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Crop-machinery management system for field operations and farm machinery selection

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The main objective of this study is to develop a computer system for farm management and selection of required farm machinery to perform field operations in time for crops grown in rotations. Excel and Visual basic software were used to develop the program. The input data included 4 crops (sorghum, sesame, sunflower and cotton), 3 field operations (seedbed preparation, seeding, and weeding operations) and 3 farming systems (zero-tillage, conventional, and heavy machines farming systems). In addition, tractor and 6 implements (wide level disk, disk harrow, chisel plow, row crop planter, inter-row cultivator and sprayer) were also used. The system estimates the size and number of machine, power requirement and fuel consumption for the implements and operations. Verification showed that, the system has the ability to estimate the required parameters as soon as input data was entered. System validation indicated no significant differences between predicted results and actual data. The sensitivity analysis showed that, changing of input variables affects the output parameters and consequently selection is possible. The system was applied to estimate the required output variables in the mechanized rainfed agriculture in Gedarif, Sudan. It can be used for proper crop and machinery management as pre-season decision making with great confidence.

Key words: Crop production, machine selection, farm management, computer system.

INTRODUCTION

Farm mechanization is the use of machines for production process. Crop production involves sequence of actions, operations and other factors that affect production. A good farm management plan has to analyze the whole farming system for maximizing production and minimizing risks. The farm manager has to study the relationships between machines, weather and crop combinations. Management can more or less control machine capacity (machine width, speed, and field efficiency), as well as selection of implement, operation and crop. Computer systems can facilitate the examination of these relationships.

Many computer systems were developed elsewhere to analyze the factors that affect field operations and machinery performance. The purposes of these systems varied from power selection and implement matching (Dahab and Mohamed, 2006; Alam et al., 2001; Bol et al., 2006; Yousif and Dahab, 2010), to systems incorporate farm size, cropping patterns, soil properties and climatic conditions to calculate tractor power, machine width and estimating costs (Isik and Sabanci, 1993; Ismail and Burkhardt, 1994). Other systems deal with special crops (Parmar et al., 1994; Dahab and O'Callagham, 1998).

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Management of rainfed agriculture is a complex process. The complexity is due to the nature of various and interrelated factors involve in crop production process. These factors include; selection of crops and agricultural machinery (tractors and implements), the expected working time for field operation, inputs cost and outputs prices. It is believed that, promotion of farm management can be realized by the use of modern techniques like computer and softwares. Computer systems can facilitate the process of planning and decision making. Therefore, a computer system was developed to be used as a tool for crops -machinery management. The goals of the system were to select the number and size of machinery (tractor and implement) required to perform timely seedbed preparation, seeding and weed control operations for 4 crops; sorghum, sesame, sunflower and cotton grown in 1, 2, 3, and 4 crops combination.

MATERIALS AND METHODS

Characteristics of the study area

The study was conducted in Gedarif State, which lies in the Eastern part of the Sudan between latitudes 12.67 and 15.75°N and longitudes 33.57 and 37.0°E, where about more than 3 000 000 ha are put under cultivation. The soil is heavy cracking clay soils (Vertisols), which was characterized by shrinking when dried and swelling when moistened. The clay content ranged between 65 and 75%.

Crops grown and field operations

Sorghum is a dominant grown crop, constitutes about 85% of the cropped area, followed by sesame, while sunflower and cotton are sown in limited areas where rain amount is sufficient for their growth. Land preparation and seeding operations usually start when the accumulative rainfall reaches about 100 to 125 mm, which is sufficient for establishing crops. This usually occurs during the second and third week of July. The wide level disk plow is the main machine used for seedbed preparation and seeding operations. However, deep plowing (chiseling) and shallow plowing (disk harrowing) and row crop planter are sometimes practiced in limited areas. Weed control usually starts 2 to 4 weeks after crops germination. Hand weeding is the common practice, however, due to shortage and high expense of labors, mechanical weed control (Sarwala operation) by WLD as well as herbicides application are recently adopted. Tractors of 75 to 80 ha are the main source of farm power; however, big tractors were recently introduced to operate large and heavy implements for improving timeliness of agricultural operations. According to the used machinery and cultural practices there are three farming system practiced; namely conventional, zero-tillage and heavy machinery farming systems. The mechanized farming system consists of large commercial farms 210 to 420 ha or more.

Data collection and analysis

The required input data to run the developed system is collected from many sources, such as agricultural engineers, Agricultural Research Corporation (ARC) Reports, Mechanized Farming Corporation (MFC), field observations, ASABE standard, John Deer publications, and agricultural machinery dealers. The collected data include; crops and their operations and type and size of machine, field efficiency, speed, draft requirement, machinery capacity, fuel consumption rates.

Statistical measures employing mean, standard deviation, maximum and minimum, correlation analysis were used as data analysis tools. Also, T-test was used to compare and test the significance between the predicted and actual data. Moreover, the Root mean square error (RMSE) criterion was used to compare the values of the predictions and actual data. The RMSE was calculated as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n=5}\left(\left(predicted\right)_i - \left(actual\right)_i\right)^2}$$

Where: n = number of observation, i = different, predicted = unit predicted values and actual = actual values.

Computer system development

System structure

The system was developed in Excel and Visual basic computer softwares. Data entry is a step by step process in specifically designed cells. The user is always given the freedom to use site specific data or use built-in data. Data input can be corrected done directly on screen. The system output can be displayed on the screen or as print out.

System description

The crop production and farm machinery combination management system was designed to work with a sequence of procedures, crop and implement procedure, farm machinery management procedure and farm costs analysis procedure. All procedures work collectively. The system flow chart was described in Figure 1.

Crop and implement selection procedure

This is the basic procedure for the whole system, which allows the user to choose crops and required field operations. The designed options of crops were 1, 2, 3, or 4 crop combinations. The designed crops were sorghum, sesame, sunflower and cotton. The system deals with 3 operations; seedbed, seeding, and weed control; via 6 implements namely; chisel plow, disk harrow, wide level disk, row-crop - planter, inter-row-cultivator and sprayer. The wide level disk with the seeder box may be used for seedbed, seeding and weed control (Sarwala) operations. The user has to enter the

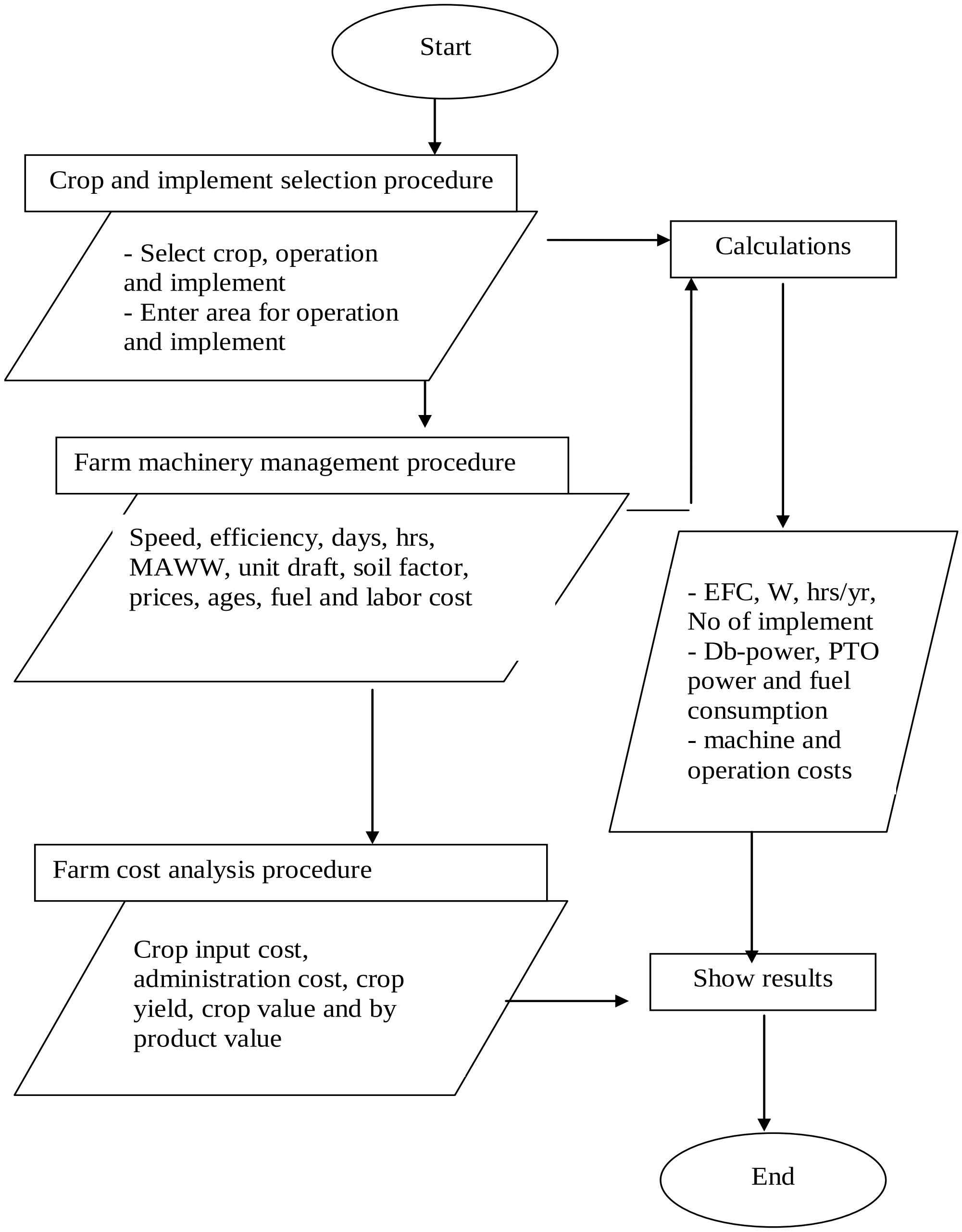

Figure 1. Crop and machinery management unit flow chart.

area (ha) to be cultivated across each crop, operation and machine. The system computes the total cultivated area for each crop according to the selected seedbed preparation methods. Also, the system computes the total area of each implement for all crops or operations.

Machinery management procedure

This procedure deals with machinery (implements and tractor). It uses the intended operations, area to be covered and implement type that had been specified in the crop production procedure. It consists of 3 sub-procedures; machinery selection, power requirement and machinery costs.

The machinery selection sub-procedure computes the size and the number of implements and power units required to complete field operations during specific period of time by computing effective field capacity (ha/h). The required input data include: speed of field operation, field efficiency, available working days, and available working hours per day.

The machinery power requirement sub-procedure determines the required drawbar power (kw), tractor PTO power (kw) and fuel consumption (L/h) for the selected implement. The required input data include: unit draft (kn/m) and soil condition factor.

Implement selection calculations

Field capacity

The effective field capacity (EFC) (ha/h) is calculated using total area and total available time as follows:

EFC (ha/h) = A/(D × h) (1)

Where: A = area under operation (ha), D = available working days and hr = available working hours per day.

Required width

The required working width (W) (m) of a machine is calculated as follows:
W = (EFC × C)/Se (2)

Where: C = conversion factor = 10, S = field speed (km/hr) and e = field efficiency of the machine, decimal.

Number of machine(s) required

The number of the machine(s) required is calculated as follows:

Number of M = W/MAWW (3)

Where, Number of M = number of machine required and MAWW = maximum available working width (m).

Machinery power requirement

Drawbar power

The drawbar power (DBHP), (kw) for an implement is calculated as follows:

DBHP = (S × D × W)/ 3.6 (4)

Where: D = Unit draft (kn/m)

Tractor take – off shaft power

Tractor PTO required power (TPTO) is calculated using implement drawbar power and soil condition factor as follows:

TPTO = DBHP × soil condition factor × 1.25 (5)

Fuel consumption

Fuel consumption for diesel engine is calculated according to the method described by (FMO, 1976) as follows:

Fuel consumption (L/hr) = DBHP (kw) × 0.226 (6)

RESULTS AND DISCUSSION

System verification

The system was verified for the implement width, effective field capacity, drawbar power, required PTO power and fuel consumption by using published data from Sumner and William (2007) as shown in Table 1. It was observed that, as soon as entering input data the unit displays the results. The predicted results were identical to that obtained by Sumner and William (2007). This means that, the unit is able to calculate the required parameters correctly.

System validation

The system validity was tested for the five implements to compare between actual and predicted effective field capacity (ha/h), implements width (m) and fuel consumption (L/h) as shown in Table 2. The root mean square of the error criterion was used as a comparison measure. The results showed very low RMSE (0.179), (1.095), and (0.1612) between the predicted and actual data for effective capacity, implements width (m) and fuel consumption (L/h), respectively (Table 2). Moreover, Paired T-test indicates no significant difference (at 5%) between the system predictions and actual data (Table 3). These indicate a high consistency between actual data and the system predictions.

System Sensitivity analysis

Effect of changing cropped area on number of implement

Increasing cultivated area from 420 to 3780 ha, the number of machines changed from 1 machine to 3, 6, 9, 9, 5, and 3 machines for wide level disk, disk harrow, chisel plow, row crop planter, inter-row cultivator and sprayer, respectively (Table 4). The results demonstrated that, chisel plow and row crop planter are highly sensitive to the changes in area. This may be due to their effective width, working speed or available working hours per day.

Table 1. Verification of the unit with published data.

Input variable	Input data for Sumner and William (2007) and the model	
Implement name	Disk harrow	
Area, ha	49	
Days	5	
Hours/day	8	
Speed Km/h	8.1	
Efficiency, decimal	0.82	
Maximum available width, m	1.8	
Unit draft, kn/m	5.37	
Output parameter	**Sumner and William (2007)**	**Model prediction**
Implement width, m	1.82	1.80
Effective field capacity, ha/h	1.21	1.20
Drawbar power, kw	21.94	21.75
Required PTO power, kw	46.12	46.00
Fuel consumption, L/h	10.00	10.00

Table 2. Comparison between predicted and actual field capacity (ha/h).

Machine name	Field capacity (ha/h)		Fuel consumption (L/h)		Implement width (m)	
	predicted	actual	predicted	actual	predicted	Actual
Wide level disk	2.7	2.9	11	12	3.6	3.7
Offset disk harrow	1.4	1.5	11	13	1.6	1.7
Chisel plow	1.3	1.4	13	13	1.9	2
Row crop planter	1.9	1.8	12	13	3.3	3.2
Sprayer	9.6	9.9	0.2	0.2	13.7	14
RMSE	0.179		1.095		0.1612	

RMSE = root mean square of the error.

Table 3. T-test for the mean difference of the evaluation indicators for system outputs and field data.

Statistical parameter	Field capacity (ha/h)	Fuel consumption (L/h)	width (m)
Variance of the difference between the means	0.0044	0.1400	0.004
Standard deviation of the difference	0.0663	0.3742	0.0632
Effective degree of freedom	4	4.0	4.0
Probability of t	0.1447	0.0993	0.1890
f-calculated	1.0661	1.1578	1.0418
T-calculated	-1.8091	- 2.1381	-1.5811
T-tabulated	2.776	2.776	2.776

On the other hand, WLD and sprayer are less sensitive to the changes in cultivated area.

Effect of changing annual workdays on implements width

The system was used to determine optimum machine width when changing annual working days. The results showed that, at specific cultivated area (e.g., 420 ha), changing annual working days changed the required width of each implement. This helps the farm manager to select the suitable working width of a machine according to the available working days and farm size. The results also indicated that, the predicted working width for all studied machines decreased as annual working days

Table 4. Effect of changing cropped area on number of machines for different operations.

Area (ha)	WLD	DH	CP	RCP	IRC	SP
420	1	1	1	1	1	1
1260	1	2	3	3	2	1
2100	2	3	5	5	3	2
2940	2	4	7	7	4	2
3780	3	6	9	9	5	3

WLD = wide level disk, DH = disk harrow, CP = chisel plow, RCP = row crop planter, IRC = inter-row cultivator and SP = sprayer.

Table 5. Effect of changing workdays on machines width.

Working days	WLD	DH	CP	RCP	IRC	SP
9	3.6	3.2	3.8	8.0	5.0	7.6
12	2.7	2.4	2.9	6.0	3.7	5.7
15	2.2	1.9	2.3	4.8	3.0	4.6
18	1.8	1.6	1.9	4.0	2.5	3.8
21	1.5	1.4	1.6	3.4	2.1	3.3
24	1.4	1.2	1.4	3.0	1.9	2.8
27	1.2	1.1	1.3	2.7	1.7	2.5
30	1.1	1.0	1.1	2.4	1.5	2.3
33	1.0	0.9	1.0	2.2	1.4	2.1

*Using total area of 420 ha, WLD = wide level disk, DH = disk harrow, CP = chisel plow, RCP = row crop planter, IRC = inter-row cultivator and SP = sprayer.

Table 6. Effect of changing soil factor on power required (kw) for different machines.

Soil factor	WLD	DH	CP	RCP	IRC
Firm (1)	51	42	58	43	29
Tilled (2)	61	50	69	52	35
Sandy or soft soils (3)	71	59	81	60	41

WLD = wide level disk, DH = disk harrow, CP = chisel plow, RCP = row crop planter and IRC = inter-row cultivator

increased (Table 5). This confirms the fact that, there is a reverse relationship between cultivated area and working time.

Effect of changing soil type on implements power requirements

The system offers the user three choices for changing soil conditions which are firm, tilled and sandy or soft soils, and then the system computes the required drawbar power for the selected implements. Table 6 shows the effect of changing soil condition factor on power requirements for the selected implements. For all tested implements, the power requirements in Kilowatts increased as soil factor changed from firm to tilled and sandy or soft soils.

Effect of the cropping system on power requirement and fuel consumption

The results showed that, conventional farming system gave the smallest values of power required, fuel consumed as well as operation cost per hour and per hectare (Table 7). These findings explain why farmers still hold on to conventional cropping system. In contrast heavy machinery system resulted in the highest values of the mentioned parameters. In this regard, Alam et al. (2001) found that, optimum power level varied with the size of farmland and cropping patterns. However, zero tillage seems to be time effective and can be used as a

Table 7. Effect of cropping system on tractor annual working hours, power requirement, fuel consumption and operations cost.

Cropping system	Tractor annual working hour	Maximum fuel consumption L/ha	Maximum power required (kw)	Operation cost (SDG/h)	Operation cost (SDG/ha)
CFS	468	11	51	123.05	46.19
ZTFS	310	12	52	394.08	122.81
HMFS	589	13	58	494.88	178.88

CFS = conventional farming system, HMFS = heavy machine farming system, ZTFS = zero tillage farming system.

farming system when all requirements for its successes are available. These results can help the user in pre season planning and management.

Conclusions

A computer system for crop-machinery management was developed. The developed system is user-friendly and could be run on most available computers. The system was validated and statistically analyzed by comparing the predicted output to the actual data and its accuracy was approved. The system can quickly be used to explore the effect of changing one or more of input parameters on output variables, and thus can help in quick decision-making. The system can be used as pre-season planning and management tool.

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