A computer Model of Fuel Consumption Estimation for Different Agricultural Farm operations

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Abstract— *A computer programme was developed to estimate fuel consumption rate in liter per hour for medium agric-tractor with load and without load under different soil conditions. The programme enables the user to insert the input data through the input interface and obtain the output rapidly. The model was verified, validated and tested by using data from literature and a private agricultural services company in Sudan, for two types of heavy disc harrow (AH280, BH360), (H56,CH65C) driven by challenger track tractors, on the other hand, seeder and ridger separately operated with wheeled 4WD tractors. It was also tested by data from Sennar Agricultural Services Center, using heavy disc harrow with 4WD tractor. The sensitivity analysis showed that the change in any of input parameters, e.g. speed, unit draft, engine power affected directly the estimated fuel consumption rate. Accordingly, the computer programme performed very well in estimating fuel consumption and can be used as a good guide to the farmer or any interested person in machinery management and for quick decision-making.*

Keywords— Computer, programming, prediction, fuel, tractor, consumption.

I. INTRODUCTION

The primary purpose of agricultural tractors is to perform dynamic drawbar works (Zoz and Grisso 2003). The value of a tractor may be measured by the amount of work carried out relative to the cost incurred in getting the work done. Therefore, the ideal tractor converts most of the energy from the fuel consumed into useful work at its drawbar.

Several methods have been used for fuel consumption prediction, some of these methods are generally based on power requirements and others are for individual engines, which require extensive engine testing to verify the amount of consumption. Grisso *et al.* (2004) developed a general model to predict fuel consumption for full and partial loads and for reduced throttle conditions using data from Nebraska Tractor Test Lab (NTTL) in U.S.A. for a specific tractor models. Using these, mathematical equations make it possible to predict fuel savings for different operating and loading tractor conditions (Grisso *et al.* (2008).

An artificial neural network (ANN) approach was used to model fuel consumption of wheat production. The developed model is capable of predicting fuel consumption under different field conditions and can help farmers to reduce their expenditure (Safa *et al.* 2009). According to Siemens and Bowers (1999), and depending on the type of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs usually represent at least 16% to over 45% of the total machine costs.

Since most tractors tested and used for agricultural purposes in the last 25 years have had diesel engines, the following equation may be used for diesel engines fuel consumption estimation:

$$Q_{avg} = 0.223 \times P_{pto} \quad \text{(Bower 2001).}$$

Where:

Q_{avg} = average diesel fuel consumption, L/h

P_{pto} = maximum PTO power, kW

The average fuel consumption of a tractor operating under a range of load conditions, over a period of time may be determined by using the power ratio (PR) as in the following equation (ASAE 2002):

$$Q = 2.64PR+3.91- 0.203\sqrt{738PR+173}$$

This equation estimates the specific volumetric fuel consumption (SVFC) in L/kW-h along the full throttle or governor response curve. It does not provide estimates of the fuel consumption during reduced engine speed settings that are often recommended for partial load applications. Kotzabassis *et al.* (1994) reported that the volumetric fuel consumption for a diesel engine at partial loads and full throttle can be calculated as

$$Q = (2.64PR+3.91-0.203\sqrt{738PR+173}) \times PR \times Ppto$$

where :

Q = diesel fuel consumption at partial load, L/h (gal/h)

PR= the ratio of equivalent PTO power (PT) to rated PTO power (Ppto), decimal

As the technology is becoming increasingly integral part of our lives, the computer is considered one of the most modern technologies that are used in statistical analysis of agricultural information and in taking decisions for managing agricultural implements. There are other computer models developed for analyzing machinery performance and management decision-making (Ruiyin *et al*. 1999; Mechalilie 1996). Computers are used also to record, keep and analyze agricultural information. Computer programmes consisting of mathematical equations are developed to estimate the cost of agricultural operation performance, to choose suitable implements and to evaluate and apply production inputs such as irrigation water, fertilizers and chemical pesticides (Landers 1992; Alam *et al*. 2001; Dahab and Mohamed 2006; Dahab *et al*. 2009).

The main objective of the present study was to estimate fuel consumption rate of agricultural farm operations by computer programming. This may be achieved through

1. Developing a computer model with programming language that can help in estimation of fuel consumption for tractor with implement.
2. verifying and validating the programme by actual field data, and testing its sensitivity and accuracy

II. MATERIALS AND METHODS

2.1 Model Development

The fuel consumption estimation programme is written in visual basic language to be used in personal computer easily and to assist in machinery decision making about fuel consumption of tractor alone or with implement.

The programme is built up of two procedures. The first one contains two methods, which compute the fuel consumption of tractor with implements. One of these methods computes fuel with loading the engine and the other one uses the specific fuel consumption equation.

The second procedure computes the fuel consumption of tractor without the implement (Figures 1, 2 and 3).

In each procedure, the input data are given directly and the output data are obtained in screen. The programme file has the ability to change input data to suit the system of measurement used.

2.2 Procedures Description

2.2.1 Procedure One: Tractor with implement (operations)

In this procedure, two files are built up. In each one, the same data but different equations are used to estimate fuel consumption.

2.2.1.1 Method one: Fuel consumption estimate depending on tractor engine load as follows:

$$1\text{- DBP} = \frac{\text{Unit Draft} \times \text{width} \times \text{Speed}}{Cf}$$

$$\text{2- Required PTO power} = \frac{\text{DBP}}{\text{TC}}$$

3- Maximum PTO power = Rated engine power × TE

$$\text{4- Engine load or PR} = \frac{\text{Required PTO power}}{\text{Max. PTO power}}$$

$$\text{5- Fuel consumption} = \frac{\text{Require PTO}}{\text{ECF}}$$

Where:

DBP = drawbar horsepower, kW

Unit Draft =draft of implement/width, kN /m

Speed =working speed, km/h

TC = Traction coefficient (depends on type of soil)

TE =transmission efficiency

ECF =coefficient of energy conversion, kW.h/L (Nebraska test table)

Cf =conversion factor, 3.6

2.2.1.2 Method two: Fuel consumption estimate with specific fuel equation.

$$\text{1- DBP} = \frac{\text{Unit Draft} \times \text{width} \times \text{Speed}}{\text{Cf}}$$

$$\text{2-Require PTO power} = \frac{\text{DBP}}{\text{TE}}$$

$$\text{3-PR} = \frac{\text{Required PTO power}}{\text{Max. PTO power}}$$

4- $Sp = 2.64PR + 3.91 - 0.203\sqrt{(738PR + 173)}$

5- Fuel consumption =Sp × Required PTO power.

Where:

Sp = specific fuel consumption; L/kW.h

cf =conversion factor 3.6

Require PTO = require power take off shaft power for implements; kW

2.2.2 Procedure Two: Tractor alone.

$$Sp = \frac{632}{(ThEf \times ThVa)}$$

$$\text{Fuel consumption (L/h)} = \frac{Sp \times EN \times ME}{DFD}$$

Where:

Sp =specific fuel consumption, kg/hp.h.

ThEf = thermal efficiency of fuel

ThVa = thermal value of fuel

EN = engine power, hp.

ME = mechanical efficiency

DFD = diesel fuel density, kg/L (0.827)

In Procedure two, the ratio of engine load depends on the required PTO power and the maximum PTO power, and from that ratio the coefficient of energy conversion was determined and the fuel consumption was estimated.

2.3 The computer model

The model input data were forward speed, engine power, transmission efficiency, unit draft, width of implement, thermal efficiency, mechanical efficiency, traction coefficient, thermal value of fuel and diesel fuel density. The outputs of the model were fuel consumption, engine load, drawbar power, specific fuel consumption and required PTO power

The computer programme was validated by comparing the computer predictions of fuel consumption with measured field data of the disc harrow, ridger and seeder from private agricultural companies. The accuracy of the model was tested by statistical analysis using the equations shown below

1. Average model error = $$\frac{\sum_{i=1}^{n}(\text{measured1} - \text{predicted1})}{n}$$

2. Average absolute difference = $$\frac{\sum_{i=1}^{n}(\text{abs}(\text{measured1} - \text{predicted1}))}{n}$$

3. Standard error of estimate = $$\sqrt{\frac{\sum_{i=1}^{n}(\text{measured1} - \text{predicted1})^2}{n}}$$

Where

Measured = measured data, Predicted = predicted data, n =number of observations

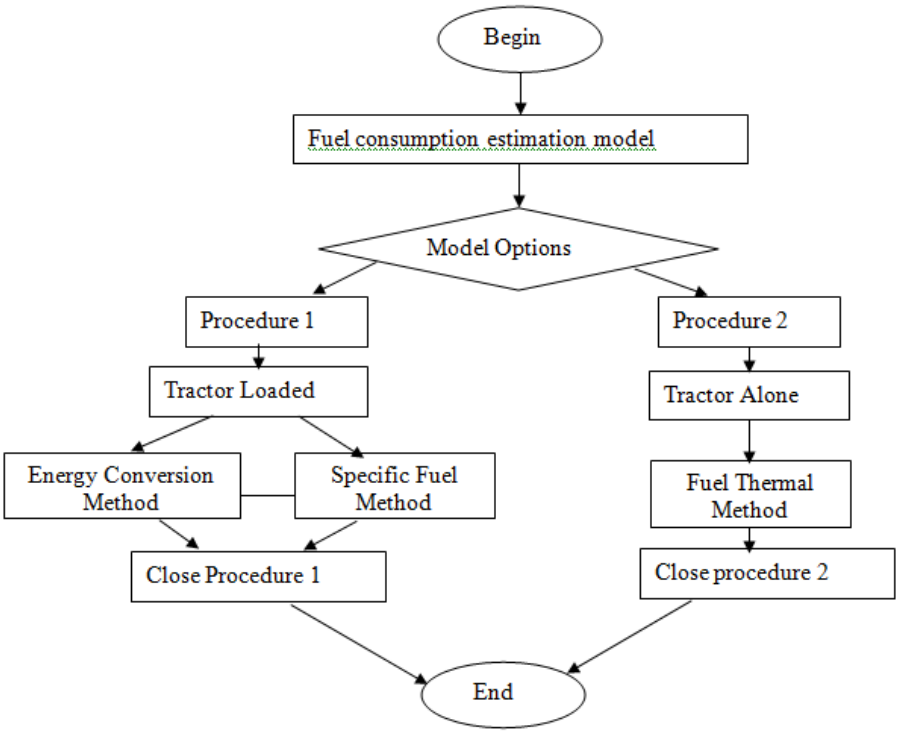

FIG. 1. THE GENERAL FLOW CHART OF FUEL CONSUMPTION MODEL

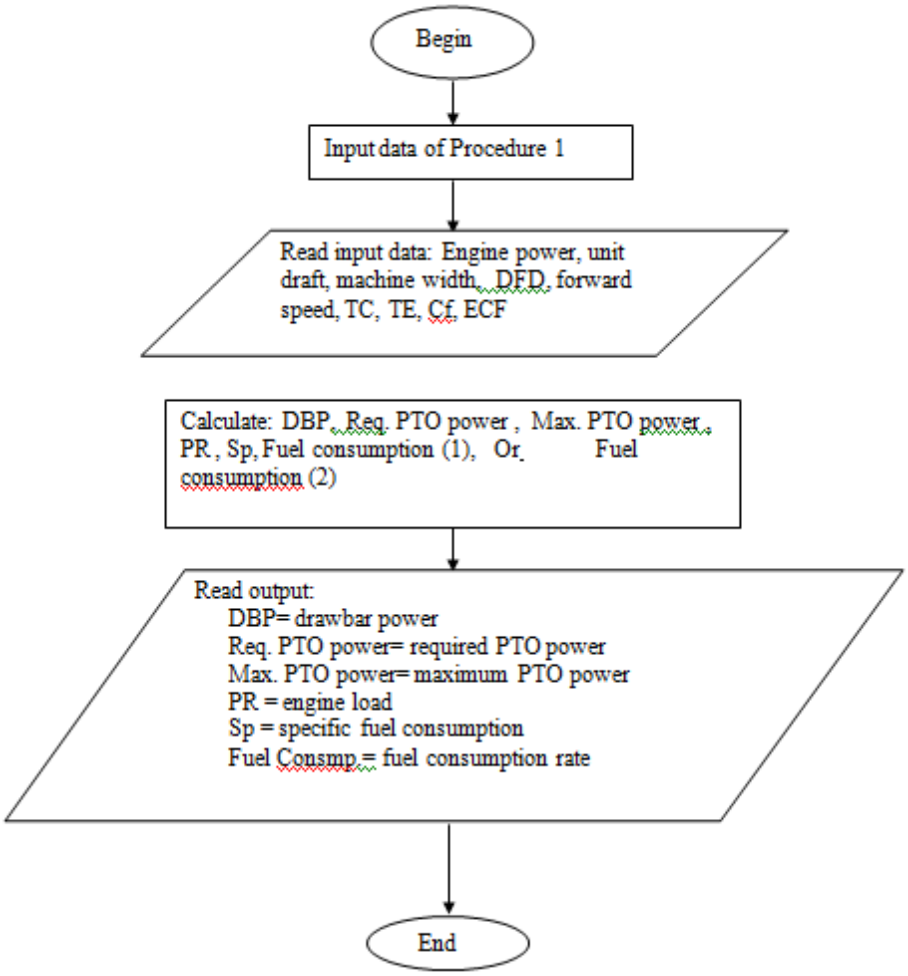

FIG.2. FLOW CHART OF THE COMPUTER MODEL FOR PROCEDURE ONE

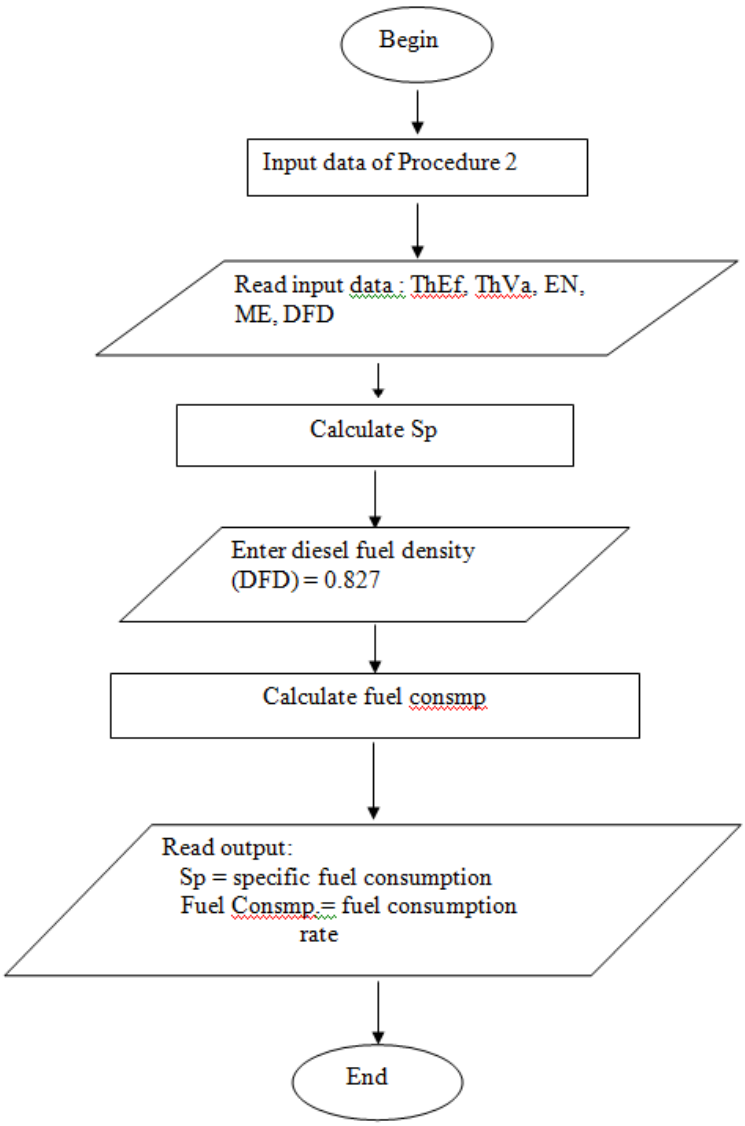

FIG. 3. FLOW CHART OF THE COMPUTER MODEL FOR PROCEDURE TWO

III. RESULTS AND DISCUSSION

3.1 Model Verification and Validation

The computer programme was verified by using data from the literature (Hunt 1995, Downs and Hansen 1998), and standard specification of the farm machinery operation (ASAE 1998). The computer programme operated well, and the results were very close to the actual data (Tables 1and 2). The predictions of the computer programme developed from the two procedures, were validated with actual data from Dal Agricultural private Company and Sennar Center for Agricultural Services (Sudan). Different types or sizes of tractors and implements were used for the validation. For all tested machines, there was a close agreement (93%-97%) between the predicted and actual (Tables 3). This means the model is well developed and can be useful in estimating fuel consumption for different operations.

3.2 Sensitivity test of fuel consumption model

Changing any of the component parameters could quickly affect the other parameters in the model and may help in quick decision-making and proper machinery management. As the unit draft was reduced from 5kN/m to 2kN/m, the fuel consumption decreased by 9.1 L/h (43.5%) and the drawbar power decreased by 12.5 kW. This is because the drawbar power mainly dependant on the unit draft of the implement. When the forward speed was increased from 5 km/h to 9 km/h, the fuel consumption increased by 47.1%, while the drawbar power increased by 44.4%. The fuel consumption increased by 10.7%

when the engine power was increased by 16.7%. As the engine power was further increased to 80 kW, the fuel consumption increased by 8.9%.

3.3 Model Accuracy Test

According to Abouda (1984), it is known that any accurate by developed model should have average model error and average absolute difference close to zero and a small standard error of estimate. In the present model, the average model error and the average absolute difference were 0.03 and 0.45, respectively, while the average standard error of estimate was 0.48 (Table 4). These values support the accuracy of the developed model which can help in agricultural tractor fuel consumption

IV. CONCLUSION

The following conclusions may be drawn from the present study

1. The model enables the user to estimate the fuel consumption for any type of machine attached to the agricultural tractor
2. The model enables the user to change any of the parameters (speed, unit draft, engine power, transmission efficiency and width) to have different outputs.
3. The model was verified and validated very well and the predicted and measured data were very close

TABLE 1
VERIFICATION OF FUEL CONSUMPTION ESTIMATION COMPUTER MODEL (PROCEDURE ONE)

	Input data				Output			
Machine type	UN	S	TC	W	DBP	Th E	FC L/h	
	(Kn/m)	(Km/h)		(m)	(kW)		Pred	Actual
Chisel plough	6.50	5.5	0.75	5.6	56.0	0.23	29.5	30
Heavy offset disk harrow	6.0	5.0	0.75	5.0	41.7	0.39	14.0	14.4
Spring tooth disk harrow	2.00	5.5	0.75	5.5	16.8	0.43	9.3	9.5
Tandem disk	2.50	5.5	0.74	5.0	19.0	0.34	14.1	14.6
Disk plough	7.00	5.0	0.75	3.0	29.4	0.33	20.0	20.5

Source : Downs and Hansen (1998)
S =speed UN= unit draft , W= width ThE =transmission efficiency, DBP =draw bar power, FC = fuel consumption, TC = traction coefficient

TABLE 2
VERIFICATION OF FUEL CONSUMPTION ESTIMATION COMPUTER MODEL (PROCEDURE TWO)

E N	T E	M E	T V	F C	
kW			kcal	Pred.	Meas.
105.00	0.28	0.85	10000	24.50	26.20
137.70	0.30	0.85	10000	31.70	33.00
153.00	0.30	0.87	10000	33.50	35.00

Source : Nebraska Tractor Test, U.S.A.
TE =Thermal Efficiency, ME=Mechanical Efficiency, TV =Thermal value, FC = Fuel Consumption , EN = Engine power

TABLE 3
AGRICULTURAL TRACTOR FUEL CONSUMPTION COMPUTER MODEL VALIDATION

Machinery	Average predicted fuel consumption (L/h)	Average actual fuel consumption (L/h)	Comparative (%)
Challenger 65+ Disc harrow (BH360)	36.70	38.2	96
Challenger 65+ Disc harrow (AH280)	34.40	35.5	97
D5B + Disc harrow (BH360)	24.50	25.6	96
John Deer 2700 + ridger	18.9	19.7	
John Deer 2700 + seeder	18.9	20.5	93

TABLE 4
COMPUTER MODEL ERROR, ABSOLUTE DIFFERENCE AND STANDARD ERROR OF ESTIMATE BETWEEN MEASURED AND PREDICTED TRACTOR FUEL CONSUMPTION

Fuel consumption L/h		Average model error (L/h)	Average absolute difference (L/h)	Standard error of estimated FC (L/h)
Meas	Pred			
38.2	37.7	0.5	0.5	0.25
34.3	33.9	0.4	0.4	0.16
36.2	35.9	0.3	0.3	0.09
34.3	33.9	0.4	0.4	0.16
26.3	25.6	0.7	0.7	0.49
24.0	23.4	-0.6	0.6	0.36
18.9	19.6	-0.7	0.7	0.49
16.6	17.1	-0.5	0.5	0.25
18.9	19.4	-0.5	0.5	0.25
18.2	18.4	-0.2	0.2	0.04
30.3	29.8	0.5	0.5	0.25
30.0	29.9	0.1	0.1	0.01
Total		0.40	5.40	2.80
Average		0.03	0.45	0.48

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