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Full Length Research Paper

Economic evaluation of centre pivot irrigation system for producing fodder crops under Sudan dry-land condition

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Abstract

The experimental work was carried out at the Farm of Arab Company for Agricultural Production and Processing, Umdom Project located at the eastern bank of the Blue Nile 35 km east of Khartoum during the period of March to June 2003 in an area of 3500 feddans. Seven centre pivot sprinkler system running at two different speeds (75% and 40%) were randomly selected and adopted to assess the hydraulic performance and the economic evaluation of the system for producing Alfalfa (*Medicago sativa*) and Abu 70 (*Sorghum bicolor*) compared to conventional surface method. These treatments were arranged in randomized complete block design (RCBD) with four replications. Crop water requirement was obtained using CROPWAT computer model. Spray catch cans were used for determination the hydraulic characteristics. Economic evaluation was determined from field data (mean) collected during the study period. The energy driving the system was operated by diesel engines. The systems were operated all year around for 22 hours a day and stopped only for maintenance, repair of breakdowns or when there was a rainfall event. SAS statistical package was used to analyze the data. The variations among means were checked by the least significant difference (LSD). The results showed that, hydraulic performance and economic evaluation significantly ($P \leq 0.05$) affected by the different management practices. Hydraulic performance of two irrigation systems fell below the recommended values mentioned by Michael (1978). Centre pivot system has been economically evaluated for producing alfalfa and Abu 70 and has given a remarkable profit margin (714.9 $/fed/year for alfalfa and 668.1$/fed/year for Abu 70) as compared to the conventional surface irrigation system (195.1$/fed/year and 560.2$/fed/year) under similar conditions. It is concluded that for producing the optimum yields for fodder crops proper technical guidelines for centre pivot system management, operation and scheduling should be developed and followed.

Keyword: Economic evaluation, Centre pivot system, Fodder crops

INTRODUCTION

Under the limitations in water availability, it is required to develop new irrigation scheduling approaches focused on ensuring optimal use of available water with high efficiency, and not based on full crop water requirements. The determination of these efficient and effective irrigation schedules (including deficit irrigation strategies) require the accurate determination of water requirements for the main crops, in order to assist the farmers in deciding when and how much to apply to their crops. If water can be applied efficiently in an irrigated field, water is saved and both crop quantity and quality are increased (Adam, 2014). Irrigation modernization is accepted as a strategic option to increase water productivity particularly in arid and semi-arid regions. This can be achieved by introducing modern irrigation system namely overhead (sprinkler) and drip irrigation systems. In Sudan the total area under irrigation which is almost entirely under conventional surface methods is estimated to be about two million hectares while the area under centre pivot irrigation systems is estimated to be about 15000 hectares mainly in the Northern, River Nile and Khartoum States (El-Hassan, 2008). Centre pivot irrigation system introduced for crops production because it is capable to improve climate, enhance agricultural production, optimize water use and decrease operation costs of irrigation by reducing the power used. Ali (2002) studied the center pivot irrigation system performance and found the application efficiency, uniformity coefficients and distribution efficiencies were about 86% -89%, 84% - 81% and 70% - 77%, respectively. The superiority of centre pivot system over conventional system may be attributed to the fact that, centre pivot irrigation system should be uniformly applied water at the right time to maximize forage or pasture yield and quality as stated by (Shideed *et al*., 2005) and (Ismail and Al-Marshadi, 2013).

Taking into consideration that there is little information regarding the operation, management and the economic efficiency of the centre pivot systems in Sudan and the limited scope under which these systems are used. Most of the centre pivot irrigation systems in Khartoum State are used for production of alfalfa for export and Abu 70 *Sorghum bicolor* fodder crops. The systems are expensive and require electrical energy to operate. The systems are normally operated all the year around and stopped only when there is rainfall or breakdown. Low crop productivity in addition to high production costs, low prices and high taxes had all resulted in a general deterioration of the agricultural sector are represent the major problems facing agricultural production (Bush *et. al.,* 2017) . This has contributed in converting agriculture from an attractive business to a repellent activity and caused many farmers to abandon agriculture and migrate to cities (Ministry of Finance and National Economy, 1996).

Therefore, the objective of this study was adopted to assess the hydraulic performance and the economic evaluation of centre pivot system for producing fodder crops (alfalfa (*Medicago sativa*) and Abu 70 (*Sorghum bicolor*)) comparing to conventional system under similar conditions.

METHODOLOGY

The experimental work was carried out at the Farm of Arab Company for Agricultural Production and Processing, Umdom Project located at the eastern bank of the Blue Nile 35 km east of Khartoum during the period of March to June 2003 in an area of 3500 feddans. Crops grown were alfalfa *Medicago sativa* and Abu 70 *Sorghum bicolor*. Two different speeds (75% and 40%) were used for centre pivot system. Wind speed and direction, humidity, temperature were recorded at nearby meteorological station.

Experimental design and data analysis

Seven centre pivot sprinkler system running at two different speeds (75% and 40%) were randomly selected and adopted to assess the hydraulic performance and the economic evaluation of the system. These treatments were arranged in randomized complete block design (RCBD) with four replications. SAS statistical package was used to analyze the data. The variations among means were checked by the least significant difference (LSD).

Specification of the centre pivot irrigation system

The main feature of the centre pivot sprinkler irrigation system consists of:

a. Power source and pumping plant

Volvo penta internal combustion engine (150 hp) is used to drive the pump to supply water from a canal to the system and at the same time the engine is used to drive an electrical generator (150 kw) to provide the system with electrical power required for it is movement.

b. Pivot point

It is a quadruped chain concrete foundation. A pipe line 200 mm in diameter rises vertically upwards from ground level where it is connected to a rotating elbow shaped fitted.

c. Drive unit (towers)

It consists of a beam on which a drive motor and two wheels are mounted. At the top of each tower there is an electrical pox through which the electrical power is transformed to the drive motor. The wheels are operated by the drive motor via a connecting rod and a gearbox.

d. Pipe line

A pipe line is suspended above the ground by the drive unit. The water is conveyed from the pivot through the pipe across the field till it is edges. The centre pivot on which the study was implemented consists of nine span. The first five towers are of 49 m length and 21.91 cm in diameter and the last four towers each has a pipe of 54.86 cm in diameter.

e. Sprinkler system

It consists of 154 sprinklers connected at the top of the pipe line. The distance between any two adjacent sprinklers is not constant. At the end of each span one direction nozzle is installed to avoid wheels getting stuck into the wet soil.

f. Fertilizer applicator

It consists of fiber glass tank. Chemical fertilizer such as urea can be dissolved in water. Solution can be discharged with irrigation water through the pipe line by an injector pump.

g. Control panel

The main advantage of this unit is that it can be fully automated and controlled from a panel near the pivot or remotely from an office. Time locks are used to start and stop the machine and many safety devices are used for protection.

System performance

The application efficiency, uniformity coefficient and pattern efficiency were calculated using spray catch cans as described by Michael (1978). Eighty cans were placed at equal distances along the pivot point outwards. The centre pivot was allowed to pass over the cans for three runs, at each run measurements were recorded. Volumetric measurements were converted into depth in millimeters.

The application efficiency (Ea%)

The application efficiency 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 as follows:

$$Ea\% = \frac{Dc}{Ds} \times 100 \quad \text{.................} (1)$$

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 uniformity coefficient (Cu%)

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). One of the first criteria defined to express uniformity was the coefficient of uniformity (Cu) as defined by Christiansen (1942). Christiansen's coefficient of uniformity (Cu) is the most widely used and accepted criterion used to define uniformity. The coefficient is computed from field observations of the depths of water caught in open cans placed at regular distances within a sprinkled area (assuming that the catch cans represent the same area) as follows:

$$Cu = (1 - \frac{\sum x}{mn}) \, 100 \quad \text{.............} (2)$$

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

Distribution uniformity (Du%)

The distribution uniformity was determined using the following equation as stated by Zoldoske and Solomon (1988) who mentioned that:

$$Du\% = 100 \left[\frac{\text{qn}}{\text{qave}}\right] \quad \text{....................} (3)$$

Where:
Du%= distribution uniformity.
qn= average rate of discharge of the lowest one fourth of the field data of nozzle discharge (l/h).
qave= average discharge rate of all the nozzle checked in the field(l/h).

Scheduling uniformity (Su)

The scheduling uniformity is calculated according to the following equation mentioned by Michael (1978):

$$Su = \frac{1}{Du} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where:
Su = Scheduling uniformity.
Du = Distribution uniformity (as decimal).

Nozzle discharge

A stop watch, calibrated containers and rubber hoses were used. Volumetric measurements of water discharge were made by connecting the hoses to the nozzles and water was directed into the containers. The stop watch was used to record the time.

Nozzle wetted diameter

Wetted diameters of 25 nozzles along the lateral were recorded using a measuring tape. Data was tabulated against nozzle location along the lateral.

Percentage of actual irrigated area

The area lost by wheels tracks was calculated as follows: Span length covered by the first tower from the pivot point to the outer edge of the first wheel was determined using a measuring tape, and then the area of this circle was determined. The inner length from the inner edge of the first wheel was measured, and then the area of this circle was determined. Subtracting the results obtained in the above step, the lost area of the first tower was determined. Repeating the same procedure, the lost area of the remaining 7 towers was calculated. The total area lost by wheels tracks was added to the area lost by road. The percentage of lost area was calculated by dividing the total lost area by the total irrigated area, then, the actual irrigated area was found.

Percentage water loss

Water loss from the system was calculated by subtracting the average depth of water reaching the ground as determined in catch cans from the average depth of application as monitored by the system flow meter.

Average depth of application

$$= \frac{Volume\ of\ water\ applied\ m3}{Irrigated\ area\ m2} \quad \ldots\ldots\ldots\ldots (5)$$

Water loss = Average depth of application – Average depth in catch cans

Percentage of water loss (%)

$$= \frac{Water\ loss}{Average\ depth\ of\ application} \times 100 \ \ldots\ldots (6)$$

Economic evaluation of centre pivot sprinkler system

The calculations included the determination of total costs (fixed (annual ownership) costs and variable (operation) costs) for using 7 centre pivots with 9 spans each of three years as follows:

Fixed cost

Fixed costs included the determination of the following items:

a. Depreciation

Depreciation was determined by the straight line method (15 year) using the following equation as stated by Dahab (2001):

$$D = \frac{Pu-Sa}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where:
D = Annual depreciation of the system.
Pu = Purchase price of the system.
Sa = Salvage value of the system.
L = Machine life (years).
Interest on investment
It was determined by the equation mentioned by Dahab (2001) as follow:

$$I = \frac{Pu+Sa \times R}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where:
I = Annual interest on investment.
Pu = Purchase price of the system.
Sa = Salvage value of the system.
R = Net interest rate (%) estimated as 15% as suggested by the Sudan Agricultural Bank.

b. Insurance

It was determined as (0.5%) of the purchase price of the system as suggested by the Sudan Agricultural Bank.

c. Taxes

Taxes cost was determined as (0.5%) of the purchase price of the system as suggested by Dahab (2001).

Table 1: Hydraulic performance of centre pivot irrigation system

Treatment	Hydraulic performance			
	Cu%	**Du%**	**Su**	**Ea%**
Centre pivot system running at 75%	71^{b}	56^{a}	1.8^{a}	65^{b}
Centre pivot system running at 40%	78^{a}	61^{a}	1.6^{a}	73^{a}
Conventional furrow system	54^{c}	52^{a}	1.90^{a}	47^{c}
LSD	5.7	6.3	0.33	6.4

Means followed by the same latter (s) in the same column are not significantly different at P ≤ 0.05

Variable (operation) costs

Variable costs included the determination of fuel, oil, labor, repair and maintenance and production (irrigation, land preparation, seeds etc) costs for determination the cost of production current market price were used.

Total cost = Fixed cost + variable cost ……….. (9)
Net profit = Total income – total cost …………. (10)
Hence, profit/feddans/year

$$= \frac{Total\ profit}{Number\ of\ pivots \times area \times number\ of\ years} \quad ..... (11)$$

RESULTS AND DISCUSSION

As presented in Table 1 uniformity coefficient (Cu%), distribution uniformity (Du%), scheduling uniformity (Su) and application efficiency (Ea%) significantly (P ≤ 0.05) affected by the two irrigation systems. Centre pivot irrigation system running speed at 40% gave the higher mean values of technical performance compared to conventional furrow irrigation system. But on the other hand there were some factors related to the systems should be considered to maximize the technical performance such as uncompleted maintenance and replacement of nozzles due to partial clogging of sprinkler packages caused by sedimentation, trashes and/or nozzle being worn out, operating pressure and inaccurate setup of the system and the overall management aspects of the irrigation system were not proper done. These results were in agreement with the results obtained by Salah (2013) and supported by (Shideed *et al*., 2005) who reported that, the superiority of centre pivot system over conventional system may be attributed to the fact that, centre pivot irrigation system should be uniformly applied water at the right time to maximize forage or pasture yield and quality.

As shown in Figure 1 the quantity of water needed by alfalfa is higher than that needed by Abu 70, this variation in water requirement is referring to that alfalfa needs seven to nine irrigation episodes whereas the Abu 70 needs five to sex ones, also the variation referring to soil condition, length of vegetative growth and climatic factors. This result may be attributed to the fact that centre pivot system is enable to apply water with high efficiency with very low in water loss and that is conversely in case of conventional surface irrigation method where water 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 as mentioned by Mohamed et. al., (2016). The results agreed with the result obtained by Connellan (2002) who revealed that to avoid undesirable levels of crop stress, scheduling uniformity of the irrigation system should be aim to achieve a Su of less than 1.3.

Economic evaluation of centre pivot irrigation system significantly affected by the different management practices. Table 2 showed the profit $/fed/year of producing alfalfa using 7 centre pivot irrigation system with 9 spans each for three years. The results revealed that the centre pivot system has been economically evaluated for producing alfalfa and Abu 70 and has given a remarkable profit margin as compared to the conventional surface irrigation system under similar conditions.

The superiority of centre pivot system over conventional irrigation system may be attributed to the fact that, centre pivot irrigation system irrigation system has high potentiality in managing water application and it can minimize water losses mainly due to runoff as compared to what occurs in surface irrigation system which about 40% and at end significantly affected the crop yield as mentioned by (Ismail and Al-Marshadi, 2013) and (Basheer *et. al.,* 2015).

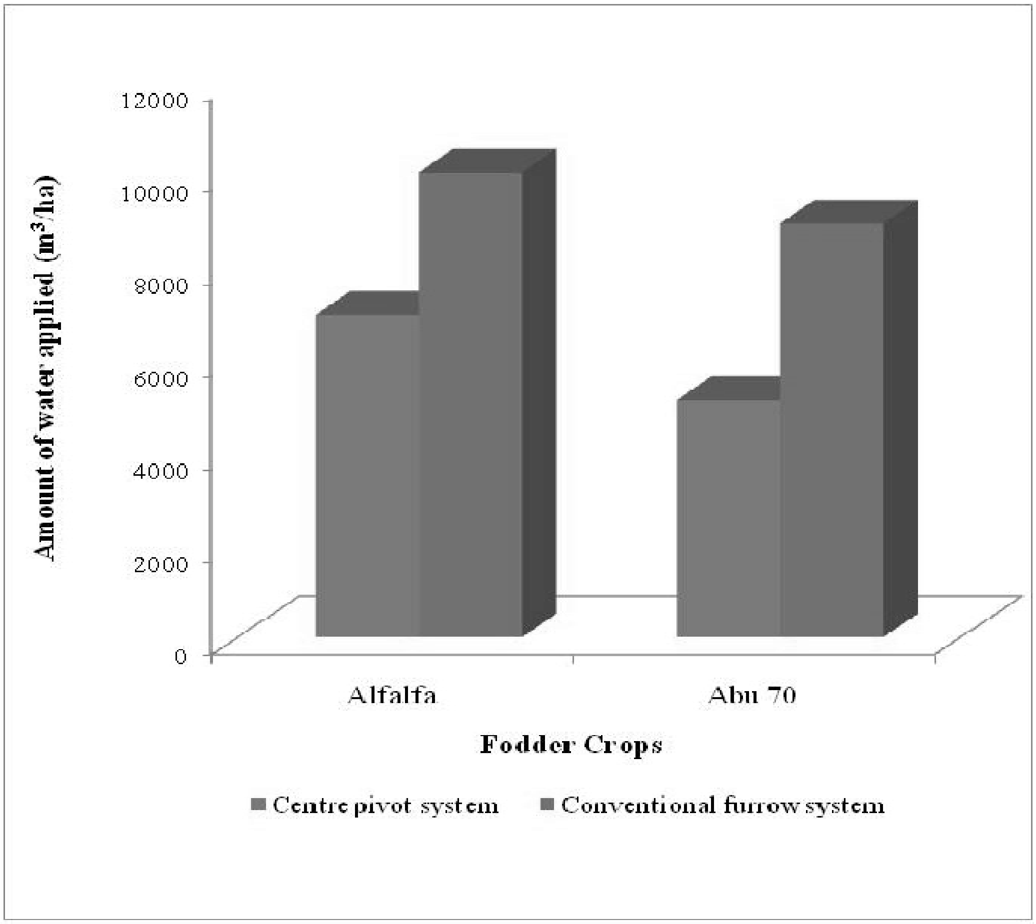

Figure 1: The quantity of water applied by the different irrigation systems

Table 2: The profit $/fed/year for producing fodder crops under two irrigation systems

Treatment	Alfalfa profit $/fed/year	Abu 70 profit $/fed/year
Centre pivot system	714.9 [a]	668.1 [a]
Conventional system	195.1 [b]	560.2 [b]
LSD	13.7	17.1

Means followed by the same latter (s) in the same column are not significantly different at $P \leq 0.05$

CONCLUSION

Regular monitoring evaluation of the irrigation system is a necessity to ensure appropriate water application and uniformity. The total cost of production for centre pivot system is very feasible compared to surface method under Sudan conditions particularly where the soil is not heavy cracking clays. Centre pivot system gave a remarkable profit margin of fodder crops as compared to the conventional surface irrigation system under similar conditions.

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