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Performance's Comparison Study Between Center Pivot Sprinkler and Surface Irrigation System

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***Abstract*—**Irrigation methods are significantly affects crop yield. Field experiment was conducted to evaluate the performance of center pivot irrigation system (CPS) and surface irrigation (SI) system with view to water application efficiency (Ea %), distribution coefficient (Du %), storage efficiency (Es %), coefficient uniformity (Cu %) Scheduling coefficient (Sc %), yield and water use efficiency (WUE) at two projects in the River Nile State (RNS), Sudan during the winter season of 2011-2012. The results showed that the Cu, Du, Ea and Sc % for the CPS were higher than those recorded by SI in the both seasons. Also, results revealed that the yield of wheat and potato under CPS was higher than the SI. The total amounts of water applied under CPS were 9019 (wheat) and 11024 m3 ha-1 (potato), while under the SI were 20000 (wheat) and 22857.6 m3 ha-1 (potato). Technical water use efficiency (TWUE) values for wheat and potato under the CPS system were found to be 1.913, and 0.205, respectively. While the corresponding values under the SI were 0.536, and 0.05, respectively. With careful management, the CPS under the study can produce high irrigation efficiency and high TWUE values, which mean higher crop production of with fewer amounts water applied.

***Keywords*—** System performance, crop, center pivot, surface

I. INTRODUCTION

Sudan is mainly an agricultural country. More than 80% of the national wealth depends on agriculture which is either rain-fed or irrigated. Irrigated agriculture relies on the water from the River Nile and its tributaries. The River Nile State (RNS) projects northern, Sudan, is a multispectral human development projects based on water resources, which are significantly to the supply of the country needs of food and fodder. Wheat and Potato are the main commercial winter crops produced in the state. Production is hindered by the costs of inputs, especially of water which is pumped from the River Nile or from underground and credit is also scarce.

Conventional irrigation methods such as furrow and basin irrigation are widely applied in RNS; however, the use of modern techniques is inevitable in the near future because of the degradation of soils, salinity problem and the high evaporation rates caused by traditional irrigation methods [1].

The improved utilization of both water and land are problems of major concern in many countries, particularly those with semi-arid climates. Water for irrigation is a serious limiting factor. In order to utilize limited water supplies to the best advantage, the methods by which irrigation water is applied to the soil may need to be critically evaluated, where there is a waste, methods need to be improved for efficient application. The application of modern irrigation techniques has occupied large part in irrigation methods and received considerable attention in the world in recent years, particularly in developing countries, so no doubt it becomes vital to conserve and economize water use and can best be achieved through the use of improved irrigation techniques, among this techniques center pivot (CPS) irrigation system is a wide diffusion worldwide because of their advantages relative to other irrigation systems e.g. drip and sprinkler and supplying balanced and adequate doses of fertilizers [2], CPS have many characterizes are high uniform and efficient water applications, high degree of automation, and ability to apply water and nutrients over a wide range of soil [3]. In Sudan CPS introduced mainly in the RNS for the crops production because it's capable to improve climate, enhance agricultural production, optimize water use and decrease operation costs of irrigation by reduce the power used and other advantages. However research on this topic is still at a very early stage so the objectives of this study were: (1) Evaluation of the performance irrigation system in schemes in Sudan under previous tow irrigation methods, including: application efficiency, storage efficiency, distribution uniformity, coefficient of uniformity, scheduling coefficient (Sc%), crop water requirement (CWR), technical water use efficiency and crop yield; (2) Comparison between the CPS and the conventional SI systems in crops production under the RNS conditions.

II. MATERIALS AND METHODS

A. *STUDY AREA AND SYSTEM DESCRIPTION*

The study was conducted in the River Nile State (RNS), north of Sudan (latitude 16^{o}- 20°N, and longitude 32^{o} - 35°E) during the winter growing seasons (2011-2012) at one scheme that was adopting center pivot (CPS) irrigation system and one

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scheme that was adopting surface irrigation (SI) as common system in the state. Those were Tala Company Agricultural and Al-misiktab project, with various cultivated area 252 and 168 ha respectively, those schemes were growing wheat and Potato. The climate is semi-arid which is hot in summer and cold in winter with range variation in temperature between 5 and 49 ^{o}C. Rains vary from 0 mm in the north to 100 mm in the south. Soil texture in those sites was predominantly sandy clay loam which characterized by high to relatively low infiltration rate (2-3 mm hr^{-1}). Physical soil properties of the study area and main feature of center pivot system are presented in Table 1 and Fig. 1.

Table 1. Soil physio-chemical characteristics of the study area

Properties	Average
Sand %	55
Silt %	3.35
Clay %	41.65
Bulk density g cm^{-3}	1.45
Water holding capacity (mm m^{-1})	27
Hydraulic conductivity mm hr^{-1}	4
Nitrogen (%)	0.05
Phosphorous (mg l^{-1})	3.4
Potassium (mmol+1 L^{-1})	0.11
Organic matter (%)	1.2
pH	7.5

Figure 1. System main features

B. MEASUREMENT OF SYSTEMS PERFORMANCE PARAMETERS

A 693 tin catch cans with the same opening, diameter, and height were used for collecting water applied by the irrigation system, measuring cylinders, measuring type, sensitive balance and square sampling ring were used. The cans were placed and distributed at three replication each of them contains three rows with uniform spacing of 4.5 meters along the column and one m space between rows outwards the pivot point (CPS) Fig 2. The CPS system was allowed to pass over the cans for three runs, at each run measurements were recorded. Volumetric measurement with graduated measuring cylinders were used and converted to depth (mm) by the following equation :

$$H = \frac{V}{A} \qquad (1)$$

Where:
H: height in cm; V: volume of water collected in ml; A: bottom surface area of can in cm^2.

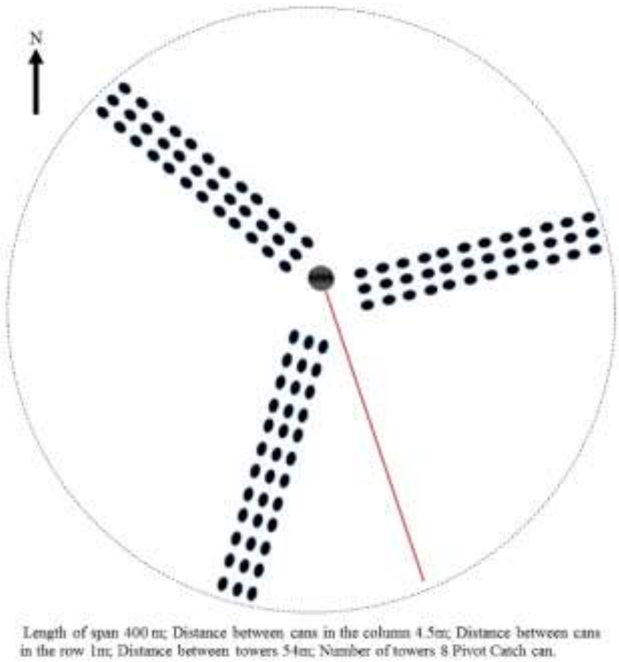

Figure 2. Catch cans layout

III. PERFORMANCE PARAMETERS WERE CALCULATED AS FOLLOWS

Application efficiency (Ea %), this was calculated by dividing the average depth of water caught in the catch cans by the average depth of application as monitored by the system flow meter [4].

$$Ea\% = \frac{Dc}{Ds} \times 100 \qquad (2)$$

Where: Ea: Application efficiency (%); Dc: Average depth of water in catch cans (mm); Ds: Average depth of application as recorded by the system flow meter (mm). The distribution

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uniformity (Du %) or pattern efficiency, determined using method that described by [5]. Distribution uniformity on pattern efficiency can therefore be stated in the following form:

$$\mathrm{Dp\%} = \frac{\mathrm{Lm}}{\mathrm{Da}} \times 100 \qquad (3)$$

Where: Dp %: Pattern efficiency %; Lm: Mean low quarter caught in catch cans (mm); Da: Average depth of water caught in all cans (mm).

The concept of water storage efficiency (Es %) shows how completely the water needed prior to irrigation has been stored in the root zone during irrigation, were calculated by using the following equation.

$$Es\% = \frac{Ws}{Wn} \times 100 \qquad (4)$$

Where: Es%: water storage efficiency; Ws: water stored in the root zone during irrigation; Wn: water needed in the root zone prior to irrigation.

A measurable index of the degree of uniformity obtainable for any sprinkler system under a given condition has been developed and is known as uniformity coefficient (Cu), this is commonly known as Christiansen coefficient of uniformity and was determined using the equation that stated by Christiansen (1942) [6], as follow:

$$\mathrm{Cu\%} = 100\left[1 - \frac{\sum \mathrm{x}}{\mathrm{mn}}\right] \qquad (5)$$

Where: Cu %: Christiansen's coefficient of uniformity; m: Average value of observations (mm); n: total number of observation points; x: numerical deviation of individual observation from the average application depth (mm).

Scheduling coefficient (Sc %) is determines the critical area in the water applicant pattern. This is the area receiving the least amount of water, which is divided by the average amount of water applied through the irrigation area [7], Sc % was calculated by using the following equation:

$$\mathrm{Sc\,\%} = \frac{1}{\mathrm{Du}} \times 100 \qquad (6)$$

Where: Sc: scheduling coefficient; Du: uniformity of distribution (decimal).

With respect to the SI system, the performance includes application efficiency (Ea %), distribution efficiency (Ed %) and storage efficiency were determined as described by Walker, (1989) [8].

$$Ea\,\% = \frac{Ws}{Wf} \times 100 \qquad (7)$$

Where: Ea %: application efficiency, percent; Ws: water stored in the root zone of the plants during irrigation; Wf: water delivered to the field.

$$Ed\,\% = \left[1 - \frac{y}{d}\right] \times 100 \qquad (8)$$

Where: Ed %: distribution efficiency, percent; d: average depth of water stored along the run during the irrigation; y: average numerical deviation from d.

Reference evapotranspiration (ET_o) was calculated using Cropwat complete packages based on FAO Penman – Monteith equation , then multiplied by kc to calculate ET_c using the following formula as suggested by Allen *et al.*, (1998) [9].

$$ET_c = ET_\circ \times K_c \qquad (9)$$

Where: ET_c: Crop water requirement (mm/day); $ET_\circ$: Reference crop evapotranspiration (mm/day); K_c: Crop coefficient.

Data on amount of irrigation water used $m^3\ ha^{-1}$ and yield kg ha^{-1} for the two grown crops were also determined. Technical water use efficiency (TWUE) was determined for the both system CPS and SI, using the following equation:

$$\mathrm{TWUE} = \frac{\mathrm{Yield\ (kg\ ha^{-1})}}{\mathrm{Amount\ of\ water\ used\ (\ m^{3}ha^{-1})}} \qquad (10)$$

Where: WUE: water use efficiency kg m^{-3}.

IV. RESULTS AND DISCUSSION

A. *EVALUATION OF CENTRE PIVOT AND SURFACE IRRIGATION SYSTEM PERFORMANCE*

The water application efficiency Ea % for CPS was found to be higher than SI during the both seasons (Fig. 3 and 4). These results may be due to seepage losses from the distribution channels, runoff losses and deep percolation below the root zone, all mentioned above losses does not exist in CPS [10], similar results were obtained by Ali, (2002) [1] at West of Omdurman, Sudan. The higher value of distribution uniformity (Du %) for CPS was found to be 80 % in the second season while, the lowest one recorded in the first season. Solomon (1988) [7], Keller and Bliensner (1990) [11]; Jorge and Pereira, (2002) [12] and Rain, (2008) [13] found that the uniformity of distribution ranged from 75 to 85%. Also, Ali, (2002) [1] found that, uniformity of distribution of about 77%. Therefore, uniformity of distribution was lay the acceptable limits of the reported range in the first and second season (Fig. 3). From the observations low values of Du% can be attributed to partial clogging of sprinkler packages caused by sedimentation, trashes and/or nozzle being worn out, operating pressure and inaccurate setup of the system these results agree with Salah, (2013) [14]. On the other hand, distribution efficiency (Ed %) in SI system was high in the second season than the first season (Fig 3), these results may be due to the acceleration of the advance of the water flow. These results are in line with Walters and Boss (1989), when reporting on small scale irrigation development, that with good care, Ed of 90 % can be reached. Results of the storage efficiency obtained under SI system were shown in Fig. 4. The highest storage efficiency of 63% was obtained in the second season, whereas the lowest one was recorded in the first season. These results might be due to the high amount of water lost by runoff in the first season. The coefficient of uniformity (Cu %) for the CPS system of the study was found to be 83.7 % in the second season while the lower was recorded in the first season Fig. 3. These results were within range of 81 to 96 % obtained by Duke (1992) [15]. Connellan, (2002) [16] mentioned that an efficient irrigation system should aim to achieve a Sc % of less than 1.3 %. Generally, irrigations scheduling based on soil water levels to avoid undesirable levels of crop stress. However, in this study scheduling coefficient (Sc %) was found to be 1.43 which is higher than the value above mentioned (Fig. 3). This result indicate that the system need more management so as to avoid crop stress.

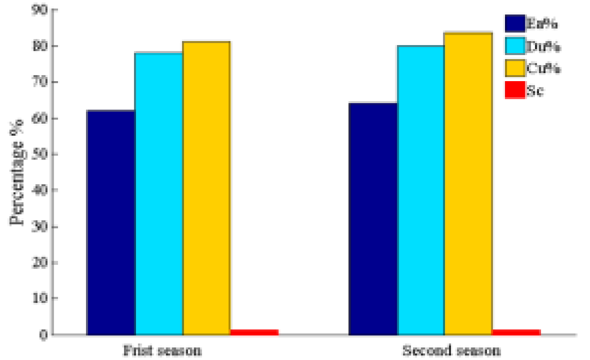

Figure 3. Average values of Ea, Du, Cu and Sc % under CPS system

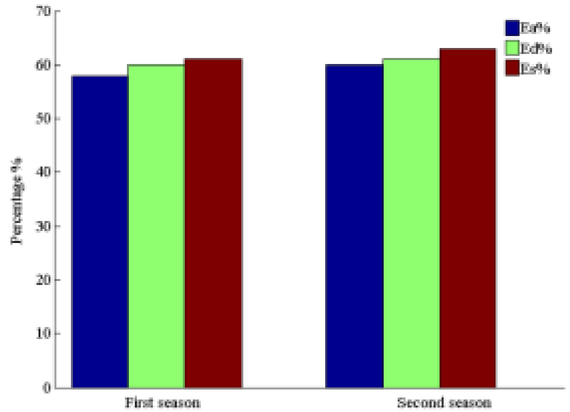

Figure 4. Average values of Ea, Ed and Es % under SI system

B. AMOUNT OF WATER APPLIED USING SI AND CPS IRRIGATION SYSTEMS

Actually the water needed by potato is higher than that needed by wheat, this variation in water requirement is referring to that potato needs five to seven irrigation episodes whereas the wheat needs three to five ones, also the variation referring to soil condition and climatic factors [17]. As shown in (Fig. 5) water amount applied by CPS was lower than those applied by traditional method. This result may be due to that CPS enable to apply water with high efficiency i.e. the water loss is very low and that is conversely in case of surface irrigation method where water can be diverted from a storage reservoir and transported to the field or farm through a system of canals or pipelines; it can be pumped from a reservoir on the farm and transported through a system of farm canals to whatever type of surface irrigation will cause water loss due to runoff, deep percolation and evaporation (Michael, 1978).

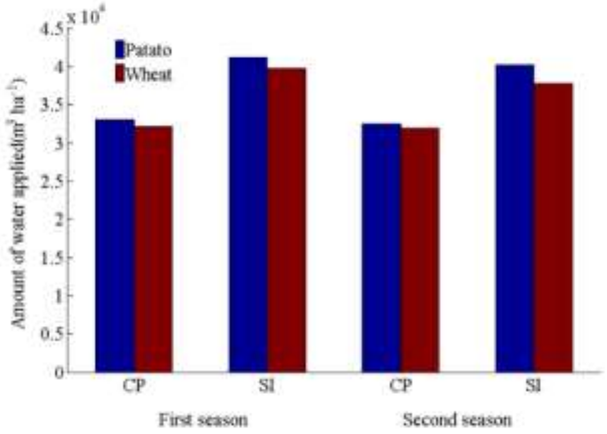

Figure 5. Amount of water applied (m3/ha) under CPS and SI irrigation systems for different crops

C. CROPS YIELD AND TECHNICAL WATER USE EFFICIENCY (TWUE)

Actually crops yield associated with high water efficiency of irrigation system, accordingly the yield of crops irrigated under center pivot irrigation system, was found to be higher than those irrigated under surface irrigation system. As shown in (Fig.6) the highest yield of potato and wheat 17500.35 and 1714.32 kg ha^{-1} respectively, were recorded under CPS in second season. Fig.7 revealed the averaged water use efficiencies values versus irrigation methods for the different crops, whereas the average TWUE values for CPS were greater than those ones obtained by SI system. Anyhow, the highest TWUE values were obtained by potato under CPS. These results illustrate the fact that TWUE is the relationship between unit produced and depth of irrigation water applied which also indicated that the lowest water applied method the highest TWUE. Thus, SI method generally have lower water use efficiency values. The results illustrated by Katerji and Mastrorilli (2009) [18] who reported that, water use efficiency of crops is affected greatly by irrigation management.

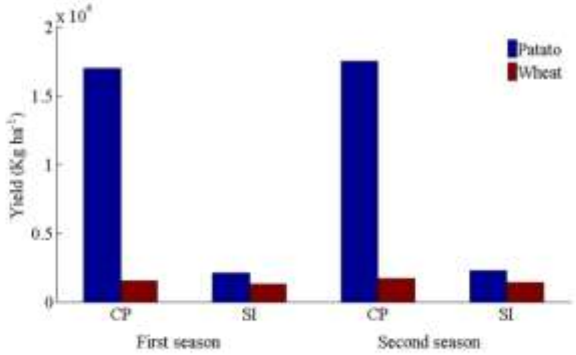

Figure 6. Wheat and Potato yield (kg ha-1) under center pivot and surface irrigation system

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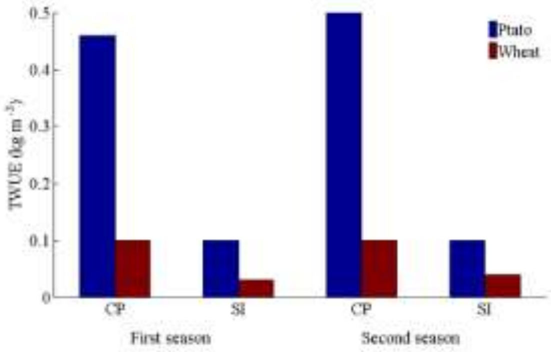

Figure 7. TWUE (kg m-3) for the different crops under center pivot and Surface irrigation system

CONCLUSION

This study conclude that; CPS irrigation system has high potentiality in managing water application i.e. it can minimize water losses comparing to what occurs in surface irrigation system which about 40%. These water losses mainly due to runoff and other different factors. Nevertheless, the highest hydraulic parameters values were obtained by CPS system. Hence, highest yield of crops and less water applied obtained under CPS irrigation system. Accordingly, this system was recorded higher TWUE than that recorded by SI system. In addition to that Potato and wheat irrigated under CPS system were recorded highest technical water use efficiency compare to those ones irrigated under SI system.
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