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# Predictive models for repair and maintenance costs of ten agricultural implements in the Gezira scheme, Sudan

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## ABSTRACT

*This study aimed to develop predictive models for estimating repair and maintenance costs of agricultural implements in Sudan's Gezira Scheme. Data was collected from 154 machinery owners. Ten types of agricultural implements categorized into primary tillage (disk plow, chisel plow, moldboard plow), secondary tillage (disk harrow, scraper, ridger, ditcher), and other operations (seed drill, sprayer, thresher) were analyzed. Moreover, five regression models were tested (exponential, linear, logarithmic, polynomial, and power). The power model was found to be the most accurate for predicting repair and maintenance costs, with $R^2$ values ranging from 0.90 to 0.99 and a highly significant correlation (F-value range: 0.001 to 0.01) between annual working hours (independent variable) and repair and maintenance costs (dependent variable) across the ten implements. Repair and maintenance costs generally increase with higher annual working hours, but variations existed depending on implement type, purchase price, and design, indicating each implement has its own specific power model to predict the costs. In conclusion, this study bridges a critical knowledge gap and supports more efficient agricultural machinery use and management in the Gezira Scheme. Studies are suggested to address this topic under other regions and operational practices.*

**Keywords:** *Implements, power prediction models, annual working hours, purchase price, individual private farmers, Gezira scheme, Sudan.*

## Introduction

Improving agricultural productivity remains a significant challenge for developing countries [1]. One key factor in addressing this challenge is the effective use of agricultural machinery, which enhances productivity through timely and efficient farm operations. However, owning and operating machinery requires specialized knowledge, including an understanding of performance, operating schedules, annual usage, and cost calculations.

Among machinery costs, repair and maintenance expenses stand out due to their tendency to increase with equipment age and usage, primarily driven by wear and tear [2]. These costs encompass expenditures on spare parts, labor for replacements, and reconditioning worn components, as well as maintenance essentials like greases and lubricants. These costs represent a substantial portion of the total expenses associated with owning and operating farm machinery. They influence decisions about the optimal time for equipment replacement [3]. Moreover, repair and maintenance costs vary across regions, influenced by factors such as soil type, weather, crop varieties, and operator skills, in addition to machine value [4]. Accurate tracking of these expenses is crucial for effective cost estimation and management. Additionally, reliable cost data are often unavailable, prompting researchers to develop mathematical models to predict repair and maintenance expenses. Among these models, the power model is widely used [5; 6; 7; 8; 9; 2]. However, some studies suggest the use of a polynomial model [10; 11]. On the other hand, researchers caution against directly applying models developed in industrialized countries to developing regions, as this can lead to inaccurate estimates [12].

In Sudan's Gezira irrigated agricultural scheme, a variety of implements powered by 70 to 80 hp two-wheel-drive tractors are used for farm operations. In the past, the public sector and/or private companies predominantly owned these tractors and implements. However, nowadays, many farmers own and manage their machinery, introducing diverse management practices. Despite the widespread use of these implements, there is insufficient information on their repair and maintenance costs.

This study aims to develop mathematical models to predict the repair and maintenance costs of ten types of implements used in the Gezira scheme. It also seeks to analyze how variations in annual working hours affect per-hour repair and maintenance costs and to evaluate the accuracy of the models by comparing predictions with actual data.

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## Materials and Methods

### *Study Area*

The present study was conducted in the Gezira irrigated Scheme, Sudan. The scheme is located in a semi-arid region, covering an area of 2.2 million feddans (one feddan = 0.42 ha). This area is characterized by Vertisol soils and an extensive irrigation network [13], which supports diverse crop cultivation across summer and winter seasons. Farmers follow a five-course crop rotation system.

Some individual farmers own tractors and implements. Tractors and implements are intensively used for land preparation [14]. The majority of the associated implements are mounted on the three-point hitch.

### Data Collection

A questionnaire was designed and distributed to 154 machinery owners. The collected data included implement types, purchase prices, annual repair and maintenance costs, in addition to work rates, and annual area covered. The study focused on ten implements, categorized into primary tillage (disk plow, chisel plow, moldboard plow), secondary tillage (disk harrow, scraper, ridger, ditcher), and others (seed drill, sprayer, thresher). A detailed description and utilization of these implements are presented in Table 1. Implement annual working hours were calculated by using the following procedures [15].

$AWH = AA \div WR$……………………………………..(1)

Where:

AWH = Annual working hours (h/year)

AA = Annual covered area (fed/year)

WR = work rate (fed/h)

### Models development

Data on the implements' purchase price, annual working hours, and repair and maintenance expenses were organized into separate Excel worksheets for each implement. Five regression models, namely exponential, linear, logarithmic, polynomial, and power, were selected to establish the relationship between annual working hours (independent variable) and annual repair and maintenance costs as a percentage of the purchase price (dependent variable). The data used to develop these models were presented in Table 2. For each model, the parameters (a, b, and c), coefficient of determination ($R^2$), F-value, and significance level were calculated.

*Table 1. Description and utilization of the studied implements*

| Implement | Description | Utilization |
|---|---|---|
| Disk plow | 3 - bottoms, rear mounted, 0.8 to 1.0 m width | Primary tillage |
| Chisel plow | 5 to 7 shanks, rear mounted, | Primary tillage |
| Moldboard plow | 4-units, rear mounted | Primary tillage |
| Disk harrow | 18 disks arranged in 2 gangs, rear mounted | Secondary tillage |
| Scraper | One unit, rear mounted, 1.5 m | Land leveling |
| Ridger | 4-units, rear mounted, 3.2 m width. | making ridges and furrows at 0.8 m. apart |
| Ditcher | Single unit, rear mounted, 1 m width | Constructing Abu VI, a water channel in a farm |
| Seed drill | Rear mounted or towed, 2.5 to 3.5 m width, with or without fertilizer box | Broadcasting and covering wheat seeds on flat beds. |
| Sprayer | Rear mounted, 400 to 600 liters capacity, 10 to 14 m width | Herbicides application |
| Thresher | Rear towed on two wheels, different sieves size | Threshing grain crops |

The regression models developed for each implement were as follows [6; 16].

Exponential function, $Y = b\,e^{ax}$…………………………………….. (2)

Linear function, $Y = ax + b$ ………………………………………….. (3)

Logarithmic function, $Y = a\ln(x) + b$ …………………………….(4)

Polynomial function, $Y = ax^2 + cx + b$ ……………………………. (5)

Power function, $Y = a X^b$…………………………………………….(6)

Where:

Y = annual repair and maintenance cost as percentage of purchase price

X = annual hour of use

a, b and c = model parameters (coefficients)

*Table 2. Data about the studied implements*

| Implement | Range of annual working hours | Number of implements |
|---|---|---|
| Disk plow | 40 to 750 | 11 |
| chisel plow | 33 to 300 | 6 |
| Moldboard plow | 120 to 300 | 6 |
| Disk harrow | 33 to 133 | 5 |
| Scraper | 44 to 168 | 9 |
| Ridger | 50 to 213 | 6 |
| Ditcher | 25 to 150 | 5 |
| Seed drill | 15 to 300 | 6 |
| Sprayer | 3 to 63 | 5 |
| Thresher | 15 to 350 | 8 |

### Implementation of the predicted power models

The power model, known for its simplicity and accuracy, was ultimately selected for its predictive reliability. The developed models were applied to predict the repair and maintenance costs per hour for the ten implements, using purchase price and annual working hours. The repair and maintenance cost per hour was calculated using the following equation:

$R\&M\ (SDG/h) = (Y\%/100) * (PP/AWH)$…………………………..(6)

Where:

R&M = Repair and maintenance costs (SDG/h)

Y% = Annual repair and maintenance cost as percentage of purchase price

PP = purchase price (SDG)

AWH = Annual working hours

## Results and Discussion

To identify the suitable model for predicting repair and maintenance costs as a percentage of purchase price (dependent variable) based on annual working hours (independent variable), five different models were tested. The tested models included exponential, linear, logarithmic, polynomial, and power functions. Data from ten types of agricultural implements were analyzed, encompassing primary tillage implements (disk plow, chisel plow, and moldboard plow), secondary tillage implements (disk harrow, scraper, ridger, and ditcher), and other implements (seed drill, sprayer, and thresher). Tables 3 and 4 present the developed models for selected implements, specifically for the chisel plow, scraper, seed drill, and thresher. The results showed that the coefficient of determination ($R^2$) values for the five models were high, ranging from 0.73 to 0.99. These findings indicate that annual working hours are a strong predictor of variations in repair and maintenance costs. However, the results also revealed variations among the models developed for different implementations. These variations could be attributed to several factors, such as maintenance practices, operator skill, timely availability of spare parts [17], as well as the implementation of design features and specifications. The power model is favored due to its simplicity in calculations and high predictive accuracy. Based on these advantages, the power model was selected to describe the relationship between annual working hours and repair and maintenance costs for the ten implements studied in the Gezira scheme.

*Table 3. Five regression models and coefficient of determination ($R^2$) to predict repair and maintenance costs for chisel plow and scraper in the Gezira scheme*

| Model | Chisel plow | Scraper |
|---|---|---|
| | Developed models ($R^2$) | |
| Exponential | $Y = 14.538\ e^{0.0091\ x}$ (0.86) | $Y = 2.3236\ e^{0.0118x}$ (0.92) |
| Linear | Y = 0.6307 x - 6.7403 (0.95) | Y = 0.0914 x - 0.7275 (0.98) |
| Logarithmic | Y = 77.732 ln(x) -277.34 (0.91) | Y = 8.1289 ln(x) - 28.369 (0.93) |
| Polynomial | $Y = 0.0006\ x^2 + 0.4394\ x + 2.2824$ (0.95) | $Y = 8E\text{-}05\ x^2 + 0.0739\ x + 0.0371$ (0.98) |
| Power | $Y = 0.1915\ x^{1.2141}$ (0.96) | $Y = 0.0507\ x^{1.1079}$ (0.98) |

*Y = Repair and maintenance cost as % of purchase price, X = annual working hours, Value between brackets refer to coefficient of determination*

*Table 4. Five regression models and coefficient of determination ($R^2$) to predict repair and maintenance costs for seed drill and thresher in the Gezira scheme*

| Model | Seed drill | Thresher |
|---|---|---|
| | Developed models ($R^2$) | |
| Exponential | $Y = 6.1111\ e^{0.0119\ x}$ (0.89) | $Y = 3.0011e^{0.0066\ x}$ (0.87) |
| Linear | Y = 0.5228x - 11.061 (0.99) | Y = 0.0627 x + 1.0667 (0.96) |
| Logarithmic | Y = 44.99 ln(x) - 144.96 (0.77) | Y = 5.5387ln(x) - 15.378 (0.73) |
| Polynomial | $Y = 0.0006x^2 + 0.3315\ x - 3.2835$ (0.99) | $Y = 6E - 05x^2 + 0.0408\ x + 2.1613$ (0.98) |
| Power | $Y = 0.1265\ x^{1.2223}$ (0.98) | $Y = 0.3324\ x^{0.6895}$ (0.91) |

*Y = Repair and maintenance cost as % of purchase price, X = annual working hours, Value between brackets refer to coefficient of determination*

The results revealed a highly significant correlation (F-value range: 0.001 to 0.01) between estimated repair and maintenance costs and annual working hours for the ten agricultural implements studied (Table 5). Regression analyses ($R^2$) showed that 90% to 99% of the variation in estimated repair and maintenance costs could be explained by variations in annual working hours. These findings confirm that annual working hours are a strong predictor of variations in implement repair and maintenance costs. Furthermore, the developed power models proved highly reliable for predicting repair and maintenance expenses. This aligns with recommendations from previous studies, [5; 18; 6; 7; 8; ;9; 2]. It was noted that there were variations in the model parameters (a and b) among the studied implements, the sprayer has the highest and the lowest model parameters values (a and b), respectively. Conversely, chisel plow has the lowest and the highest model parameters values. These parameters indicated that sprayer the predicted costs varies among the studied implements.

*Table 5. Developed power models, coefficient of determination ($R^2$) and F-value to predict repair and maintenance costs for the selected implements in the Gezira scheme*

| Implement name | Power model | $R^2$ | F-value |
|---|---|---|---|
| Disk plow | $Y = 0.0099\ x^{1.6205}$ | 0.97 | 82.94 *** |
| chisel plow | $Y = 0.1915\ x^{1.2141}$ | 0.96 | 154.11 *** |
| Moldboard plow | $Y = 0.0059\ x^{1.457}$ | 0.94 | 69.86 *** |
| Disk harrow | $Y = 0.3184\ x^{0.9654}$ | 0.96 | 54.18 ** |
| Scraper | $Y = 0.0507\ x^{1.1079}$ | 0.98 | 350.20 *** |
| Ridger | $Y = 0.0056\ x^{1.6173}$ | 0.99 | 527.36 *** |
| Ditcher | $Y = 0.1073\ x^{1.3138}$ | 0.99 | 153.05 *** |
| Seed drill | $Y = 0.1265\ x^{1.2223}$ | 0.98 | 402.50 *** |
| Sprayer | $Y = 4.7591\ x^{0.3671}$ | 0.90 | 46.01 ** |
| Thresher | $Y = 0.3324\ x^{0.6895}$ | 0.91 | 166.43 *** |

*Y = Repair and maintenance cost as % of price, X = annual hours, ***, ** = significant at 0.001 and 0.01%, respectively.*

The developed power models for the ten implements were used to predict repair and maintenance costs as percentage of purchase price based on annual working hours ranging from 75 to 300 hours as shown in Table 6. The results showed that the predicted repair and maintenance costs increased as annual working hours increase for the ten implements. This result in line the findings of other studies [19; 20; 16], they found that repair and maintenance cost increases as annual working hours increase. Also, the results showed that there were noticeable variations amongst the studied implements in the predicted costs. Moreover, the results revealed that chisel plow and ridger implements resulted in the highest and the lowest predictions among the other implements, respectively. These results indicated that each implement has its own specific model to predict repair and maintenance costs in the Gezira scheme. The authors believe that the furnished information is necessary for managing and organizing repair and maintenance for farm machinery in the Gezira scheme, as it is first time to establish such type of information.

The results in Table 6 also illustrate how variations in annual working hours impact the predicted percentage of repair and maintenance costs for different implements. For instance, increasing annual working hours from 75 to 300 resulted in a dramatic rise in repair and maintenance costs: 845.3% for the disk plow, 840.6% for the ridger, and 160.3% for the thresher. This variation implies that certain implements may be more susceptible to wear and tear with prolonged use, highlighting the need for tailored maintenance strategies based on the type of implement and its usage intensity.

*Table 6. Predicted repair and maintenance cost as percentage of purchase price for the selected implements in the Gezira scheme*

| Implement | 75 h | 125 h | 175 h | 225 h | 300 h |
|---|---|---|---|---|---|
| Disk plow | 10.82 | 24.76 | 42.70 | 64.17 | 102.28 |
| Chisel plow | 36.20 | 67.30 | 101.26 | 137.39 | 194.82 |
| Moldboard | 3.18 | 6.70 | 10.94 | 15.78 | 23.99 |
| Disk harrow | 20.57 | 33.68 | 46.60 | 59.40 | 78.41 |
| Scraper | 6.06 | 10.67 | 15.49 | 20.46 | 28.15 |
| Ridger | 6.04 | 13.79 | 23.76 | 35.68 | 56.81 |
| Ditcher | 31.19 | 61.03 | 94.95 | 132.10 | 192.77 |
| Seed drill | 24.77 | 46.25 | 69.78 | 94.88 | 134.86 |
| Sprayer | 23.22 | 28.01 | 31.69 | 34.75 | 38.63 |
| Thresher | 6.52 | 9.28 | 11.70 | 13.92 | 16.97 |

Table 7 illustrates the predicted repair and maintenance costs (SDG per hour) for the ten implements under this study by using their developed power models, purchase prices and annual working hours of use. The used annual working hours of use were ranged from 50 to 250 hours. The results showed that there were noticeable variations amongst the implements in the predicted repair and maintenance costs. The scraper implement resulted in the lowest cost values across other implements; this may mainly due to its lowest purchase price. On the other hand, the disk harrow implement resulted in the highest cost. It was also noted that the cost values increased with the increases in annual working hours of use for all of the studied implements, except for disk harrow, sprayer and thresher implements, where the cost decreased as annual working hours increased. This indicated that the purchase price of each implement affects the predicted repair and maintenance costs. This result suggested that each implement has its own specific and distinguished power model for predicting monetary values of repair and maintenance costs.

This result agreed with [21], They reported that the relations between annual repair and maintenance cost as percentage of purchase price and annual hours of use were highly and very highly significance.

***Table 7. Predicted repair and maintenance costs (SDG/h) for the selected implements at different annual working hours of use in the Gezira scheme***

| implement | Price (SDG) | 50 h | 100 h | 150 h | 200 h | 250 h |
|---|---|---|---|---|---|---|
| Disk plow | 600000 | 673.0 | 1034.6 | 1330.6 | 1590.7 | 1826.9 |
| Chisel plow | 400000 | 1770.0 | 2053.2 | 2239.4 | 2381.7 | 2498.2 |
| Moldboard | 1000000 | 352.6 | 484.0 | 582.5 | 664.4 | 735.7 |
| Disk harrow | 1300000 | 3615.2 | 3529.5 | 3480.4 | 3445.9 | 3419.4 |
| Scraper | 250000 | 193.3 | 208.3 | 217.6 | 224.5 | 230.0 |
| Ridger | 500000 | 313.3 | 480.6 | 617.2 | 737.2 | 846.1 |
| Ditcher | 300000 | 1098.6 | 1365.6 | 1550.9 | 1697.4 | 1820.5 |
| Seed drill | 1250000 | 3773.0 | 4401.5 | 4816.7 | 5134.8 | 5395.9 |
| Sprayer | 500000 | 2000.9 | 1290.3 | 998.3 | 832.1 | 722.5 |
| Thresher | 3000000 | 2959.7 | 2386.6 | 2104.3 | 1924.5 | 1795.7 |

The predicted repair and maintenance costs (SDG/h) varied significantly among the implements. For example, although the ridger and sprayer have the same purchase price (Table 7), their predictions under increased annual working hours differ. When annual working hours increased from 50 to 250, the sprayer's repair and maintenance costs decreased by 63.9%, while the rider's costs increased by 170%. Similarly, the disk harrow and seed-drill, which share a higher purchase price, showed contrasting trends: the disk harrow's costs decreased by 5.4%, whereas the seed-drill's costs increased by 22.6%. These suggests that factors beyond purchase price, such as design, material durability, or operational characteristics, play a critical role in determining the long-term repair and maintenance costs of agricultural implements.

The results showed that there were notable variations between the primary tillage implements in the predicted repair and maintenance costs (Fig. 1). The chisel plow obtained the highest values of prediction followed by the disk plow whereas moldboard plow obtained the lowest. It was observed that for all of the three implements, the predicted lower values of repair and maintenance costs at fewer annual working hours of use and increases with the increases in annual working hours of use. These variations may be due to the differences in their purchase price. Moreover, these variations may be due to differences in the design components of the implements.

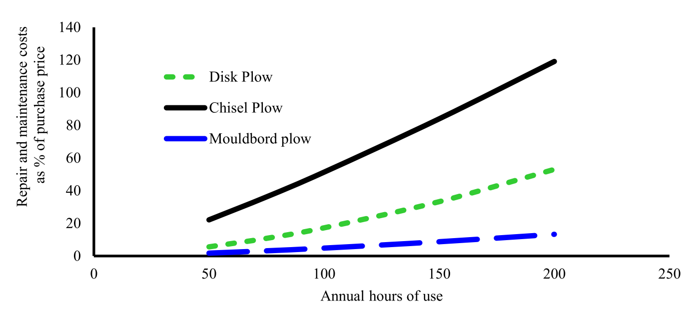


Fig. 1. Trend of repair and maintenance costs for primary tillage implements in the Gezira scheme

The results revealed remarkable variations in the predicted repair and maintenance costs among the secondary tillage implements (Fig. 2). The scraper showed the highest predicted costs, followed by the disk harrow, then ditcher, while the ridger recorded the lowest. For all four implements, lower repair and maintenance costs were predicted at fewer annual working hours, with costs increased as annual working hours rose. The disk harrow, ditcher and ridger showed relatively similar trends in cost prediction compared to scraper.

These variations can be attributed to variations in their design features and purchase price. These variations underscore how differences in both initial purchase price and structural design contribute to disparities in repair and maintenance expenses.

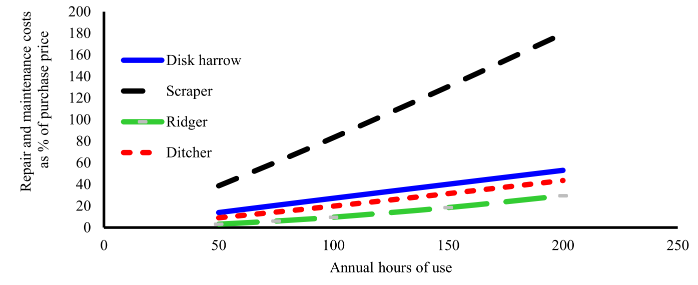


Fig. 2. Trend of repair and maintenance costs for secondary tillage implements in the Gezira scheme

The results revealed noticeable variations in the predicted repair and maintenance costs among the seed-drill, sprayer and thresher implements (Fig. 3). The seed-drill recorded the highest predicted costs, followed by the sprayer, while the thresher recorded the lowest. For all three implements, lower repair and maintenance costs were predicted at fewer annual working hours, with costs increasing as annual working hours rose. These variations can be attributed to differences in the purchase prices of the implements, as well as variations in their design and engineering features [17].

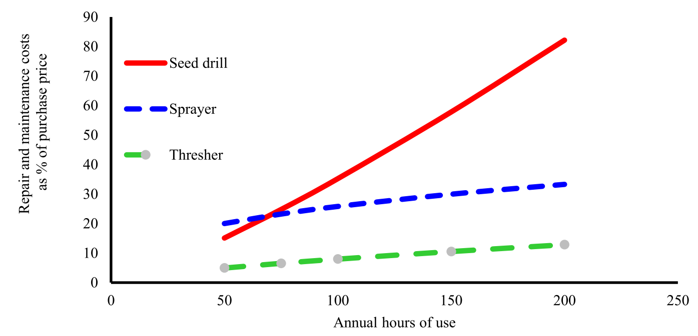


Fig. 3. Trend of repair and maintenance costs for some other implements in the Gezira scheme

The developed power models were utilized to predict repair and maintenance costs for the ten studied implements. Figure 4 illustrates a comparison between the actual and predicted values of these costs. The results demonstrated a strong agreement between the predicted and actual values across all implements, indicating that the models are highly accurate in estimating repair and maintenance costs within the Gezira scheme. Figure 4 also demonstrates that each implement has it own distinguished model for cost prediction which differ from others, this confirms the difference between these implements. These findings suggest that the developed models can be confidently applied to estimate repair and maintenance costs for these agricultural implements. To the authors' knowledge, this study represents the first attempt to develop predictive models of this nature specifically for the Gezira scheme. As such, the models provide a valuable tool for cost estimation in the region and can be reliably used unless significant changes in operational conditions or management practices occur.

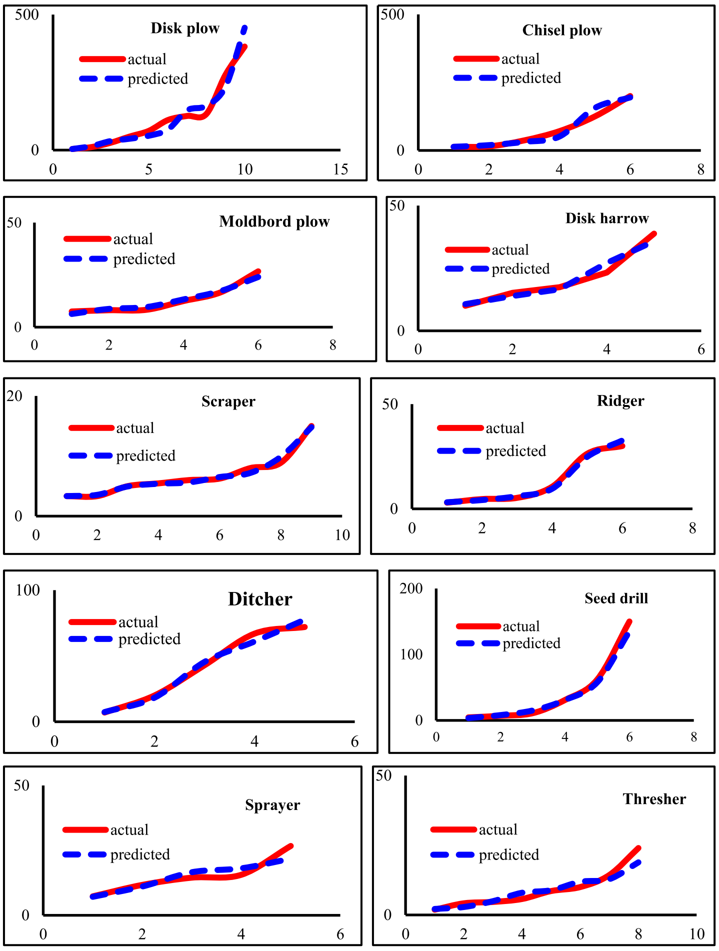


*Fig. 4. Actual versus predicted values of repair and maintenance costs for ten implements in the Gezira scheme*

## Conclusions

- The exponential, linear, logarithmic, polynomial, and power models were used to predict repair and maintenance costs as a percentage of purchase price (dependent variable) based on annual working hours (independent variable), for ten types of agricultural implements. These implements encompassed primary tillage implements (disk plow, chisel plow, and moldboard plow), secondary tillage implements (disk harrow, scraper, ridger, and ditcher), and other implements (seed drill, sprayer, and thresher).
- The power model proved to be the most reliable and accurate for predicting repair and maintenance costs, with highly significant correlations (F-value range: 0.001 to 0.01) and $R^2$ values ranging from 0.90 to 0.99.
- Repair and maintenance costs generally increase with higher annual working hours, but variations existed depending on implement type, purchase price, and design.
- These power models provide a robust framework for estimating repair and maintenance expenses, offering valuable insights for farmers and policymakers in machinery management.
- The predictive power models developed by this study bridges a critical knowledge gap and supports more efficient agricultural machinery use in the Gezira Scheme.
- Studies are suggested to address this topic under other regions and operational practices.

## Conflict of interest

The authors have not declared any conflict of interest.

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