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Financial viability of centre pivot sprinkler irrigation systems in a semi-arid climate

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Abstract: This study was carried out to evaluate the financial performance of centre pivot sprinkler irrigation systems in a semi-arid region. The analysis focused on financial performance indicators, including internal rates of return, benefit-cost ratio, and total yearly benefits. Specifically, the goal was to select the most appropriate irrigation system and determine the optimal crop productivity under semi-arid conditions. Field surveys were conducted during the 2022/2023 and 2023/2024 harvest seasons across two sites. The fieldwork focuses on two types of irrigation systems, namely: Almutawar and Zimmatic central pivots. The internal rates of return for Almutawar and Zimmatic systems corresponded to two harvesting seasons: for the 2022/2023 season, 12.9% and 11.7%; for the 2023/2024 season, it was 11.6% and 11.5%. The benefit-cost ratio: for the 2022/2023 season it was 1.13% and 1.12%; for the 2023/2024 season it was 1.13% and 1.12%. The total annual benefit: in the season of 2022/2023 was USD159,081.47 and USD158,888.20; in the 2023/2024 were USD158,845.39 and USD159,116.69, respectively. The results obtained from this study showed that the assessment of the financial performance of these two central pivot systems was viable and cost-effective. Moreover, the Zimmatic system outperformed the Almutawar system. These financial performance ratings can help agricultural investors make informed decisions.

Keywords: annual benefit, annual cost, alfalfa productivity, irrigation system, internal rate of return

INTRODUCTION

Sudan occupies a region located in the middle part of the Nile basin in southern Egypt, and lies within the Sudano-Sahel region in Northeast Africa, with geographic coordinates: between latitudes 4–22° N and longitudes 22–38° E (Bechtold, 2015). Following the secession of South Sudan in 2011, the total area was reduced from 2,500,000 km^2 to 1,882,000 km^2. The country is crossed by the Blue Nile and White Nile rivers, which converge in the capital city, Khartoum, to form the main river Nile which flows north into the Mediterranean Sea. Agriculture is the main source of income and livelihood for 60–80% of Sudan's population and serves as the engine of growth for other economic sectors such as trade, industry, and transport (World Bank, 2020). While Sudan's water resources mainly come from rainfall, seasonal streams, and groundwater, the Nile River and its tributaries are the most significant, supporting over 5 mln people in areas with reliable agriculture development and sufficient water availability. The northern part receives less than 300 mm of rain per year, mainly from the Nile River. Agriculture contributes 60%

of Sudan's total manufacturing output in the form of raw materials and accounts for 80% of non-petroleum exports (Melesse and Demissie, 2024).

Irrigation methods in Sudan 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 (World Bank, no date). The centre pivot irrigation system is an example of an efficient sprinkler irrigation system, with efficiency rates from around 60 to over 90%. The improvement is primarily attributed to better water application methods and a reduction of evaporation losses, rather than reduced electricity consumption. According to Song *et al.* (2019) and Wassie *et al.* (2019), alfalfa (*Medicago sativa* L.) grows in climates where daily temperatures exceed 50°C during the growing season. However, the optimal growth temperature is 25°C, with a significant decline in growth when temperatures rise above 30°C and fall below 10°C (Al-Hamdani and Todd, 1990). In hot climates, irrigation systems have proven to be more efficient than wetting methods. Alfalfa is a perennial crop, and its growing season varies depending on the climate. After planting seeds, the plant takes around three months to establish itself.

In Sudan, the number of alfalfa cuttings per growing season fluctuates depending on the weather, typically ranging from 9 to 12. Furthermore, yields obtained per unit area fluctuate during the year, influenced by seasonal climatic variations. Alfalfa is regarded as a sustainable crop due to its ability to fix organic matter (nitrogen) in the atmosphere, thereby reducing the need for synthetic nitrogen fertilisers (Elgharably and Benes, 2021). Most of the irrigation systems in Sudan are used to produce alfalfa for export. The growing development of modern irrigation systems, especially pivot irrigation systems, requires knowledge of their proper use during operation. Moreover, understanding water distribution characteristics within the system and the irrigation area is very important to minimise maintenance costs. Mohamed (2010) highlighted the significant advancements in Sudan's centralised irrigation infrastructure over the past two decades, which has evolved into a modern and automated system. By 2010, the country had established 20,028 pivot centres, primarily dedicated to agricultural irrigation. The growing demand for water resources in Sudan underscores the critical need to enhance and efficiently manage irrigation systems (Anjela, 2008). To address the rising energy costs associated with water pumping, both researchers and farmers are encouraged to assess the financial performance of various irrigation systems. The design and management of irrigation systems should focus on several key objectives, including efficient water utilisation, improved agricultural productivity, and increased income during harvest seasons. A vital component of irrigation system planning involves calculating the annual ownership and operating costs for alternative designs. These costs consist of variable costs, which fluctuate with production levels, and fixed costs, which remain constant regardless of production output.

The most effective management of agricultural systems is closely linked to the financial performance across the entire machinery system. A successful farm operation views machinery not as a fixed asset but simple means of production that are employed commercially to create profitable crop production. The financial performance of an agricultural system is expressed in terms of monetary value per unit of produce (cost per hectare). This study examined two types of pivot systems: Almutawar from Saudi Arabia, with a 15-year useful life, and Zimmatic from the United States, with a 20-year lifespan. This assessment was conducted five years after installation to ensure accurate mid-life financial performance evaluation of central sprinkler irrigation systems. The study used the following key financial performance indicators: internal rate of return, cost-benefit ratio, and total annual profit to identify the best irrigation method and determine crop productivity under such conditions.

MATERIAL AND METHODS

THE STUDY AREA

Field surveys were conducted during the 2022/2023 and 2023/2024 harvest seasons in two agricultural sites within the West Omdurman Alfalfa Production Agricultural Project in Sudan. The project is located about 120 km from the district of Omdurman, on the west bank of the Nile River, at geographic coordinates 32°15'–32°20' E longitude and 15°27'–15°33' N latitude, at an elevation of 380 m above mean sea level. The total area of the project is about 2,000 ha, with each centre pivot rotation system covering an area of 38.5 ha. The sole crop grown in the project during the study period was alfalfa. The irrigation water was sourced from the groundwater table, with a central rotary system drawing water from wells using submersible pumps. Furthermore, during these two seasons, the first farm was irrigated using the Almutawar pivot system, while the second farm was irrigated with the Zimmatic pivot system.

MATERIALS

The engineering specifications of the centre pivot irrigation systems for the two irrigated farms are summarised in Table 1. Both systems consisted of seven spans. Electricity required for operation was supplied by a gasoline generator.

The two types of pivot systems used in this study were the Almutawar system and the Zimmatic system. Moreover, the following materials were used:

- a meter of 30-meters and a small ruler – to measure plots of one square meters;
- plastic ropes: used to connect the target plot of one square meter;
- the scythe: used to cut the alfalfa within the plots of one square meter;
- a sensitive scale: used to measure the dry weight of alfalfa collected from each plot;
- scientific calculator, pen and score sheet – used for recording weights.

DATA COLLECTION

The experiments were conducted using two pivot irrigation systems within two harvesting seasons. After randomly selecting plots of 1 m^2 (100 cm × 100 cm), the productivity of alfalfa per one square meter was assessed. The alfalfa was harvested and exposed to sunlight for drying for five days. After drying, the biomass was weighed.

Table 1. Specifications of two centre pivot irrigation systems

System discharge ($dm^3 \cdot s^{-1}$)	Sprinklers numbers	System pressure (MPa)	Distance between sprinklers (m)	Sprinkler discharge ($dm^3 \cdot s^{-1}$)	System length (m)	Type of sprinklers
1st farm: Almutawar centre pivot system						
44.3	144	0.2	2.9	0.5	350	Nelson R3000
2nd farm: Zimmatic centre pivot system						
45.5	108	0.2	3.0	0.6	336	Nelson R3000

Explanation: R = rotator.
Source: own study.

ESTIMATION OF THE COSTS OF IRRIGATION SYSTEMS

Determining the annual ownership and operating costs of potential irrigation system alternatives is an important part of irrigation system design (Dahab, 2000; Marwa, 2015). Total costs consist of two main categories, which vary according to such factors as raw materials, and fixed costs, which are independent of the quantity produced, e.g. the cost of assets. The total cost and benefit can be calculated following Marwa (2015):

$$TCs = TFCs + TVCs \tag{1}$$

$$TBs = TIs - TCs \tag{2}$$

where: *TCs* = total costs, *TFCs* = total fixed costs, *TVCs* = total variable costs, *TBs* = total benefits, and *TIs* = total incomes.

TOTAL FIXED COSTS

Total fixed costs are associated with the ownership of fixed inputs and are incurred regardless of whether the input is actively used. These costs typically include equipment and land depreciation, water access fees, insurance, taxes and interest, and in some instances repairs and maintenance. Fixed costs remain unchanged in the short term, even as production levels fluctuate. However, in the long term, they may vary when the scale or quantity of fixed inputs changes. By definition, fixed costs are relevant only in the short run and are considered zero in the long run (Mohamed *et al.*, 2017). Therefore, fixed costs reflect a long-term commitment, which can only be recovered through the use of fixed assets in the production of goods and services for sale. The calculation of fixed costs includes determining components listed below.

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

$$D = \frac{Pu\ -\ Sa}{L} \tag{3}$$

where: *D* = annual depreciation of the system, *Pu* = purchasing price of the system, *Sa* = salvage value of the system (10% of purchase price of the system), and *L* = machine life-span (years) (Dahab, 2000).

B. Interest on investment: it was determined by the equation suggested by Dahab (2001) as follows:

$$I = \frac{Pu\ +\ Sa\ \cdot\ R}{2} \tag{4}$$

where: *I* = annual interest on investment, *R* = net interest rate (%) estimated as 15% as suggested by the CBOS (2008).

C. Insurance: the insurance was determined as 0.5% of the purchasing price of the system as suggested by the CBOS (2008).

D. Taxes: taxes cost was determined as 0.5% of the purchasing price of the system as suggested by Dahab (2001).

TOTAL VARIABLE COSTS

Total variable costs, or total operating costs, are expenses over which the manager has direct control, or in other words, costs that can fluctuate in response to changing production conditions. The total variable costs were determined by summing individual variable costs, each equal to the amount of input purchased multiplied by its unit price. These costs include energy costs, maintenance and repair costs, and labour costs (Mohamed *et al.*, 2017). Additionally, the cost of professional services, such as irrigation and fertiliser scheduling advice, should also be included. As reported by Dahab (2001), variable costs include expenditures on fuel, oil, labour, repair and maintenance, as well as production inputs, including irrigation, land preparation, and seeds.

INTERNAL RATE OF RETURN (*IRR*)

The internal rate of return is the discount rate or opportunity cost of capital that equals the net present value (*NPV*) to zero. The *IRR* is the rate of return that the company expects to receive and is expressed as a percentage (Adusumilli, Davis and Fromme, 2016). The *IRR* was calculated acc. to Equation (5):

$$IRR(\%) = \frac{Bs\ -\ Cs}{Cs} 100 \tag{5}$$

where: *Bs* = benefits and *Cs* = costs.

BENEFIT-COST RATIO (*BCR*)

The rule of thumb is to accept the project with a *BCR* greater than 1 (Adusumilli, Davis and Fromme, 2016), and it's calculated acc. to Equation (6):

$$BCR(\%) = \frac{Bs}{Cs} 100 \tag{6}$$

RESULTS AND DISCUSSIONS

ALFALFA PRODUCTIVITY

The average alfalfa productivity across two centre pivot irrigation systems over two growing seasons was as follows: in the 2022/2023 season, yields reached 2,599 and 2,610 $kg \cdot ha^{-1}$ for the

Almutawar and Zimmatic systems, respectively. In the 2023/2024 season, the yield was 2,600 and 2615 kg·ha^{-1} for the Almutawar and Zimmatic systems, respectively. The yields were notably higher than those reported by Elkamel (2015) under similar conditions in the north, Loung (2016) in the western Omdurman in Sudan, by Ahmed and Elagabani (2017) in the New Hamdab programme in the Northern State of Sudan, and by Osman (2004) in the Nile State of Sudan. The productivity was lower than that obtained by Saeed and Ebeidalla (2015) at the University of Khartoum, Sudan. Water deficiency at any stage of crop growth can reduce yield, affecting both crop quantity and quality. Insufficient irrigation may lead to early maturity in a few days after harvest or excessive ripening under suboptimal conditions (Imrak *et al.*, 2007). In both seasons, the alfalfa yield under the Zimmatic system was higher than that of the Almutawar system. This difference is due to the proper installation and more efficient water distribution of the Zimmatic system.

TOTAL ANNUAL INCOME OF THE CENTRE PIVOT SYSTEMS

The total annual income in the 2022/2023 season was USD299,913.12 and USD301,180.96 for Almutawar and Zimmatic systems, respectively (Tab. 2). For the 2023/2024 season, it was USD300,027.04 and USD301,759.44 for Almutawar and Zimmatic system, respectively. The total income for the 2023/2024 season under the Zimmatic system decreased compared to the 2022/2023 season, which might have been due to the lack of repair and maintenance of the system.

Table 2. The total annual income of the centre pivot irrigation systems in the 2022/2023 and 2023/2024 seasons

Item	Income (USD) of	
	Almutawar system	Zimmatic system
2022/2023 season		
The income in one hectare	974.63	978.75
The income in one harvest	37,489.14	37,647.62
The total annual income	299,913.12	301,180.96
2023/2024 season		
The income in one hectare	975.00	980.63
The income in one harvest	37,503.38	37,719.93
The total annual income	300,027.04	301,759.44

Source: own study.

FIXED COSTS OF THE CENTRE PIVOT SYSTEMS

The total annual fixed costs were USD 96,189.20 and USD 97,650.30 for Almutawar and Zimmatic systems, respectively (Tab. 3). These values remained constant for the two growing seasons. The investment interest rate was calculated at 15% as suggested by the Central Bank of Sudan. Taxes and insurance were set at 0.5% of the purchasing price of the system, as suggested by the CBOS (2008) and Dahab (2001). Overall, the Zimmatic system incurred higher fixed costs compared to the Almutawar system.

Table 3. Total fixed costs of pivot systems in two growing seasons (2022/2023 and 2023/2024)

Item	Cost in			
	Almutawar system		Zimmatic system	
	USD	USD·ha^{-1}	USD	USD·ha^{-1}
Depreciation	7,695.14	200.06	7,812.03	203.17
Insurance	855.02	22.23	868.01	22.57
Taxes	855.02	22.23	868.01	22.57
Interest	86,784.02	2,256.18	88,102.25	2,290.45
Total annual fixed cost	96,189.20	2,500.70	97,650.30	2,538.68

Source: own study.

VARIABLE COSTS OF THE CENTRE PIVOT SYSTEMS

The total variable costs were USD44,642.45 and USD44,992.45 for Almutawar and Zimmatic systems under 2022/2023 and 2023/2024 seasons, respectively (Tab. 4). Total variable costs in both systems increased by USD350.00 compared to the 2022/2023 season.

The total annual costs of the two centre pivot systems over two growing seasons are presented in Table 5. For the 2022/2023 season, the total annual cost was USD140,831.65 and USD 142,292.75 for Almutawar and Zimmatic systems, respectively. For the 2023/2024 season, it was USD141,181.65 and USD 142,642.75 for Almutawar and Zimmatic systems, respectively.

Table 4. Total variable costs of the centre pivot irrigation systems in the 2022/2023 and 2023/2024 seasons

Item	Cost in			
	Almutawar system		Zimmatic system	
	USD	USD·ha^{-1}	USD	USD·ha^{-1}
2022/2023 season				
Water	13,331.58	346.59	13,331.58	346.59
Power	28,883.37	750.90	28,883.37	750.90
Repair and maintenance	477.50	12.41	477.50	12.41
Fertilisers and chemical	500.00	13.00	500.00	13.00
Labours	700.00	18.20	700.00	18.20
Land preparation	750.00	19.50	750.50	19.50
Total annual variable cost	44,642.45	1,160.60	44,642.45	1,160.60
2023/2024 season				
Water	13,331.58	346.59	13,331.58	346.59
Power	28,883.37	750.90	28,883.37	750.90
Repair and maintenance	477.50	12.41	477.50	12.41
Fertilisers and chemical	500.00	13.00	500.00	13.00
Labours	1,000.00	26.00	1,000.00	26.00
Land preparation	800.00	20.80	800.00	20.80
Total annual variable cost	44,992.45	1,169.70	44,992.45	1,169.70

Source: own study.

Table 5. Total annual costs of the centre pivot irrigation systems in the 2022/2023 and 2023/2024 seasons

Item	Cost in			
	Almutawar system		Zimmatic system	
	USD	USD·ha^{-1}	USD	USD·ha^{-1}
2022/2023 season				
Total fixed cost	96,189.20	2,500.70	97,650.30	2,538.68
Total variable cost	44,642.45	1,160.60	44,642.45	1,160.60
Total annual cost	140,831.65	3,661.30	142,292.75	3,699.28
2023/2024 season				
Total fixed cost	96,189.20	2,500.70	97,650.30	2,538.68
Total variable cost	44,992.45	1,169.70	44,992.45	1,169.70
Total annual cost	141,181.65	3,670.40	142,642.75	3,708.38

Source: own study.

TOTAL ANNUAL BENEFITS OF THE CENTRE PIVOT IRRIGATION SYSTEMS

The internal rate of return for the 2022/2023 season was 12.9 and 11.7% for Almutawar and Zimmatic systems, respectively. For the 2023/2024 season, it was 11.6 and 11.5% for Almutawar and Zimmatic systems, respectively. Across both seasons, the benefit–cost ratio was 1.13 and 1.12% for Almutawar and Zimmatic systems, respectively. The total benefit was USD159,081.47 and USD158,888.20 for Almutawar and Zimmatic systems for 2022/2023 season, respectively. For the 2023/2024 season, it was USD158,845.39 and USD159,116.69 for Almutawar and Zimmatic systems, respectively (Tab. 6). As suggested by Adusumilli, Davis, and Fromme (2016), the general rule is to accept a project with a *BCR* greater than 1. In both seasons, the total benefit of the Zimmatic system was greater than that of the Almutawar system. The results indicate that both systems demonstrated efficient and cost-effective financial performance.

Table 6. Total annual benefits of the centre pivot irrigation systems in the 2022/2023 and 2023/2024 seasons

Item	Centre pivot sprinkler irrigation system			
	Almutawar system		Zimmatic system	
	benefit	benefit per hectare	benefit	benefit per hectare
2022/2023 season				
Internal rate of return (%)	12.9	0.34	11.7	0.30
Benefit-cost ratio (%)	1.13	0.03	1.12	0.03
Total annual benefit (USD)	159,081.47	4,135.75	158,888.20	4,130.72
2023/2024 season				
Internal rate of return (%)	11.6	0.30	11.5	0.30
Benefit cost ratio (%)	1.13	0.03	1.12	0.03
Total annual benefit (USD)	158,845.39	4,129.61	159,116.69	4,136.66

Source: own study.

CONCLUSIONS

This study evaluated the financial performance of the centre pivot irrigation systems, focusing on their efficiency and potential for improving agricultural productivity. Based on the analysis, the following conclusions are drawn, which highlight the key findings and offer recommendations to optimise the operation of the two centre pivot irrigation systems and enhance alfalfa productivity. The internal rates of return in the 2022/2023 season were 12.9 and 11.7%; in the 2023/2024 season, they were 11.6 and 11.5%. The benefit-cost ratios for the 2022/2023 season were 1.13 and 1.12%; for the 2023/2024 season they were 1.13% and 1.12%. The total annual benefit indices in the season of 2022/2023 were USD159,081.47 and USD158,888.20, whereas in the 2023/2024 season they were USD158,845.39 and USD159,116.69. The financial performance values confirm that these two central pivot systems were financially viable and cost effective. However, the performance of the Zimmatic system was better as its annual rate of return was high compared to the Almutawar system. These financial performance ratings provide good guidance for investors in agricultural production.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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