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Computer system development for Combine Harvesters management at Northern State of Sudan

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ABSTRACT: Combine harvesters are highly required in the northern state of Sudan for harvesting the large areas grown by wheat, the important cash and food crop. The objective of the present study was to develop a computer program for Managing and selecting combine harvester under Northern State conditions. The required input data included machine initial prices (SDG), expected No. of working hours, repair and maintenance costs for each machine as (%) of initial purchase prices, machine age (years), area to be covered (ha), machine rent per hour (SDG), labor wage per hour, fuel unit price (SDG/L) and required tractor power (Kw). The results showed that predictions of the computer system which included machinery effective field capacity (EFC) in ha/h and costs in SDG/h; were compared well with actual data and the comparative percentage was within 81% to 120%. Moreover, the predicted effective field capacity was significantly higher (1.505ha/h) for Class dominator (4.30m) as compared to FOTTON4Lz2 (2.70m) which ranked the least (0.788 and 0.945 ha/h).. On the other hand, developed program predicts the lowest operation cost for FOTTON4Lz2 (2.70m) compared with SONALIKA International (4.20m).The developed program was verified and validated using actual data from the field. The results showed positive and strong correlations between the predicted and actual effective field capacity and operation costs. Moreover, for FOTTON4Lz2, SONALIKA International and CLAAS dominator, the predicted operation costs were lower than the actual ones by 16%, 19% and 9%respectively. Sensitivity analysis and accuracy tests were carried out and the developed computer system was found significantly respond to changes of inputs with high accuracy. It was concluded that, after optimization, the best combination option for planting %operation it was required two machines of size 4.20m, and field capacity 1.495 ha/h, in combination with 43machines of size 4.30m and 1.505 ha/h to cover an area of 50,000 ha.The obtained results of the computation were verified and validated for applications. It was concluded that the developed system was user oriented, dynamic and responded well to alterations in the input data which affected the output parameters.

KEYWORDS: Computer Program; Management, Combine Harvester, optimization

I. INTRODUCTION

Machinery management and selection has increased in importance in recent farming operations because of its direct relation to the success of mixing land, labor and capital for profitable return. Successful business in farms obtained when machinery considered as only tools of production and operated in a business-like manner to produce crops at a profit [1]. Selection of machinery size is one of important parts of machinery managementto match with field requirements and power available. It involves fitting of the proper equipment size to the amount of work for a given period of time as reported by [2].Size selection of machinery must necessarily depend on anticipated performance and anticipated costs. Selection must proceed with aflexible view towards some relationship among the pertinent variables. The most pertinent variables are machine capacity, power and forwardspeed [3].One of the best ways to determine how large amachine needs to be is to determine the necessary capacity to complete the operation within a specific period and correctly estimated number of hours that can be worked during that periodas mentioned by [4].Accurate estimation of machinery cost plays an important role in every machinery management decision. Opportunities now exist to augment managerial experience with analytical procedures to obtain more accurate estimate of machinery performance, operating costs with respect to available working hours [5]. Recently, many computer programs were developed elsewhere and published to analyze the factors affecting machinery performance, selection, field operations and total farm costs [6, 7, 8,9].[10]developed a computer system for managing farm machinery and to estimate variable capacities of machines on the basis of per hour unit area and also to calculate fixed, variable and total costs of farm machinery. Harvesting operation is an important and sensitive operation and any delay in harvest can reduce both quantity and quality of production.Therefore, it is important to select and manage combine harvesters that can fulfil the harvesting operation properly [11, 12, 13,].Wheat is an important food and cash crop in Sudan and grown in the irrigated agricultural sector and mainly in the northern states. The annual cultivated area ranged between 200 – 400 thousand hectares[14, 15]. There are many farm machineries and tractors which are used to carry out the field operation within the available working hours and of variable costs. Management and selection of these machinery is complicated and need more powerful tools for proper decision making, therefore the main objective of this study was to develop a computer system to select the size and numbers of combine harvesters required to perform timely wheat crop harvesting operation at Dongola area, Northern Sudan, within the planned areaand period of time at reasonable costs.

II. MATERIALS AND METHODS

2.1 The study area

The study was conducted in Northern State of Sudan which lies between latitudes 16 ^{o} - 22^o N and longitudes 20^o-32^o E. The total area of the Northern State is about 85.5 million Feddan, about 5% of which is suitable for agricultural production. The total planned area to be cultivated by Wheat crop was 50.000ha. The soils are divided into two main groups, namely soil of recent flood plain and soil of upper terrace[16]. There are different types and makes of tractors and machineries are used in the area to carry out farm operations, but the maim combine harvester makes used are FOTTON 4Lz(2.70m),SONALIKA International (4.20m) andClass dominator130 (4.30m)

2.2 Datarequired for system development

The required input data to for system development were collected from many sources, such as John Deer publications. [17] standard, mechanized Farming Corporation, field observations. agricultural engineers and agricultural machinery dealers. The collected data included type and size of machine (tractor and implement), workingspeed, field efficiency (%), actual combinecapacity (area/time) and fuel consumption rate, machinery initial price (SDG), available working days and working hours per day.

2.3 programdevelopment and description

A computer program was developed to predict the performance of machinery used in the selected operation in addition to predict machinery costsper hour. Data entry is step by step process in specifically designed files.On the other hand; data input canbe corrected directly on the screen. Moreover, the system output can be displayed on the screen or printed out.

The developed farm machinery management system was designed to calculate implement performance effective field capacity (EFC), tractor fuel consumption, number of required combines to cover the planned area, combine fixed and variable costs and total harvesting operation cost per hour. The user has the choice to select the tractor and implement that used to cover the planned area for the specific operation. All procedures work collectively. The system flow chart was described in Figure 1.

2.4 Machinery performance calculations procedure

Machine capacity equation: Based on the equation given by[18, 3, 19],machinery performance can be calculated as follows:

Effective field capacity (EFC) = S.W.E /C

Where:

EFC =Effective field capacity (ha /h).

S= Machine working speed (km /h).

W =Machine width (m).

E= Field efficiency (%).

C= Constant= 10

Combine harvester cost calculation

Combine harvester Fixed Cost (HFC) =0.298 of purchase price as mentioned by [20].

Combine harvester Variable Cost (HVC), included repair and maintenance costs (R&M), fuel cost, oil cost and labor cost which Calculated as a percentage of purchase price depends on annual hours of use as stated by by[20].

Combine harvester oil (HO c) = 15% of fuel cost SDG

Farm operations cost per hour = Operation Fixed cost /h + Operation Variable cost /h (SDG/h)

Operation cost / ha =

$$\frac{Operation\ cost/hr\ (\frac{SDG}{hr})}{Machine\ capacity(EFC)\ ha/hr}\ (SDG)[2]$$

Number of required machines for field operationCalculated according to equation suggested by [21] as follows

$$\text{Number of required machines} = \frac{A}{EFC \times Ann\ hrs}$$

Where,

A = area to be covered (ha)

EFC = effective field capacity (ha/hr)

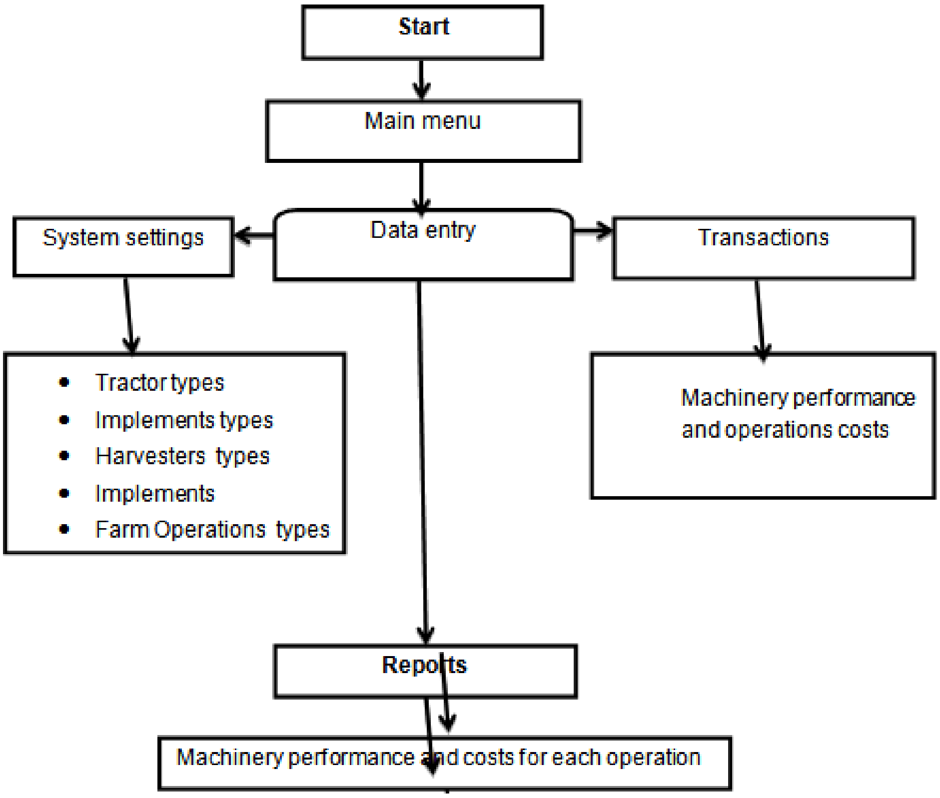
Ann.hrs. = annual hours of use

2.5 System implementation and optimization

According to the study objective, the out puts effective machine capacities (EFC) for different machine sizes (ha/hr) and their corresponding costs (SDG/hr) in addition to the collected field data concerning harvesting operation of wheat crop in Dongola area, are used to formulate linear programing problems (maximization) of machine size (EFC) wishing optimization of size and cost of machinery in each operation, applying (OR) tool simplex method technique[22].

2.6Statistical analysis and test of the system accuracy

To test the system accuracy, a comparison was carried between computer system predicted results, and that field actual. Excel 2007 application and T-test statistical techniques using IBMSPSS 26 software was used to analyze and compare the significance test between the predicted and actual results and to test the accuracy of the system.



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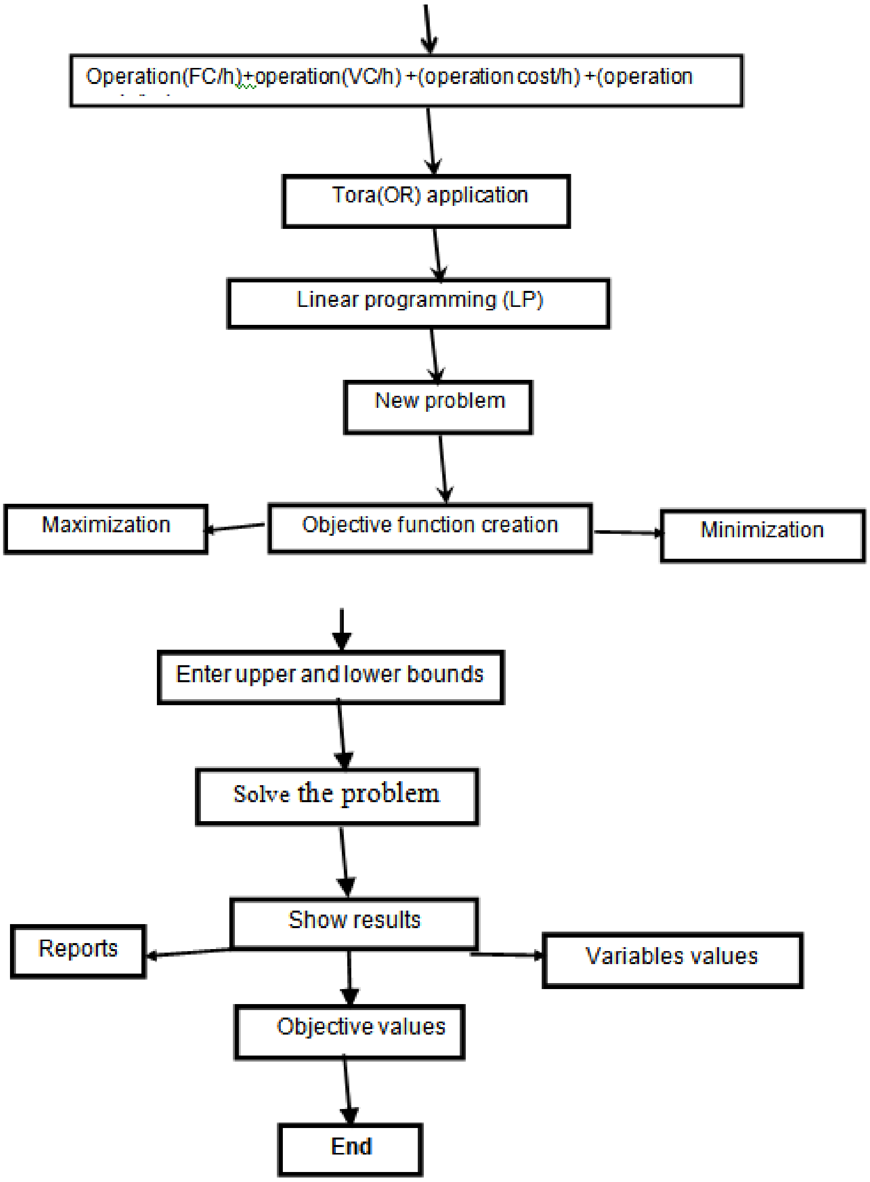

Figure 1 Program flowchart

III. RESULTS AND DISCUSSION

3.1 Computer system development

The developed system allows the user to inter-act with its components through the entered data then predicted results and reports can be obtained in the screen and/or printed out. The system contains data of various types of combine harvesting machinery. The system composed of two sections:

1st Section contains two units: -

1/ Machinery performance unit: It is used to calculate and estimate effective field capacity (EFC) in (ha/hr) for different machines used in the selected operations.

2/ Field operations cost unit: In this unit fixed cost (FC) and variable cost (VC) for different tractors power and seed drill used in each of the selected operation can be calculated and consequently field operation cost per hour (SDG/hr) and operation cost (SDG/ ha) can be estimated.

2nd Sectioncontains output reports of machine field capacity (EFC in ha/hr) and field operation cost (SDG/hr). Through employing operation research (OR) using linear programming (LP) software and applying simplex method, with consideration of machine effective field capacity (ha/hr) as objective function coefficients, (machine

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numbers, working hours/ day and operation cost per hour) as decision variables coefficients and (total machine numbers, total operation cost per hour according to the assumed budget and annual hours of use) as constraints (available resources) for the harvesting operation. This case considered as linear programming production problem (maximization) that can be solved by application of simplex method maximization technique[23].

3.2System validation by estimate effective field capacity (ha/h)and cost (SDG/hr) of combine harvester

As shown in Table 1, three types of combine harvesters namely; Class dominator 130 (4.30m), SONALIKA international (4.20 m) and FOTTON 4Lz2 were used to predict the EFC and total cost and compare withtheir actual field performance and cost of operation.The predicted field performance significantly ($P \leq 0.05$) increased as compared to the actual field performance of combine harvesters. The predicted effective field capacity (EFC) increased by 13% for SONALIKA International and 19% for FOTTON 4Lz2 compared to actual effective field capacity, while it was decreased by 4% under Class dominator 130 combine harvester. These results may be attributed to the variations in machinery management which significantly affected on the field performance. Width of the implement was found to have a noticed effect in improving and determining the field efficiency, this mainly due to that, width is fixed for one machine as reported by [4]. Statistical analysis of paired samples correlations (predicted and actual EFC) for harvesting machinery. showed positive and strong correlations between the two parameters (R^2=0.950). This proves that the developed program is valid to estimate EFC for harvesting machinery with a high level of confidence.

Table 1 System predicted and actual EFC (ha/h) and total operation cost for combine harvesters

Operation	Machine	Predicted	Actual	Comparative (%)
EFC	FOTTON4Lz2 (2.70m)	0.945	0.788	119
	SONALIKA International (4.20m)	1.4945	1.313	113
	Class dominator 130 (4.30m)	1.505	1.575	96
Total cost	FOTTON 4Lz2 (2.70m)	174841.33	202400	86
	SONALIKA International(4.20m)	150743.16	186644	81
	Claas dominator 130(4.30m)	253587.82	279600	91

It was observed that the actual total combine harvester operation costs were higher than the system predicted total operation cost (table 1). The larger size combine harvester (4.30m) gave the highest operation cost per hour followed by combine harvester of size (2.70 m) as compared to medium size combine harvester (4.20m) which ranked the least. The results agreed with results obtained by [19].The variations between actual and predicted harvesting costs may be attributed to the high market prices of spare parts, the high percentage rate (%) of inflation in addition to the fact that repair and maintenance costs (R&M) costs increased with increasing machine life as mentioned by [3]. Moreover, in developing countries, the cost of repairs is considerably higher due to sometimes lack of knowledge of proper operation and maintenance. Statistical analysis of correlations between predicted and actual total operation costs for the harvesting operation showed positive correlations between predicted and actual total costs (R^2=0.864). The results confirmed that the developing program is valid to estimate total operation costs for the present operation with a high level of accuracy.

3.3 Sensitivity analysis of the program

The sensitivity analysis of the system was carried out to show the effect of changing one or more of the input parameters on the program outputs.The input variables include, machine width or size (m), speed (km/h) and expected efficiency (%). Tables, 2, shows that, as the width increased all combine harvesters recorded higher EFC. For

FOTTON 4z2 combine harvester the EFC increased by 86%, while for SONALIKA and Claas dominator, the increase was 18% and 23% respectively. The results agreed with[24],who reported that the lost time due to small width is the most important factor that affects the field capacity and efficiency of a machine. Increasing Claas dominator130, working speed from 5.00 Km/h to 7.00Km/h, recorded the highest increase mean values of EFC while FOTTON4Lz2 gave the lowest (Table 3). The obtained results showed that any increase in the implement working speed increases effective field capacity (ha/h), but this increase should be limited to an extent that keeps the implement operate to its optimum quality. The results are in agreement with the result obtained by [19] and[2]. Table 4 shows that decreasing field efficiency from 70 percentage to 60 percentage of the combine harvesters observed reduced the effective field capacity by 0.215, 0.210 ha/h and 0.135 ha/h for Class dominator 130, SONALIKA international and FOTTON 4Lz2, respectively. The obtained results showed that any decrease in field efficiency resulted in decreased machine effective field capacity (ha/h). The results were in agreement with the result obtained by [2].

Table 2. Effect of increasing machine width on effective field capacity (ha/h)

Implement	Width (m)	Speed (Km/h)	Efficiency (%)	EFC (ha/h)
FOTTON 4Lz2	2.70	5.00	70	0.945
	5.00			1.755
SONALIKAInternational	4.20	5.00	70	1.490
	5,00			1.755
CLAAS dominator 130	4.30	5.00	70	1.505
	5.30			1.855

Table 3. Effect of increasing working speed on machine effective field capacity (ha/h)

Machine	Width (m)	Speed (km/h)	Efficiency (%)	EFC (ha/h)
FOTTON4Lz2	2.70	5.00		0.945
		7.00	70	1.323
SONALIKA International	4.20	5.00		1.495
		7.00	70	2.058
Class dominator 130	4.30	5.00		1.505
		7.00	70	2.107

Table 4. Effect of decreasing machine efficiency on EFC (ha/h)

Machine	Width (m)	Speed (Km/h)	Efficiency (%)	EFC (ha/h)
FOTTON4Lz2	2.70	5.00	70	0.945
			60	0.810
SONALIKA International	4.20	5.00	70	1.470
			60	1.260
Class dominator 130	4.30	5.00	70	1.5.05
			60	1.290

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The results in Table 5 showed that, whenever annual working hours of farm machinery increased, the average annual costs decrease till it reaches the lowest value then it start to increase gradually with the increase of working area and variable costs. Class dominator 130 and SONALIKA international combine harvesters recorded lower values of operation cost when annual hours of use was increased from 765 to 900hours, while decreasing of annual hours of use for FOTTON4Lz2 combine harvester increased the operation cost per hour. The results are agreed to that obtained by [3] who mentioned that, one way or method to reduce machinery fixed costs (FC) per hour is the highly annual use of the machine per season. While [21] stated that fixed costs don't depend upon annual hours of use, but it is affected by it.

Table 5 Effect of changing annual hours of use on harvesting operation costs (FC/h)

Combine harvester make	Purchase price(SDG)	Annual hours of use	Predicted operation cost/h SDG
FOTTON4LZ2(2.70m)	160000	765	62.3267
		510	93.4902
SONALIKA International(4.27m)	3000000	765	1168.6274
		935	956.1497
Class Dominator130(4.30m)	250000	765	97.3856
		900	87.6471

3.4 Effect of developed system on decision making

The developed system had ability to predict No. of required machine as well as No. of required labors in addition to the total cost and machine field performance.Table 6 showed that, according to the developed system, the harvesting operation requires 69 small machine size Fotton4LZ2(2.70m) and 138labors to accomplish the harvesting operation with operation costs per hour of 228.55 SDG/h. Relying on small machines will increase the risk of inability to perform the operation in time due to its small capacity (EFC), while medium machine sizes need less number of machines and labors than small ones, but higher costs should be considered. On the other hand, the large machines requirea smaller number of machines and labors to operate (86 machine and 43 labour). Risk of timeliness is reduced during the peak period to its minimum due to large machine capacity (EFC). Hence**,** optimization of different machine capacities (EFC) becomes the best choice to be adopted to utilize time, operation costs (SDG/h) and other production resources as mentioned by [21]. Moreover. The system outputs enable Agricultural System Managers (ASM) to better manipulate inputs and save production resources since optimization operation defined as finding an alternative with most costs effective or higher achieved performance.

Table 6. Machinery options harvesting operations

Machine	Size (m)	EFC (ha/h)	No.of required machines	No. of required labors	Cos per hour (SDG)
FOTTON4LZ2	2.70	0.945	69	138	228.5507
SONALIKA International	4.20	1.495	44	88	1970.4982
Class dominator 130	4.30	1.505	43	86	331.4873

3.5 Satisfaction of the system purpose for the harvesting operation

Since optimization means finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing the desired factors and minimizing undesired ones. As shown in Table7, the program system had achieved the study goals (optimization costs and maximizing of machinery performance according to machine sizes for the harvest operation in addition to the developed system will be validated by testing the achievements of these targeted objectives. Moreover, the developed system predicted the required machine before and after optimization as well as the No. of labor before and after optimization for each operation (table 7).

As presented in Tables 8, the reduction in machines number after optimization, significantly decreased the overall operation cost per hour for the harvesting operation. Small size machines (2.7m) reduced the overall cost of operation from 15769.91 SDG to zero cost (reduction percentage 100%), while for medium size machines (4.2m) reduction percentage was 95%. %. On the other hand, the overall operation costs per hour for large size implements (4.30m) does not change because the required number of machines does not change after optimization [25].

Table 7. Satisfaction of the system purpose for harvesting operation

Combine harvester	Size (m)	Required No. before optimization	Required No. after optimization	Needed No. of labors before optimization	Needed No.of labors after optimization
FOTTON 4Lz2	2.70	69	0	138	0
SONALIKInternational	4.20	44	2	88	4
Class dominator 130	4.30	43	43	86	86

Table 8. Effect of optimization on combine harvesters operation costs per hour

Combine harvester name & size	Required No. before optimization	Required No. after optimization	Operation costs (SDG/h) before optimization	Overall harvesters cost (SDG/h) before optimization	Overall harvesters costs (SDG/h) after optimization
FOTON 4Lz (2.70m)	69	0	228.5506	15769.914	0
SOALIKA International (4.20m)	44	2	1970.4982	86701.9208	3940.9964
Class dominator 130 (4.30)	43	43	331.4873	14253.9539	14253.9539
Total operation costs (SDG/h)				116725.7887	18194.9503

3.6 Sensitivity analysis of linear program (LP) solution for planting operation

Table 9 presented the sensitivity analysis of (LP) of harvesting operation and showed that decreasing (RHS) budget constraint (SDG) leads into changes to feasible region of the solution, and it gives a new optimal solution with a new objective value (67.33ha/h - 5150745ha/season) which is lower than the first optimal solution, while increasing the (RHS) annual hours of use constraint, translated into changes in feasible solution which resulted a new objective value (82.66ha/h- 632349 ha/season) which is the highest among the others. The results were in agreement with result obtained by [26], who mentioned that selection the optimum width of implements in addition to adjusting machines were found to have a noticed effect in improving the field capacity and efficiency.

IV. CONCLUSIONS

The following conclusions may be drawn from the results of present study:

1. A computer system program was designed and developed to estimate effective field capacity (EFC), fixed costs (FC) and variable costs (VC) for different sizes of combine harvesting machinery used for wheat production in Dongola area.
2. The developed system was verified, validated and statistically analysed by comparing the predicted with the actual field data and proved to be fairly accurate.
3. Linear and integer programming (LP) software (Tora) was used in the maximization problems to optimize machinery sizes and costs for machinery used and results revealed that using different machine capacities was the best option among many other alternatives considering time and costs and available machine numbers as main constraints that restricts maximization.
4. The developed computer program showed that after optimization the numbers of planting machines predicted were two of 4.20m and forty three of 4.30 m in size and costing 3941.0 and 14254.0 SDG/h respectively.

Table 9. Sensitivity analysis of linear program (LP) solution for harvesting operation

Type of the changed constraint	Constraints value (RHS)	Decision variables	Solution value	Objective function (max) value
Budget/h (SDG)	94117.6470	X1	0	67.71
Available number ofcombine harvesters	55	X2	2	
Annual hours of use (h)	765	X3	43	
Decreasing RHS (Budget/r)	17000	X1	**0**	**67.33**
	55	X2	1.31	
	765	X3	43	
Decreasing RHS (total number of harvesters)	94117.6470	X1	0	60.20
	40	X2	**0**	
	765	X3	4	
Increasing RHS(annual hours of use)	55	X1	0	82.66
	94117.6470	X2	12	
	1000	X3	**43**	

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