Mathematical models to predict repair and maintenance cost for 2WD tractors in the mechanized rainfed areas, eastern Sudan

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ABSTRACT

Many tractor makes are working in the mechanized rainfed areas of eastern Sudan. Most of them are two-wheel drive (2WD) tractors. However, information concerning their repair and maintenance (R and M) costs are inadequate. Moreover, depending on information on R and M costs from other farming systems or countries is unrealistic. Four tractors were studied, which were Massy Ferguson (MF-290), Ford (FD-6610), Belarus (BL-800) and New Holland (TT-75). The objectives were to develop mathematical models to estimate tractors' annual R and M costs, to rank the studied tractors according to their predicted R and M costs and to compare estimations of the general model developed from this study with models developed elsewhere. Data on purchase price, annual working hours, fuel consumption, R and M costs, labor wage and oil costs were collected. The regression and F test analyses methods were used. Results revealed that the power function $Y= aX^b$ can be used to estimate tractor R and M costs; where Y is R and M costs as percent of purchase price and X is annual working hours. The annual working hours had very highly significant (P= 0.001) effect on R and M costs. The values of coefficient of determination (R^2) were above 0.95 for all tractors and their general model. The developed models for all tractors were arranged in ascending order according to their predicted R and M costs as follows; $Y = 0.05 (X/100)^{1.3}$ for TT-75, $Y = 0.04(X/100)^{1.4}$ for BL-800, $Y= 0.03 (X/100)^{1.7}$ for MF-290 and $Y = 0.05 (X/100)^{1.5}$ for FD-6610. The general model from this study was $Y = (0.041 (X/100)^{1.43})$. This general model predicted lower R and M costs compared to the models suggested for irrigated schemes of Sudan and some other countries. It is advised that each specific area and country must develop its own mathematical model.

INTRODUCTION

Agricultural machinery is essential inputs in modern agricultural production systems, especially in large scale commercial production systems. However, costs of agricultural machinery represent a significant portion of the total production cost (Anderson, 1988; Buckmaster, 2003). Machinery cost includes fixed and operation costs; the later encompass fuel, labor and repair and maintenance costs. Estimation of machinery costs is necessary for proper machinery planning and management.

Repair and maintenance (R and M) costs of farm machinery are those expenditures necessary to restore or maintain the technical soundness and reliability of the machine (Srivastava, *et al.*, 2006). Accurate prediction of R and M costs is essential to determine the optimum economical life of a machine, and to make appropriate decisions for machinery replacements and for general farm management purposes (Hunt, 2001). Since variation in R and M costs depends on time and site specifications, a general relationship cannot be suggested; but prediction of these costs at an acceptable level can be made by fitting a regression model based on the previous data (Rotz, 1987; Sharma and Mukesh, 2013).

Tractor R and M costs vary widely from one country to another and within the same region depending on many factors such as type of work done and working conditions, degree of care and preventive maintenance given, availability of spare parts and their quality and prices, skills of servicemen and operators, and design features of the tractor. Ahmed *et al.*, (1999) mentioned that the use of predictions of American and European countries to estimate R and M costs of tractors in developing countries would result in misleading estimates. They also mentioned that Sudan estimates of R and M costs are higher compared to the developed countries. This was because Sudan relies on imported replacement parts which were expensive, poor repair and maintenance facilities, especially for preventive maintenance, unavailability of replacement parts at the appropriate time due to scarcity of foreign exchange and long procedures of procurement, and poor skill of tractor operators due to inadequate training facilities and low salaries and incentives.

In the Sudan, tractors have been used in irrigated as well as in rainfed areas for a long period of time. Although the working conditions in these areas are similar, in term of soil and climate; but they differ in intensification of use.

The use of tractors in irrigated areas is higher than in rainfed areas. In irrigated areas, there are two cropping seasons per year (summer and winter), whereas in rainfed areas there is only one cropping season per year (summer). Moreover, the types of machine as well as the number of operations performed in irrigated areas differ also from that in rainfed areas. Dawelbeit (1998) mentioned that the ratio of tractor to area in Sudan was one tractor for 420 ha in the mechanized rainfed areas and one tractor for 200 ha in irrigated schemes. Moreover, the power to area ratio was 0.18 hp/ha in the rainfed sector, while in irrigated schemes it was 0.41 hp/ha. Ahmed *et al.*,(1999) and Dahab and Adam (2002) have developed mathematical models to predict R and M costs for tractors working under general conditions of Sudan and the irrigated schemes of Sudan, respectively. Therefore, it is necessary to develop models that can predict R and M costs for tractors working in the rainfed areas of eastern Sudan.

Several models have been developed elsewhere to estimate tractor's R and M costs. These models predicted R and M costs as a percentage of purchase price (dependent variable) using annual hours of use (independent variables). Literature review showed that the power function $Y = aX^b$ is the best and most superior function for estimating R and M costs of tractors (Sabir *et al.*,1990; Bakht *et al.*,2009; Khodabakhshian and Shakeri, 2011 and Abubakar *et al.*, 2013).

Many tractor makes and models are working in the mechanized rainfed areas of Gedarif State, eastern Sudan, since the mid 1940s. Most of these tractors are of the two-wheel drive (2WD) type. These tractors are used to perform several tasks such as seedbed preparation, seeding, weeding, threshing and transportation. However, there is inadequate information about the R and M costs of these tractors. It was envisioned that providing dependable information about tractor operating costs, especially R and M costs can help in farm management. Provision of such information can mitigate and minimize the associated production risks in rainfed areas such as fluctuations in rainfall and production. Therefore, the objectives of this study were as follows:

1. Development of mathematical models to estimate R and M costs for each of the selected tractors and their general mean.
2. Ranking of the selected tractors according to their predicted R and M costs.
3. Comparison of the estimations of the general model developed in this study with the estimations of similar models developed elsewhere.

MATERIALS AND METHODS

A field survey was carried out during season 2013/2014 in the mechanized rainfed farms of eastern Sudan. Data on R and M costs of 2WD tractors of medium size (44 to 56 kw PTO shaft) were collected. Four makes of tractors working in the mechanized rainfed areas of Gedarif State were studied. These tractors were Massy Ferguson (MF-290), Ford (FD-6610), Belarus (BL-800) and New Holland (TT-75). The latter two tractors were recently introduced in the area. In this research work, data from 83 tractors were collected. A total of seven to fourteen tractors of each make were studied. Basic information of the studied tractors is presented in Table 1.

Table 1. Basic information about studied tractors.

Tractor's make and model	Number of tractors	PTO shaft power (kw)	Range of age (years)	Average annual working hours
MF 290	14	48.5	1 - 12	1832
Ford 6610	7	53.7	4 - 12	787
Belarus 800	11	56.0	1 - 10	854
New Holland TT 75	13	44.0	1 - 7	1507

Tractors' operating conditions and management

The studied tractors work in areas of arid to semi-arid climate conditions with hot summer and warm winter. The main field operations carried out by these tractors are land preparation and seeding with the use of wide level disk (WLD) plow, weed control using sprayer and the WLD, stationary threshing and transportation. These field operations are carried out in a large scale farm of about 420 ha, with heavy clay soil. The drawbar and PTO shaft are the most exploited sources of power from the tractors.

The annual working period extends from June to January each year and most of the tractors stay idle from February to May. The tractors work two shifts per day (16 to 20 hours/day) especially during the peak period of the growing season (July and August).

The tractors are owned and managed by farmers, who have long experience in dealing with tractors and their implements. For routine maintenance, farmers are committed to change fuel and oil filters as well as oils regularly. Additionally, the miner repair work such as wheel puncturing and night light are done by seasonal drivers in the field. However, for major repair work such as fuel pump, gearbox and engine overhauling, farmers consult specialists. Most of tractors' facilities and services are centralized in the big city, which is far away from the fields. Moreover, good quality spare parts and their costs beside scarcity of skilled operators are the real challenges facing the tractors' owners.

Data collection and analysis

A closed questionnaire was designed and distributed among tractors' owners to collect the required data for the purpose of this research. Data on tractor make, purchase price and type of field operations, annual working hours, annual cultivated area and annual fuel consumption were collected. Moreover, data on tractor operation costs were also obtained; which included labor, fuel and R and M costs. Repair cost items covered all costs that had been done to the tractor engine such as fuel, electrical and power transmission systems and wheels. The maintenance cost items included the costs of fuel and oil filters, oils and grease.

The collected data were inserted in an Excel workbook and the necessary arrangements and grouping were made for each tractor make. The total R and M costs were calculated as a percent of tractors' purchase price (Sharma and Mukesh, 2013). The annual working hours for each tractor were also obtained. The average values of R and M costs were determined for those tractors with similar working hours. Tractors having odd values of R and M costs and/or annual working hours were excluded. Regression analysis was carried out to develop a relationship between accumulative R and M costs as a percent of purchase price (dependant variable) and annual use of each 100 hours (independent variable). The regression analyses were performed by using the Statistical Package for Social Sciences (SPSS) computer program. The power function model ($Y= ax^b$) was used to describe the relationship between the dependant and independent variables (Dahab and Adam, 2002).

Also, the regression coefficient (R^2) and F-test were determined to explain the strength of the developed relationship. The power function and its associated variable were established for each tractor make, and then a general model was developed. Moreover, the general model was compared with models developed by other researchers. Additionally, sensitivity analysis to the developed general model was made.

RESULTS AND DISCUSSION

Table 2 illustrates the average annual operating costs for the studied tractors. These results revealed that the tractors' R and M costs as a percent of the annual operating cost varied with the tractor make. R and M cost was found to be in the range of 17.9% for BL-800 to 34.4% for FD-6610. Figure 1 shows the overall average of fuel, labor and R and M costs as a percent of the operation cost. Fuel cost was found to be 56% of the operation cost, which was followed by 25% for R and M costs, while labor cost amounted to 19%. On the average, 25% of tractors operation costs was spent in R and M which is a considerable costs not to be neglected. Further analysis was made to the R and M cost components; it was divided into repair and maintenance costs (Fig. 2). BL-800 and TT-75 tractors gave the lowest values of repair cost compared to the other maintenance costs; whereas, MF-290 and FD-6610 tractors gave the highest values of repair cost. These variations between tractors in R and M costs were expected due to the variations in received care, maintenance program and management.

Table 2. Tractors' annual operating cost (SDG).

Tractor's make and model	Fuel cost	Operator cost	R and M cost	Operating cost	% of R and M of operation cost
MF 290	12985	6161	8507	27653	31
Ford 6610	11562	4199	8276	24037	34
Belarus 800	14162	3298	3807	21266	18
New Holland TT 75	19805	6410	5997	32211	19
Average	14628	5017	6647	26292	25

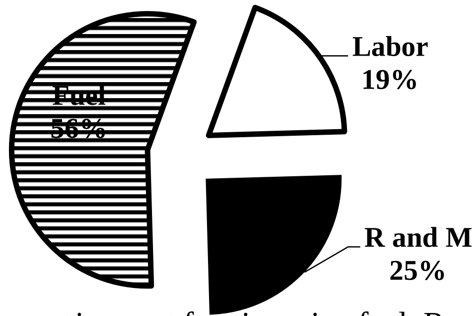

Fig. 1. Mean annual opeartion cost fractions, i.e. fuel, R and M and labor.

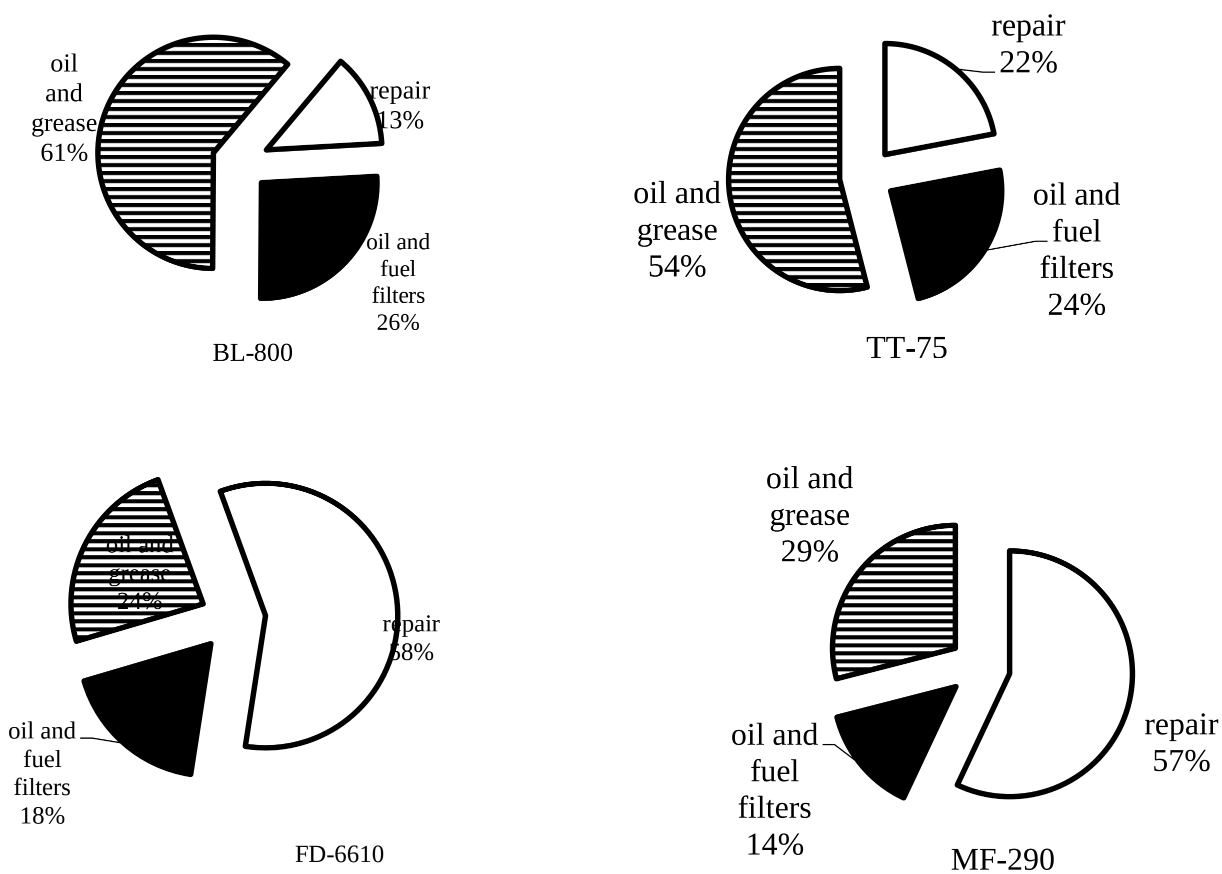

Fig.2. Mean annual repair and maintenance costs for the studied tractors

Results of all tractor makes showed that R and M costs increased proportionally with annual hours of use (Table 3). This proportional relationship was described by the power function $Y= aX^b$; where Y is repair and maintenance cost as percent of purchase price and X is annual hours of use each 100 hours. Several studies (ASAE, 1989; Ahmed *et al*., 1999; Dahab and Adam, 2002; Abubakar *et al*., 2013) suggested the use of the power function for estimating R and M costs as a percent of the tractor purchase prices. The results also showed that the coefficients of determinations (R^2) for the studied tractor makes were very high ranging between 95% and 98%. Moreover, the results revealed that the annual working hours had very highly significant (P = 0.001) effect on R and M costs for all studied tractors and their general model as shown by F values in Table 3. These results indicate that the annual working hours can effectively explain the variation in R and M costs. Also, the results indicated that the developed models may have a high confidence level in predicting R and M costs.

The results revealed that there were variations in the developed model for the studied tractors. For example MF-290 and FD-6610 tractors have higher values of R and M costs compared to BL-800 and TT-75 tractors (Fig. 3). This variation was obvious, especially when the annual working hours exceeded 400 hrs. This variation could be attributed to the given care and maintenance management, skill and attitude of tractor operators and availability of replacement parts at the appropriate time, and design features of the tractors (Dahab and Adam, 2002). This variation could also be attributed to the fact that BL-800 and TT-75 tractors are newly introduced in the studied area; thus they require no or few repair costs such as overhaul and wheels changes.

A general model for the studied tractors was developed to predict R and M costs of tractors working in rainfed conditions of eastern Sudan (Table 3). This general model followed the same trend of the models of the studied tractors (the power function). However, this general model predicts lower values of R and M costs compared to MF-290 and FD-6610 and higher values in comparison with TT-75 and BL-800 (Fig. 3).

Table 3. Developed mathematical models for different tractor makes and the summary of models constants regression functions

Tractor make and model	Developed model	R^2	F
MF- 290	$Y = 0.03\ (X/100)^{1.7}$	0.95	124.72 ***
Ford- 6610	$Y = 0.05\ (X/100)^{1.5}$	0.95	96.62 ***
Belarus- 800	$Y = 0.04\ (X/100)^{1.4}$	0.96	146.65 ***
New Holland- TT-75	$Y = 0.05\ (X/100)^{1.3}$	0.98	235.43 ***
General model	$Y = 0.041\ (X/100)^{1.43}$	0.99	11151.44***

Y = Repair and maintenance cost as percent of purchase price, X = Working hours, *** = significant at P = 0.001%.

Table 4 shows the predicted values of R and M costs for the studied tractors. The results revealed that FD-6610 tractor had the highest R and M costs followed by MF-290 tractor. However, the model for FD-6610 predicted higher cost up to 1200 hours of use compared to MF-290, and then MF-290 gave higher cost values. On the other hand, the lowest cost was obtained by TT-75 and BL-800.

However, the model for TT-75 and BL-800 tractors predicted similar R and M values up to 1200 hours of use, after which BL-800 gave higher prediction cost values compared to TT-75 (Table 4). The variations of R and M costs percentage between these tractor makes could be due to their age, power and design features as well as operator's skill and attitude, and maintenance program.

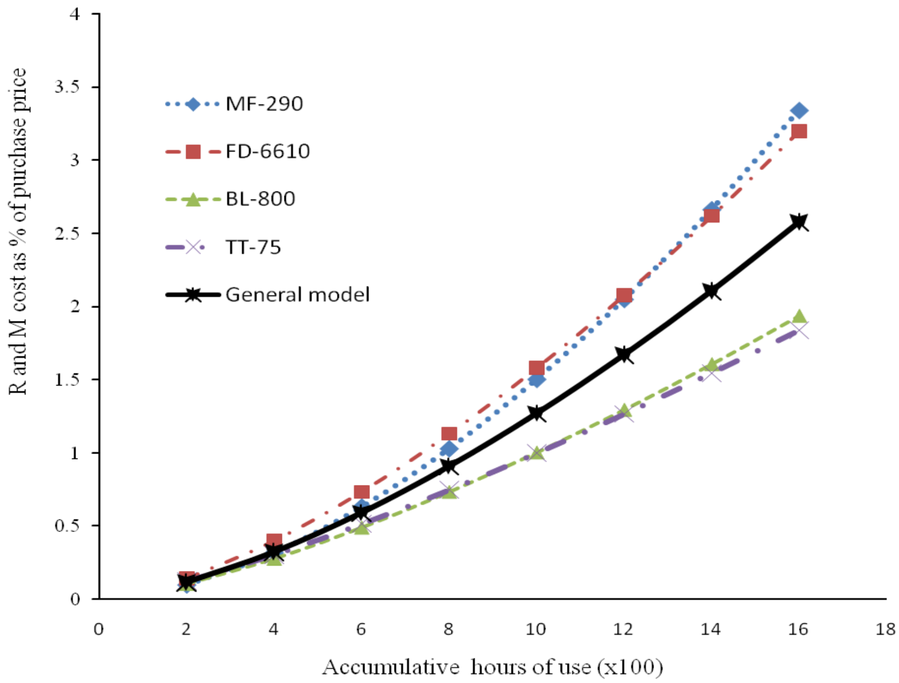

Fig. 3. Effect of annual hours of use on tractors R and M cost

Table 4. Predicted R and M cost for different tractor makes and working hours.

Tractor make	Predicted R and M costs as % of purchase price				
	400 h	800 h	1200 h	1600 h	2000 h
MF 290	0.3	1.0	2.0	3.3	4.9
Ford 6610	0.4	1.1	2.1	3.2	4.5
Belarus 800	0.3	0.7	1.3	1.9	2.7
New Holland TT 75	0.3	0.7	1.3	1.8	2.5

Table 5 displays the tractors R and M costs that predicted with the use of general model of this study in comparison with other similar models developed elsewhere. It was evident that the general model gave lower R and M costs estimations. For example, the estimated tractor R and M costs by the general model of this study was lower by two folds compared with that suggested by Dahab and Adam (2002) for irrigated schemes in Sudan, and by five folds compared with that suggested by Ahmed *et al.* (1999) as standard model for the Sudan. Moreover, this model also predicted lower values of R and M costs compared to the developed and developing countries models (Ward *et al.*,1985; Morris, 1987 and Abubakar *et al.*, 2013).

On the other hand, the general model of this study gave similar estimation compared to ASAE (1989). Differences of R and M costs between these models may be attributed to the nature of the different farm operations, skill of operators, annual service hours of tractor, wage-rate of operator and spare-part costs (Ranjbar *et al.*, 2010).

Table 5. Comparison between the models for predicting R and M costs developed in other places and this study.

The developed models	Source and country	Predicted R and M cost as % of purchase price			Ratio
		800 h	1200 h	1600 h	
$Y = 0.042\ (X/120)^{1.9}$	Ward *et al.*,(1985), Ireland	1.5	3.3	5.8	2
$Y = (0.0996\ X^{1.48})\ 10^{-3}$	Morris (1987), UK	2.0	3.6	5.5	3
$Y = (1.2\ X^{2})\ 10^{-6}$	ASAE (1989) U.S.A.	0.8	1.7	3.1	1
$Y = (2.53\ X^{2.4})10^{-7}$	Ahmed *et al.*, (1999), Sudan	2.4	6.2	12.4	5
$Y = (4\ X^{1.25})10^{-4}$	Dahab and Adam (2002), Sudan	1.7	2.8	4.1	2
$Y = 0.005\ X^{1.2}$	Abubakar *et al.*, (2013), Nigeria	15.2	24.8	35.0	17
$Y = (0.041\ (X/100)^{1.43})$	This study, Sudan	0.8	1.4	2.20	

Y = Repair and maintenance costs as percent of purchase price, X = Working hours

Figure 4 compares the trend of the predicted R and M costs of tractors from the developed general model in this study in comparison with other models. All models gave lower values of R and M costs at few annual working hours and then the R and M costs increased with the increase in annual working hours, but the trend of the rate of increase was variable. Therefore, it is highly advised that each specific area or country must develop its own model according to prevailing operational and field conditions and prices.

Sensitivity analysis and application of the developed general model

The sensitivity of a model can be tested by observing the changes made in the model parameters on the predicted results. Table 6 illustrates the effect of changing the parameters "a" and "b" of the developed general model in this study on the predicted R and M costs. It was observed that changes in the values of model parameters resulted in changes in the predicted R and M costs. At 1000 annual working hours, increasing the "a"

value only by 10% will increase the R and M cost by 9.76%, and by increasing "b" value only by 10% will increase the R and M costs by 38.04%, but by increasing both "a" and "b" values by 10% will increase the R and M costs by 51.51%. However, by decreasing only "a" value by 10% will decrease the R and M costs by 9.76%, and by decreasing "b" value only by 10% will decrease the R and M costs by 27.56%, but by decreasing both the "a" and "b" values by 10% will decrease the R and M costs by 34.62%. Moreover, increasing and decreasing the value of "a" by 10% needs to decrease and increase the value of "b" by 2.8%, respectively, to

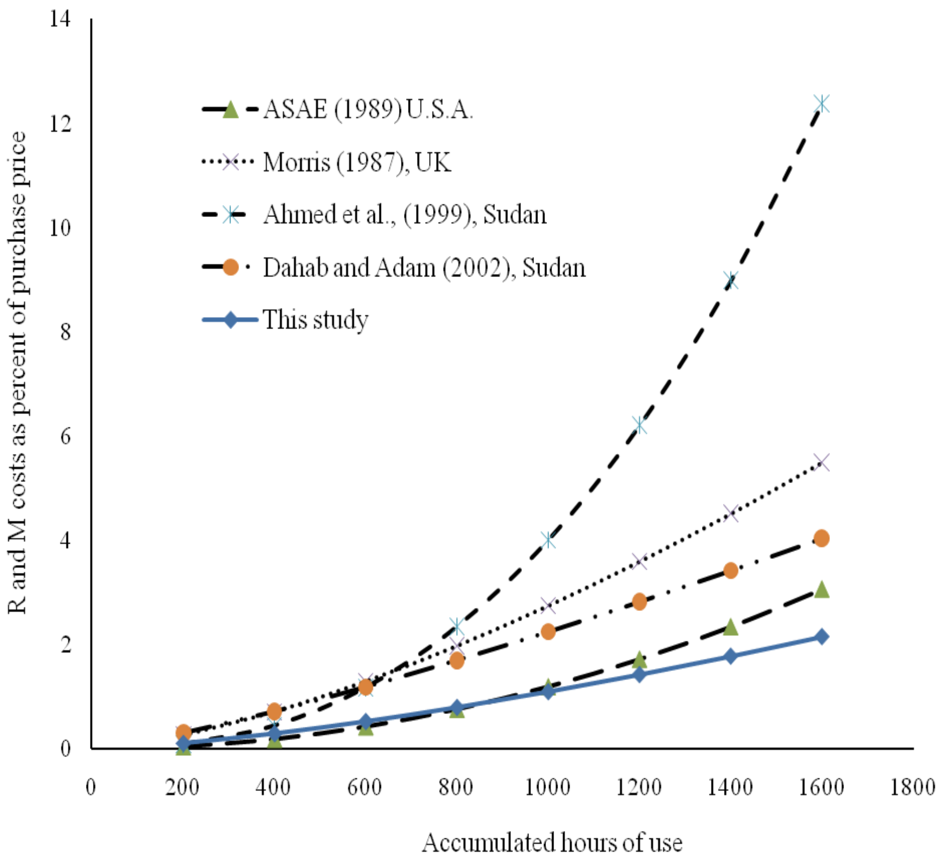

Fig.4. Comparison of predicted tractor R and M costs of this study with predictions by some other studies

obtain the same value of R and M costs. However, increasing and decreasing the value of "b" by 10% it needs a decrease and increase in the value of "a" by 26.83% and 36.6%, respectively, to obtain the same value of R and M costs. The magnitude of the R and M costs predicted by the general model, therefore, can be varied through changes in the values of its parameters.

In addition to that, the analysis revealed that the developed general model was sensitive to changes in tractor purchase price and annual working hours. Increase or decrease in both purchase price and annual working hours will increase and decrease the predicted costs, respectively. These results suggest that each specific area or country has to develop their own models depending on the prevailing field operations, prevailing conditions and prices. For the developed general model application, assume that two tractors are working in the mechanized rainfed areas of eastern Sudan and the purchase price of the first and the second tractors were 130 thousand SDG and 90 thousand SDG, respectively. The first tractor works 1100 hours annually and the second tractor works only 700 hours. By using the developed general model in this study, the predicted R and M costs for the first tractor will be1644 SDG annually and 1.5 SDG for each hour during the year. Whereas for the second tractor, the predicted R and M costs will be 861 SDG annually and 0.9 SDG/h. These findings can help farmers in selecting, using and managing their tractors.

Table 6. Effect of changing values of the general model parameters on the predicted R and M cost.

Change in values of model parameters (%)	Values of model parameters		Predicted R and M cost as % of purchase price	Changes in R and M cost (%)	Change needed in "a" and "b" to obtain the same R and M cost (%)
	a	b			
No change	0.041	1.43	1.10	-	-
+ 10% in "a"	0.045	1.43	1.21	+ 9.76	- 2.8% in "b"
+ 10% in "b"	0.041	1.57	1.52	+ 38.04	- 26.83% in "a"
+ 10% in "a" and "b"	0.045	1.57	1.67	+ 51.51	- 10% in "a" and "b"
- 10% in "a"	0.037	1.43	1.00	- 09.76	+ 2.8% in "b"
- 10% in "b"	0.041	1.29	0.80	- 27.56	+ 36.6 % in "a"
- 10% in "a" and "b"	0.037	1.29	0.72	- 34.62	+10% in "a" and "b"

CONCLUSIONS

From the results of this study, the following conclusions could be drawn:

1. The studied tractors varied in their annual R and M costs; and the average R and M costs comprised by about 25% of the tractor operating cost.
2. Tractor's annual hours of use had very highly significant ($P = 0.001$) effect on R and M costs.
3. All of the studied tractors showed that R and M costs increased proportionally with annual hours of use. This proportional relationship was described by the power function $Y = aX^b$ where Y is R and M costs as a percent of purchase price and X is annual use each 100 hours.
4. The developed models for the studied tractors showed that predicted R and M costs was high for FD-6610 and MF-290 tractors and lower for TT-75 and BL-800 tractors.
5. A general model for estimating R and M costs for 2WD tractors that used in rainfed areas of Sudan was developed. It could be described by the following equation $Y = 0.041\ (X/100)^{1.43}$.
6. The developed general model in this study estimated lower R and M costs compared to the models suggested for tractors in the irrigated schemes of Sudan, and also in some developed and developing countries.
7. The general model was sensitive to changes in its parameters of tractor price and annual working hours.
8. It is advisable that each specific area or country must develop its own model according to the prevailing operational and field conditions and prices.

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نماذج رياضية لتقدير تكاليف الصيانة والإصلاح للجرارات ثنائية الدفع (2WD) في مناطق الزراعة المطرية الآلية بشرق السودان

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الخلاصة

العديد من ماركات الجرارات تعمل في مناطق الزراعة المطرية الآلية في شرق السودان، ومعظم هذه الجرارات من النوع ثنائي الدفع (2WD). ولكن لا توجد معلومات كافية عن تكاليف الصيانة والإصلاح لهذه الجرارات. بالإضافة لذلك هنالك عدم واقعية في استخدام معلومات من نظم زراعية أخرى أو من بلدان أخرى. تمت دراسة أربعة من الجرارات **هي:** ماسي فيرجوسون (MF-290) وفورد (FD-6610) وبيلاروس (BL-800) ونيوهولاند (TT-75). وأهداف هذه الدراسة هي تطوير نماذج رياضية لتقدير تكلفة الصيانة والإصلاح السنوية للجرار وترتيب هذه الجرارات حسب تكاليف الصيانة والإصلاح التقديرية ومقارنة التقديرات بواسطة النموذج العام لهذه الدراسة مع التقديرات من نماذج تم تطويرها في مواقع مختلفة. تم جمع بيانات عن سعر الشراء وعدد ساعات التشغيل السنوية واستهلاك الوقود بالإضافة إلى تكاليف الصيانة والإصلاح وتكاليف العمالة والزيوت. لتحليل البيانات تم استخدام تحليل الإنحدار وكذلك تحليل التباين. اشارت النتائج إلى أنه يمكن استخدام دالة القوة $Y = aX^b$ لتقدير تكاليف الصيانة والإصلاح، حيث تمثل Y تكاليف الصيانة والإصلاح السنوية كنسبة من سعر الشراء وتمثل X عدد ساعات التشغيل السنوية. عدد ساعات التشغيل السنوية لها تأثير معنوي عالي جدا ($P = 0.001$) على تكاليف الصيانة والإصلاح السنوية. وقيم معامل الإنحدار (R^2) للنماذج تزيد عن 0.95 لكل الجرارات وللنموذج العام لجميع الجرارات. والنماذج المطورة للجرارات تم ترتيبها تصاعديا بناء على تقدير تكاليف صيانتها **وإصلاحها كالآتي:** $Y = 0.05 (X/100)^{1.3}$ للنيوهولاند TT-75 و$Y = 0.04(X/100)^{1.4}$ للبيلاروس BL-800 و$Y = 0.03 (X/100)^{1.7}$ للماسي فيرجوسون MF-290 و$Y = 0.05 (X/100)^{1.5}$ للفورد FD-6610. والنموذج العام من هذه الدراسة كان $Y = (0.041 (X/100)^{1.43})$. وهذا النموذج العام أعطى أقل تقديرات لتكاليف الصيانة والإصلاح عند مقارنته مع تقديرات النماذج المقترحة للمشاريع المروية في السودان وبعض الدول الاخرى. وينصح بأن تطور كل منطقة أو قطر محدد النموذج الرياضي الخاص به.