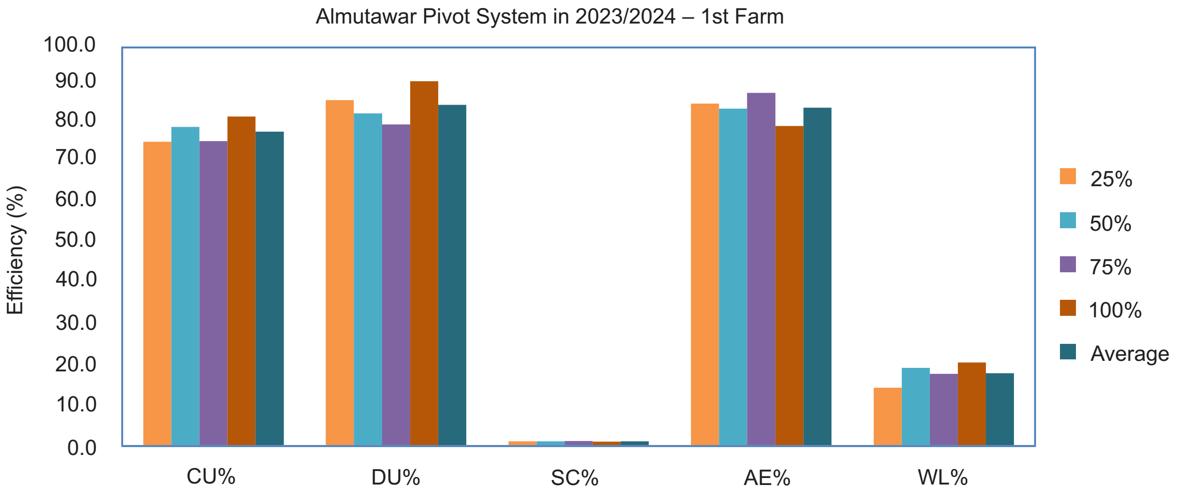

Fig. 4. Performance of pivot system in 1st farm (source: Authors' own elaboration)

5. The average results of the DU obtained in two systems: in the 2022/2023 season was 85.7% and 87.5%; while; In the 2023/2024 season, it was 85.6% and 85.8%. Results were similar to those reported by Aimar et al. (2022) of 85% in Argentina, Pereira et al. (2002) gave the DU ranged from 75-85% in New York, 76–85 found by Salih (2004) in Sudan and Elhassan (2008) in Sudan who obtained DU ranging from 76–85%. However, the results were greater than those reported by Osama (2002) for the Elargam project west of Omdurman in Sudan, which found a DU of 70%, Reuben et al. (2010) reported a value of 75% for DU in Tanzania, Elbadawi (2001) in Umdom project gave 76% in Sudan and Salah (2013) had 56–76% DU in Sudan. As suggested by Henggeler and Vories (2009), Merriam et al (1983) and Zoldoske et al. (1994), the average DU results obtained at 25%, 50%, 75% and 100% speeds were fair in two systems. The low DU values obtained from both center pivots can be attributed to blockage of the nozzles by small sedimentation and the inaccurate design of the system. Additionally, the scattering method of the

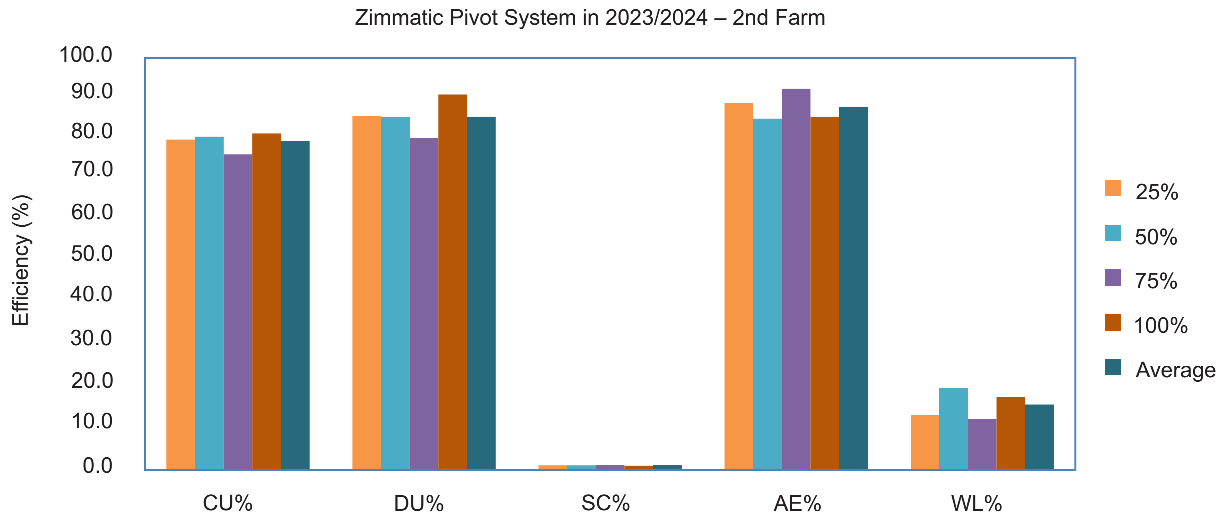

Fig. 5. Performance of pivot system in 2nd farm (source: Authors' own elaboration)

sprinkler is also a critical factor (Evans, 2001). Cisneros et al (1999) suggested that DU is an important factor that directly links the concept of efficiency and distribution, therefore should be taken into account in any evaluation.

Scheduling Coefficient (SC)

The average results of the scheduling coefficient obtained in this study regarding the pivot system of the first and second farm at different speed levels are shown in Fig. 2, 3, 4 and 5. The average results of SC obtained in alfalfa growing seasons 2022/2023 and 2023/2024 for two systems at both farms were 1.2%. The average results obtained at the two farms were below the limit i.e., 1.3 which indicates the scope of the results is reasonable. The results of SCs found in two systems at speeds of 25%, 50%, 75% and 100% are acceptable, as suggested by Merriam and Keller (1978) and Zoldoske et al. (1994), Henggeler and Vories (2009). Acceptable values were obtained as positive distribution results obtained from both pivot systems. Connellan (2002) and Abdelrahman (2006) stated that the SC value of a good irrigation system should be less than 1.3. The results were valid when compared with those of Adam et al. (2018) in Sudan: The India project gave a value of 1.3% and the Arab Authority for Agricultural Investment and Development (AAAID) project gave a value of 1.4%, while for Sedonix project it gave a value of 1.2%, which consistent with our results. This may due to wind distortions affecting the distribution or design of the system (Sabri, 2007; Loung, 2016; Jonal et al., 2021). Irrigations should be planned according to groundwater levels to prevent undesirable levels in plant (Evans, 2001).

Application Efficiency (AE)

The results of the application efficiency found in this study on the system in the first and second farms in two growth periods of alfalfa at different rates (25%, 50%, 75% and 100%) are as shown in Fig. 2, 3, 4 and 5. The average results of AEs found in the two systems: In the 2022/2023 season this was 84.3% and 87.4 %, and in the 2023/2024 season it was 84.9 % and 88.2 %. The center pivot point in the second farm was within the acceptable range recommended by the South African Irrigation Institute (2000). The results were similar to those of Medani (2013) in River Nile State, Salih (2004) in Khartoum State, and Elhassan (2008) in Northern Province. Although the center pivot in the first farm looks less balanced; recorded high performance. The optimal irrigation system for the first farm was close to the range recommended by Merriam and Keller (1978). The lowest values used show that there is water loss due to infiltration and deep seepage in the light soils (Hawait, 2015).

Water Loss (WL)

In this study, the average water loss obtained for the pivot system in the first and second fields in the two growing seasons of the alfalfa operated at running speed (25%, 50%, 75%, and 100%), as seen in Fig. 2, 3, 4 and 5. The average results of WL achieved in two systems: 18.3 % and 17.0 % in the season 2022/2023, and in the 2023/2024 season were 18.3 % and 15.9%. The results are consistent with those observed by Mohammed et al. (2016), who held 18.0 % at AlGIMMA scheme – GIAD Crop Production Company in the River Nile State of Sudan. These results were better compared to Mohammed (2019) who had 23.0 % water losses in the AlGIMMA scheme – GIAD Company for Crop Production in the River Nile State – Shandi in Sudan, Loung (2016) who had an average of 38.1% at West Omdurman Scheme in Sudan and Sabri (2007) who gave 23.8% at Khartoum North Area in Sudan. The results show a fair level of efficiency due to the presence of high evaporation. The increase in water loss can be caused by strong wind drift since there is no protected shelter belt to act the wind.

CONCLUSIONS

In summary, as a result of the distribution uniformity in both systems, a scheduling coefficient of 1.2% was obtained. Apart from that, it was determined that the water loss caused by inadequate repair and installation of the system was high. Moreover, the field performance of two irrigation systems in this study was below the desired values; This may be caused by water loss from main pipes and sub-main pipes. ANOVA revealed that the differences in CU, DU, and AE across treatments were not statistically significant ($P = 0.01$), though a general trend suggesting improved performance in the 2023/2024 season was noted. The study found that the hydraulic function of the center pivot system varied with different steering modes, suggesting potential issues with design compliance and efficiency. Further investigation into these discrepancies could help in optimizing system performance.

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REFERENCES

Abdelrahman, A.I. (2006). Designing and developing an automated sprinkler irrigation system. Ph.D. Thesis, Faculty of Agriculture, University of Khartoum.

Adam, B.A., Aldaim, A.M.A., Mohamed, A.E. (2018). Enhancing water productivity of alfalfa (Medicago sativa) under centre pivot irrigation system. International Journal of Engineering and Information Systems IJEAIS), 2, 12, 24–30.

Aimar, F., Martínez-Romero, Á., Salinas, A., Giubergia, J.P., Severina, I., Marano, R.P.A (2022). Revised equation of water application efficiency in a center pivot system used in crop rotation in no tillage. Agronomy, 12, 2842. DOI: 10.3390/agronomy12112842

Ali, O.O (2002). Evaluation of the performance of center pivot irrigation system West of Omdurman. Unpublished M.Sc. (Agric.) Thesis, University of Khartoum.

Ali, O.O. (2012). Performance of centre pivot irrigation systems in River Nile State. Nature and Science, 10(12), 184–187.

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998). Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. http://www.fao.org/docrep/X0490E/X0490E00.htm (accessed: June 2, 2012).

Almond Board of California (2017). Determining your application rate, impact sprinkler irrigation. https://www.almonds.com/sites/default/files/2020-04/websiteupdate_ALM%20Impact%20Sprinkler%20Application%20Rate%20v2.pdf (accessed: September 30, 2024).

ASAE (American Society of Agricultural Engineers) S436.1 (1996). Test Procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles. St. Joseph, MI: ASAEM.

Bhattacharya, A. (2014). Irrigation technology: theory and practice. New Delhi: Venus Books.

Christiansen, J.E. (1942). Irrigation by sprinkling. University of California Agricultural Experiment Station Bulletin, 670, 124.

Cisneros, F., Torres, P. and Feyen, J. (1999). Quantitative analysis of the performance of sprinkler irrigation in the southern Sierra of Ecuador on slopes steeper than 12%. In Proceeding of the inter-American conference on water resources management, II water meeting, 15–18.

Connellan, G. (2002). Efficient irrigations: A reference manual for turf and landscape. Burnley College, University of Melbourne.

Crews, T.E., Peoples, M.B., (2004). Legume versus fertilizer sources of nitrogen: Ecological tradeoffs and human needs. Agric. Ecosyst. Environ., 102 (3), 279–297. DOI: 10.1016/j.agee.2003.09.018

Dirksen, C. (1999). Soil physics measurements. Reiskirchen, Germany: Catena Verlag.

Elbadawi, A.M. (2001). Center pivot performance at Omdoum: A case study. M.Sc, (Agric) Thesis, University of Khartoum.

Elhassan, Z.A. (2008). Assembling and performance evaluation of center pivot irrigation system New Hamdab Irrigation Project Northern State. Unpublished M.Sc. (Agric) Thesis, University of Khartoum.

Evans, R., Saneed, R.E., Cassel, D.K. (1996). Irrigation scheduling to improve water- and energy-use efficiencies. Publication Number: AG 452-4: North Carolina Cooperative Extension Service.

Evans, R.G. (2001). Centre pivot irrigation. Supervisory Agricultural Engineer and Research Leader, Agricultural Systems Research Unit, North Plains Agricultural Research Laboratory, USDN-Agricultural Research Service, 1500 North Central Ave. Sidney, MT 59270.

FAO (2002). Deficit irrigation practices. FAO Water Report No. 22. Rome, Italy.

FAO (2008). Global map of monthly reference evapotranspiration – Geo-Network: Grid database. Rome, Italy.

FAO (2010). Pressurized irrigation techniques. The centre pivot irrigation systems. Rome, Italy.

FAO (2013). The practice of irrigation. Guidelines for designing and evaluation surface irrigation systems. http://www.fao.org/docrep/t0231e/t0231e03htm (accessed: August, 2, 2013).

FAO (2020). World Food and Agriculture – Statistical Yearbook 2020. Rome, Italy. DOI: 10.4060/ cb1329en

Garg, S.K (2007). Irrigation engineering and hydraulic structures. New Delhi: Khanna Publisher.

Ghorbani, B., Amini, M. (2011). Evaluation and comparison of conventional, wheel move and center pivot systems performance at Shahrekord Township. Iranian Journal of Irrigation and Drainage, 4 (3), 454–464.

Harrison, K., Perry, C. (2007). Evaluating and interpreting application uniformity of center pivot irrigation system. Cooperative Extension, University of Georgia.

Hawait, A.E. (2015). Technical evaluation of performance of center pivot sprinkler irrigation system at West Omdurman, Sudan. Unpublished M. Sc. Thesis, Sudan University of Science and Technology, College of Graduate Studies.

Henggeler, J.C., Vories, E.D. (ASABE) (2009). Evaluating centre pivot distribution uniformity from catch can tests.

Islam, Z., Mangrio, A.G., Ahmad, M.M., Akbar, G., Muhammad, S., Umair, M. (2017). Application and distribution of irrigation water under various sizes of center pivot sprinkler systems. Pakistan J. Agric. Res., 30 (1), 415–425.

Jonal, Y., Shaibu, A., Abagale, F.K. (2021). Effects of centre pivot system speed configuration on water application efficiency at Kukobila Nasia farms limited in the Savelugu Municipality, Northern Region of Ghana. International Journal of Creative Research Thoughts (IJCRT), 9 (10).

Keller, J., Bliesner, R.D. (1990). Sprinkle and trickle irrigation. Van Nostrand Reinhold, New York, NY.

Li, J.S., Rao, M.J., Zhang, J. (2002). Influences of spatial variations of soil and non-uniform sprinkler irrigation on spring wheat yield in arid regions. Transactions of CSAE, 18, 15–21.

Loung, Z.J. (2016). Hydraulic and economic evaluation of a center pivot irrigation system in West Omdurman District, Sudan. Unpublished M.Sc. (Agric) Thesis, University of Khartoum.

Makhlof, H.A.H., Elamin, A.W.M., Mohamed, M.A., Adam, A.B., Abdeldyim, A.M. (2021). Demarcation of groundwater quality for irrigation purposes in Sirte, Libya. Water Resources and Irrigation Management, 10 (1–3), 15–24. DOI: 10.19149/wrim.v10i1-3.2299

Mandor, I.M.K., El Sadig, M.A. (2010). Evaluation of operation speed effect on center pivot irrigation system performance. A case study of El Waha and El Zahra Project in Northern State (Sudan).

Matthews, R.B., Stephens, W. (2002). Crop soil simulation models: Applications in developing countries. Wallingford, Oxon, UK: CABI Pub.

Medani, M.H. (2013). Evaluation of hydraulic and operational performance of centre pivot irrigation system for wheat (Triticum aestivum) production in river Nile state. Unpublished M. Sc. (Agric) Thesis, University of Khartoum.

Merriam, J.L., Keller, J. (1973). Irrigation system evaluation and improvement. Utah: Utah State University, Logan.

Merriam, J.L., Keller, J. (1978). Farm irrigation system evaluation: A guide for management. Dept. of Biological and Irrigation Engineering, Utah State Univ., Logan, UT.

Merriam, J.L., Shearer, M.N, Burt, C.M. (1983). Evaluating irrigation systems and practices. In: M.E. Jensen (Ed.), Design and operation of farm irrigation systems. ASAE, monograph no. 3. St Joseph, Michigan: American Society of Agricultural Engineers.

Michael, A.M. (1978). Irrigation theory and practice. New Delhi, India: Vikas Publishing House, PVT. Ltd.

Mohamed, M.T. (2010). Evaluation of operation speed effect on center pivot irrigation system performance. A case study of El Waha and El Zahra project in Northern State (Sudan). MSc. Thesis Dept. of Agriculture Engineering College of Agricultural Studies, Sudan University of Science and Technology.

Mohammed, A.A.I., Fadlallah, E.Y.I., Abdelkarim, H.B.A., Mustafa, M.M.M. (2016). Evaluation of performance and potential runoff for center pivot irrigation system. B.Sc. Thesis, Faculty of Agriculture, University of Khartoum.

Mohammed, W. (2019). Study for the improvement of water use efficient irrigated Alfalfa, Sudan Alfalfa and Grain Symposium, 10–12 December 2019.

Osama, O.A. (2002). Evaluation of center pivot irrigation system. M. Sc. Thesis. Faculty of Agriculture, University of Khartoum.

Pereira, L., Jorge, S.T., Zairi, A. (2002). Irrigation management under water scarcity. Agricultural Water Management, 57(3), 175–206.

Reuben, P.M., Mahoo, H., Thadei, S.Y., Ernest, E. (2010). Evaluation of the performance of centre pivot sprinkler irrigation system and its effects on crop yield at Kagera, Tanzania. Second RUFORUM Biennial Meeting 20–24 September 2010, Entebbe, Uganda.

South African Irrigation Institute (2000). Design norms. SABI, Strand, RSA. http://www.sabi.co.za/html/design_norms.html (accessed: September 9, 2000).

Sabri, J.L. (2007). Evaluation a center pivot sprinkler irrigation system in Khartoum North Area, University of Gezira M. Sc., Sudan.

Salah, A.S. (2013). Evaluation of speed effect on centre pivot irrigation system performance at Waha Project under Sudan North State Conditions. International Conference on Civil and Architecture Engineering (ICCAE'2013) May 6–7, 2013, Kuala Lumpur, Malaysia.

Salih, A.H. (2004). Evaluation of the centre pivot and linear move sprinkler irrigation system under Sudan conditions. Unpublished M.Sc. (Agric) Thesis, University of Khartoum.

Solomon, K.H. (1988). Irrigation systems and water application efficiencies. California: California State University, Fresno.

Solomon, K.H., Jorgensen, G. (1992). Subsurface drip irrigation. Grounds Maintenance, 27 (10), 24–26.

Zoldoske, D.F., Solomon, K.H., Norum, E.M. (1994). Uniformity measurements for turf grass: Center for Irrigation Technology, California State University Fresno, USA. Available from: http://cati.csufresno.edu/cit/rese/94/941102.index.html (accessed: April 23, 2004).

EWALUACJA WYDAJNOŚCI HYDRAULICZNEJ I POLOWEJ CENTRALNYCH SYSTEMÓW NAWADNIANIA W OBSZARACH PÓŁSUCHYCH

ABSTRAKT

Cel pracy

Celem niniejszego badania była ocena wydajności hydraulicznej i polowej centralnych systemów nawadniania w warunkach klimatu półsuchego w celu określenia ich efektywności w ramach optymalizacji wykorzystania wody i plonów w takim środowisku.

Materiał i metody

Ocena wydajności systemu centralnego obejmowała rozmieszczenie dwóch rzędów pojemników do zbierania wody rozstawionych co trzy metry i rozchodzących się promieniście od punktu centralnego, w celu analizy rozkładu i równomierności nawadniania. Metoda ta umożliwiła ocenę wydajności systemu w dostarczaniu wody.

Wyniki i wnioski

W systemie Almutawar średnie wskaźniki wydajności dla sezonu 2022/2023 wynosiły: CU = 77,8%, DU = 85,7%, SC = 1,2%, AE = 84,3% i WL = 18%. Dla sezonu 2023/2024 wskaźniki te wynosiły: CU = 78,9%, DU = 85,6%, SC = 1,2%, AE = 84,9% i WL = 18,3%. W systemie Zimmatic średnie wyniki wynosiły: CU =

79,1%, DU = 87,5%, SC = 1,2%, AE = 87,4% i WL = 17,0% dla 2022/2023 oraz CU = 79,9%, DU = 85,8%, SC = 1,2%, AE = 88,2% i WL = 15,9% dla 2023/2024. Analiza ANOVA wykazała, że różnice w CU, DU i AE między grupami nie były statystycznie istotne (P = 0,01), chociaż zauważono ogólny trend sugerujący poprawę wydajności w sezonie 2023/2024. Badanie wykazało, że wydajność hydrauliczna systemu centralnego zmieniała się wraz z różnymi trybami sterowania, co może stanowić potencjalny problem w kontekście wydajności i projektowania systemu. Dalsze badania nad tymi rozbieżnościami mogą pomóc w optymalizacji wydajności systemu.

Słowa kluczowe: zaopatrzenie w wodę, system nawadniania, system centralny, system Almutawar, system Zammatic