Fuel predictive models for 74 and 75 horsepower tractors during ploughing operation in a sandy loam soil

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Abstract: Fuel predictive models were developed for 74 and 75 horsepower tractors during ploughing operation in a sandy loam soil. This study involved the use of three different tractor models of similar horsepower capacity namely, YTO-750, YTO-754 and TAK DI-75 which were used for carrying out ploughing operation at the experimental field of the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. The ploughing implement mounted on the three tractors during ploughing operation was a 3-bottom disc plough. The test parameters measured during ploughing operation include travel reduction (wheel slippage), draught force, speed of operation, effective field capacity, theoretical field capacity, field efficiency, time of operation, drawbar power, tractive efficiency, soil moisture content, soil bulk density and soil cone index. The experimental field measuring 50 m by 100 m was laid in a randomized complete block design (RCBD) and which was replicated three times. Data obtained were subjected to multiple linear regression by pairing each measured test parameter with speed of operation. Test results showed that the model involving speed of operation and average soil moisture content as independent variables performed better than the other models developed based on obtaining the highest R^2-value of 0.972 and least residual standard error of 0.11650 l/ha.

Keywords: tractor, plough, performance, soil, speed, fuel predictive models

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1 Introduction

Tractors formerly known as puller were used only for towing works. With time, due to the development in agriculture and agricultural machinery techniques, the structure of the tractor significantly changed. Tractors are presently used in agricultural and forestry activities for pulling or pushing, transporting tools and machines, and towing trailers (OECD, 2019). It was gathered in some research works that farm tractors in Nigeria are underutilized resulting from limited seasonal application of farm tractors and lack of technical and managerial competence to use, handle and maintain farm machinery (Usman and Umar, 2003; Dauda et al., 2010). Tractors are one of the fastest farm machines

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used by farmers for tillage operations instead of human tools and animal-drawn implements (Panam et al., 2010). Land preparation is one of the most energy consuming operations in the field. Tillage operations require the most energy and power spent on farms (Al-Suhaibani and Ghaly, 2010). As energy becomes more expensive, its efficient utilization in agricultural production has become the major concern of agricultural engineers and tractor owners.

Soil tillage is considered as one of the biggest farm operations (Al-Suhaibani and Ghaly, 2010). It is also a conventional farming system that involves the use of tractors thereby resulting in high energy costs. The sustainability of such a system requires a well-controlled resource management that will give room for a reduce cost of crop production derived from savings in fuel consumption (Serrano et al., 2009). Agricultural tillage involves soil cutting, soil turning and soil pulverization and thus demands high energy, not just due to the large amount of soil mass that must be moved, but also due to inefficient methods of energy transfer to the soil. The most widely used energy-transfer method is to pull the tillage tool through the soil. This is mainly realized with the use of tractors (Ahaneku et al., 2011). Ploughing is a primary tillage operation which is performed to shatter and achieve soil inversion. The operation is deep and leaves a rougher surface for secondary tillage (ASAE Standards, 2002). The draught of the disc plough is very enormous when compared with other tillage implements. For a given soil type and speed of travel, Scheruddin (1988) observed that the disc plough has a higher total specific draught value than other tillage implements which is attributed to the design of the implement.

Forces applied by tillage tools to the soil results in soil failure thereby accounting for increased infiltration rate, improved plant rooting, enhanced seedling emergence, and controlled soil erosion (Lindstrom et al., 1990). The primary interest in tillage operations is the application of mechanical forces by machines to change the soil condition for agricultural production purposes (Schafer and Johnson, 1982). In Nigeria, similar studies on tillage effect on soil strength properties have been carried out (Oni and Adeoti, 1986; Ojeniyi, 1989; Onwualu and Anazodo, 1989; Ahaneku, 1997; Ahaneku and Sangodoyin, 2003). Despite the enormity of these studies, limited research information exist in the country on the effect of tractor speed on soil physical conditions.

According to Oyelade and Oni (2013a), most farming operations in Nigeria are accomplished through the use of hand hoes and cutlasses which are labour intensive, time consuming, drudgery laden and expensive. This traditional method of farming in Nigeria puts serious limitations on the growth of the nation’s agricultural sector thus exacerbating reduced food production leading to increased food importation. Agriculture plays a major role in developed nation’s economy. Therefore the word, agriculture, as defined by Lasisi (2010) is the production of food and goods through farming. In agriculture, the most fuel consuming machine is the tractor. About 20–55% of available tractor power is lost in the process of interaction between the soil surface and the tyres. The vertical wheel load and tyre pressure are the two parameters that are both easily managed, which play a significant role in controlling the traction force, the slip and the fuel consumption of a tractor (Janulevicius and Damanauskas, 2015).

Agricultural mechanization involves the use of tractors and other machinery that require energy input in terms of fuel (Umar et al., 2007). Fuel consumption in the study of agricultural machinery management, is seen as a very significant factor that plays a major role in the selection and management of tractors and equipment. The use of agricultural machinery in carrying out farm work has gained much importance. The application of machines to agricultural production activities has been one of the outstanding developments in agriculture. In most farm businesses, machinery contributes a major capital input cost (Oyelade and Oni, 2018). Umar et al. (2007) stated that a number of factors such as depth of cut and soil moisture content affect tractor fuel consumption. Bukhari et al. (1982) observed that fuel consumption of field machinery is affected by speed of operation, depth of cut, width of cut, type of soil and skill of the operator.

One of the problems facing Nigeria and other developing countries, is the need to improve on agricultural productivity (Nkakini et al., 2008). It is actually important to study the data obtained from the various tractors and implements for use during farm machinery management and their selection process for a particular task in the farm ((Sharm et al., 2016; Saeed et al., 2017). Authors like Igbeka (1986); Anazodo (1986) and Adeoti (1996) have made concerted effort in this area, but the need for continual search for accurate fuel consumption of tractors in tillage operations cannot be overemphasized in Nigeria. The knowledge on comprehensive compiled data on tractor fuel consumption in tillage operations will help to actualize realistic costing of tillage operations. This will make one know when a tractor is consuming more than necessary so as to diagnose the fault on time. In addition to this, the quantity of fuel needed for a farming season can be estimated for better economic and business management.

Oyelade and Oni (2018) stated that the use of models for budgeting of tractor fuel consumption in developed nations has been of great use to their farmers. Most studies on model development for tractor fuel consumption centred on ploughing operation which is the first tillage operation carried out. The continuous use of agricultural tractors with its tillage implements remains the only way to tackle food demand of the ever-increasing world population by rapidly bringing more farmland under cultivation. Having known the importance of ploughing operation to the practice of soil tillage in Nigerian agriculture, it is necessary to come up with model equations that will be used to predict tractor fuel consumption during ploughing operation in a sandy loam soil. Therefore, this research work aim at generating predictive models for fuel consumption of 74 and 75 horsepower tractors in litres per hectare (l/ha) during ploughing operation in a sandy loam soil.

2 Materials and methods

Three different tractor models of similar horsepower capacities were evaluated at the experimental field of the National Centre for Agricultural Mechanization (NCAM), Ilorin (370 m above sea level, Longitude $4^0 30$’E, Latitude $8^0 26$’N) in the North Central States of Nigeria under the southern guinea savannah vegetation (Ahaneku and Onwualu, 2007). The experimental design for the field evaluation was randomized complete block design (RCBD) replicated three times. A 50 m by 100 m plot size was used for each test trail. The implement used for ploughing operation was a 3-bottom disc plough. The particle size analysis of the soil where each tractor was tested was carried out using the hydrometer method described by Gee and Or (2002). The textural class of the soil was determined using USDA Textural Triangle. The soil textural classification of the three test sites was sandy loam. The soil in the three test sites was classified as Alfisols (Soil Survey Staff, 1975) under the USDA soil order. The specification of the three tractors used in this study are provided in Table 1. The choice of making use of these three different tractors of similar horsepower capacities as shown in Table 1 is because they are among the most common tractor makes and models used for farming operations in Nigeria. The specification of the 3-bottom disc plough used is provided in Table 2. The pictorial views of the three tractors used in this study are shown in Figures 1 to 3.

Parameters measured include speed of operation which was measured by calculating the average time it took the tractor to travel 20 m placed in-between the 100 m length of the field; fuel consumed for each ploughing operation was measured by starting each field trial by filling the fuel tank before and after completing the operation; time factors such as actual time, total time and turning time used for each field trial were measured with the aid of a stop watch; draught force was determined using the trace tractor technique; depth and width of cuts were measured through the use of a measuring tape; soil cone index was recorded using the digital cone penetrometer; soil moisture content was determined through the use of oven dried method; and soil bulk density was determined from the mass per unit volume of soil. The three soil properties, which include soil moisture content, soil bulk density and soil index were measured at depths 0 – 7 cm, 7 – 14 cm and 14 – 21 cm, respectively. The resulting mean values of these three soil properties form part of the data collected. All data obtained in this research work were measured and recorded in accordance to the recommendation of RNAM Test Codes and Procedures for Farm Machinery (1983). All the measured parameters obtained from the field were subjected to multiple linear regression. The SPSS statistical package of version 25.0.0.0 was used for developing the model.

Table 1 Tractor Specifications

Parameters	**Tractor Models**		
	YTO-750	YTO-754	TAK DI-75
Effective output (hp)	74	74	75
Tractor type	4 Wheel	4-Wheel-Drive	4 Wheel
Crankshaft rated speed (rpm)	2400	2400	2200
Bore/stroke (mm)	105/125	105/125	100/118
Displacement (cm^3)	4,300	4,300	3,707
No. of cylinders	4	4	4
Engine firing order	1-3-4-2	1-3-4-2	1-3-4-2
Type of cooling system	Water-cooled	Water-cooled	Water-cooled
Type of fuel	Diesel	Diesel	Diesel
Type of injector pump	In-line	In-line	In-line
Fuel tank capacity (l)	135	115	65
Type of steering system	Power steering	Power steering	Mechanical
Lifting capacity (kg)	1,651	1,346	2,500
Size of front tyre	7.50 - 16	11.2 - 24	7.50 - 16
Ply rating	8	8	8
Type of tread	Radial	Bias	Radial
Recommended inflation pressure for field work (kPa)	147 - 196	147 - 196	250
Size of rear tyre	14.9 - 30	16.9 - 30	16.9 - 30
Ply rating	10	10	10
Type of tread	Bias	Bias	Bias
Recommended inflation pressure for field work (kPa)	147 - 196	147 - 196	110
Wheel base (mm)	2400	2314	2212
Country of origin	China	China	India

Table 2 Disc Plough Specification

Item	Disc plough
Type of implement	Mounted
Number of bottom/blades	3
Diameter of disc (mm)	660
Diameter of plane blade (mm)	-
Diameter of notched blade (mm)	-
Spacing of disc (mm)	500
Lower hitch point span (mm)	800
Overall length (mm)	2,022
Overall width (mm)	880
Overall height (mm)	1,016

Figure 1 Pictorial view of YTO-750 tractor

Figure 2 Pictorial view of YTO-754 tractor

Figure 3 Pictorial view of TAK DI-75 tractor

2.1 Test Parameters

2.1.1 Travel reduction (wheel slippage)

Travel reduction otherwise known as wheel slippage was determined using the expression given by Ahaneku et al. (2011) as:

$$A = \frac{B_2 - B_1}{B_2} \times 100\% \tag{1}$$

Where,

A = travel reduction/wheel slippage (%)

B_2= distance covered at every 10 revolutions of the tractor drive wheel at no-load (m)

B_1= distance covered at every 10 revolutions of the tractor drive wheel with load (m)

2.1.2 Drawbar power

The drawbar power was determined using the expression given by Oyelade and Oni (2013a) as:

$$C = \frac{D \times E}{3.6(constant)} \tag{2}$$

Where,

C = drawbar power (kW)

D= draught force (kN)

E= speed of operation (km/h)

2.1.3 Effective field capacity

Effective field capacity can be expressed mathematically according to Oyelade (2016) as:

$$F = \frac{G(3600)}{H} \tag{3}$$

Where,

F = effective field capacity (ha/h)

G =field area (ha)

H=total time taken to complete each tillage operation (s)

2.1.4 Field efficiency

The field efficiency was determined using the expression given by Smith et al. (1994) as:

$$I = \frac{F(100\%)}{J} \tag{4}$$

Where,

I = field efficiency (%)

F = effective field capacity (ha/h)

J = theoretical field capacity (ha/h)

Theoretical field can further be expressed according to Oyelade and Oni (2021) as:

$$K = \frac{G(3600)}{L} \tag{5}$$

Where,

K = theoretical field capacity (ha/h)

G = field area (ha)

L = actual time taken in doing the main tillage work (s)

2.1.5 Fuel consumption

The refilling of the fuel tank which happens to be a common method for determining the fuel consumed by a tractor as earlier described in this study was also used in the study of Udo and Akubuo (2004), Ikpo and Ifem (2005), Ajav and Adewoyin (2011), Kudabo and Gbadamosi (2012) and Oyelade and Oni (2018). The fuel consumption was determined using the expression given by Okoro and Olosunde (2023) as:

$$M = \frac{N}{G} \tag{6}$$

Where,

M = fuel consumption (l/ha)

N = amount of fuel consumed (l)

G = field area (ha)

2.1.6 Time of operation

The time of operation was determined using the expression given by Oyelade and Oni (2013b) as:

$$P = \frac{1}{F} \tag{7}$$

Where,

P = time of operation (h/ha)

F = effective field capacity (ha/h)

2.1.7 Tractive efficiency

Tractive efficiency can be expressed mathematically according to Macmillan (2002) as:

$$R = \frac{C}{S} \times 100\% \tag{8}$$

Where,

R = tractive efficiency

C = drawbar power (kW)

S = wheel power (kW)

It can assume power losses in the transmission from engine to the wheels of, say 10%, then the expression becomes:

$$R = \frac{C}{0.9 \times T} \tag{9}$$

Where,

R = tractive efficiency (%)

C = drawbar power (kW)

T = engine power (kW)

2.2 Soil Parameters

2.2.1 Soil moisture content

The soil moisture content, according to the definition of Klenin et al. (1985), is the amount of liquid (water) that is present in the soil. It is also expressed as a percentage of the mass of water in the soil to the mass of the dried soil (for dry weight classification). This can be expressed mathematically as:

$$M_c = \frac{M_w(100\%)}{M_s} \tag{10}$$

Where,

M_c= Soil moisture content (%)

M_s = Mass of oven dried soil (g)

M_w = Mass of water present in the soil (g)

2.2.2 Soil bulk density

The soil bulk density in this study was determined using the core method described by Blake and Hartge (1986). The core samples were oven dried at a temperature of 105ºC to attain a constant weight. Soil bulk density is a measure of the mass of soil per unit volume which is usually reported on an oven-dry basis. This can be expressed mathematically as:

$$\sigma_b = \frac{M_s}{V_t} \tag{11}$$

Where,

σ_b= Soil bulk density (g/cm^3)

M_s= Mass of oven dried soil (g)

V_t= Total volume of soil (cm^3)

3 Results and discussion

3.1 Results

The result of the data obtained for the three different tested tractors during ploughing operation is presented in Table 3. Presented in Table 4 is the result of the effects of tractor performance on soil physical properties during ploughing operation.

Table 3 Results of field test on the three different tractors during ploughing operation

Measured Parameters*	Ploughing operation		
	YTO-750	YTO-754	TAK DI-75
Horsepower (hp)	74	74	75
Depth of cut (cm)	22.40±1.61	23.20±1.67	24.50±1.77
Width of cut (cm)	92.91±6.70	123.81±8.93	143.67±10.36
Draught force (kN)	5.40±0.39	5.50±0.40	6.12±0.44
Effective field capacity (ha/h)	0.59±0.05	0.65±0.05	0.63±0.05
Field efficiency (%)	80.00±5.77	75.00±5.40	78.77±5.68
Tractive efficiency (%)	24.15±1.74	21.53±1.55	18.84±1.36
Travel reduction (%)	17.00±1.23	21.00±1.51	20±1.44
Time of operation (h/ha)	1.69±0.12	1.54±0.11	1.58±0.11
Speed of operation (km/h)	8.00±0.58	7.00±0.50	5.58±0.40
Drawbar power (kW)	12.00±0.87	10.69±0.77	9.49±0.69
Fuel consumption (l/ha)	7.00±0.50	6.00±0.43	6.30±0.45

* Parameter values are average of three replicates

Table 4 Effect of field operation on soil physical properties during ploughing operation

Tractor Model	Ploughing operation		
	AMC (%)	ABD (g/cm^3)	ACI (N/cm^2)
YTO-750	9.37±0.68	1.43±0.10	39.05±2.81
YTO-754	8.44±0.61	1.47±0.11	51.68±3.72
TAK DI-75	9.07±0.65	1.49±0.11	65.20±4.70

Note:AMC= Average moisture content; ABD = Average bulk density; ACI = Average cone index

The results of the ANOVA table and other useful information concerning the models developed are presented in Table 5. Also presented in Tables 6 and 7 in respect of the models developed are the fuel predictive and fuel residual values, respectively. It should be noted that Table 6 have a total of nine observations based on three replications made for each of the tractors tested during ploughing operation.

Table 5 Details information on the developed Models

Model No.	Model p-value	R^2-value	Adj. R^2-value	Residual standard error of the model	coefficients	Model variables	p-value	Status of the Model
					-.094	Constant	0.968Ns	
1	0.038	0.663	0.550	0.40225	.397	E	0.020**	Model fits the data
					.163	Dc	0.100Ns	
					1.945	Constant	0.488Ns	
2	0.118	0.510	0.346	0.48494	.493	E	0.068Ns	Model does not fit the data
					.009	Wc	0.426Ns	
					-.912	Constant	0.639Ns	
3	0.012	0.770	0.693	0.33217	.461	E	0.006*	Model fits the data
					.737	D	0.028**	
					2.969	Constant	0.290Ns	
4	0.151	0.468	0.291	0.50514	.352	E	0.066Ns	Model does not fit the data
					1.681	F	0.669Ns	
					-1.293	Constant	0.260Ns	
5	0.00067	0.913	0.883	0.20475	-1.809	E	0.004*	Model fits the data
					.936	R	0.001*	
					-1.292	Constant	0.302Ns	
6	0.0011	0.897	0.863	0.22218	.202	E	0.036**	Model fits the data
					.081	I	0.002*	
					4.359	Constant	0.107Ns	
7	0.164	0.453	0.271	0.51226	.345	E	0.083Ns	Model does not fit the data
					-.015	A	0.867Ns	
					-1.178	Constant	0.165Ns	
8	0.00012	0.950	0.934	0.15413	.046	E	0.484Ns	Model fits the data
					4.542	P	0.0001*	
					-1.220	Constant	0.220Ns	
9	0.00031	0.932	0.909	0.18059	-1.459	E	0.002*	Model fits the data
					1.646	C	0.001*	
					-.921	Constant	0.134Ns	
10	0.000023	0.972	0.962	0.11650	.175	E	0.005*	Model fits the data
					.686	ASMC	0.0001*	
					.537	Constant	0.833Ns	
11	0.061	0.606	0.475	0.43456	.332	E	0.050**	Model does not fit the data
					2.475	ASBD	0.174Ns	
					.713	Constant	0.785Ns	
12	0.069	0.590	0.453	0.44372	.602	E	0.035**	Model does not fit the data
					.031	ASCI	0.203Ns	

* = Significant at 1% level; ** = Significant at 5% level; Ns = Not significant

Keynote: A = Wheel slippage (%); C = Drawbar power (kW); D = Draught force (kN); Dc = Depth of cut (cm); E = Speed of operation (km/h); F = Effective field capacity (ha/h); I = Field efficiency (%); P = Time of operation (h/ha); R = Tractive efficiency (%); Wc = Width of cut (cm); ASMC = Ave. soil moisture content (%); ASBD = Ave. soil bulk density (g/cm^3); and ASCI = Ave. soil cone index (N/cm^2)

Table 6 Results of observed and predicted fuel values of the developed models

Observed values (l/ha)	Predicted values (l/ha)											
	Model No.											
	1	2	3	4	5	6	7	8	9	10	11	12
6.58[a]	6.32	6.44	6.30	6.54	6.35	6.32	6.71	6.39	6.38	6.44	6.35	6.38
6.86[b]	6.60	6.63	6.60	6.70	6.68	6.64	6.81	6.72	6.70	6.75	6.60	6.62
7.56[c]	7.28	7.11	7.37	7.09	7.49	7.45	7.06	7.53	7.51	7.53	7.22	7.22
6.48[d]	6.99	6.88	6.95	6.81	6.79	6.80	6.63	6.71	6.76	6.66	6.98	6.99
5.64[e]	6.07	6.24	5.93	6.31	5.75	5.75	6.33	5.71	5.72	5.67	6.14	6.18
5.88[f]	6.34	6.42	6.22	6.46	6.05	6.05	6.42	6.00	6.02	5.95	6.38	6.41
6.17[g]	5.99	5.90	6.03	5.93	6.11	6.06	5.95	6.11	6.12	6.13	5.96	5.98
5.92[h]	5.74	5.75	5.75	5.81	5.79	5.77	5.89	5.83	5.80	5.84	5.75	5.77
6.80[i]	6.61	6.31	6.74	6.23	6.85	6.82	6.12	6.87	6.85	6.86	6.52	6.53

Keynote: Observed fuel values a, b and c stands for replicates 1, 2 and 3, respectively for YTO-750 tractor; observed fuel values d, e and f stands for replicates 1, 2 and 3, respectively for YTO-754 tractor; and observed fuel values g, h and i stands for replicates 1, 2 and 3, respectively for TAK DI-75 tractor

Table 7 Results of residual fuel values of the developed models

Residual fuel values (l/ha)											
Model No.											
1	2	3	4	5	6	7	8	9	10	11	12
0.26	0.14	0.28	0.04	0.23	0.26	-0.13	0.19	0.20	0.14	0.23	0.20
0.26	0.23	0.26	0.16	0.18	0.22	0.05	0.14	0.16	0.11	0.26	0.24
0.28	0.45	0.19	0.47	0.07	0.11	0.50	0.03	0.05	0.03	0.34	0.34
-0.51	-0.40	-0.47	-0.33	-0.31	-0.32	-0.15	-0.23	-0.28	-0.18	-0.50	-0.51
-0.43	-0.60	-0.29	-0.67	-0.11	-0.11	-0.69	-0.07	-0.08	-0.03	-0.50	-0.54
-0.46	-0.54	-0.34	-0.58	-0.17	-0.17	-0.54	-0.12	-0.14	-0.07	-0.50	-0.53
0.18	0.27	0.14	0.24	0.06	0.11	0.22	0.06	0.05	0.04	0.21	0.19
0.18	0.17	0.17	0.11	0.13	0.15	0.03	0.09	0.12	0.08	0.18	0.15
0.19	0.49	0.06	0.57	-0.05	-0.02	0.68	-0.07	-0.05	-0.06	0.28	0.27

Keynote: Residual fuel values for the developed models were arranged the way they appeared in Table 6

3.2 Discussion

3.2.1 Model development

3.2.1.1 Model 1 of ploughing operation

Model 1 of ploughing operation consist of speed of operation and depth of cut as the two independent variables involved in the model developed. Model 1 of ploughing operation as shown in Table 5 had a p-value of 0.038, R^2-value of 0.663 and Adjusted R^2-value of 0.550. According to Table 5, the residual standard error of the model developed gave a value of 0.40225 l/ha. Also from same Table 5, it was observed that speed of operation was found to be significant at 5% level which signifies that speed of operation contributed to the model developed.

The model expression for Model 1 of ploughing operation as contained in Table 5 is expressed as:

$$\hat{y}=-0.94+0.163Dc+0.397E \quad (12)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

Dc = Depth of cut (cm)

E = Speed of operation (km/h)

The predicted fuel values of Model 1 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7. The positive coefficient obtained for both speed of operation and depth of cut in this study is in agreement with the study of Ajav and Adewoyin (2011) who developed a model for predicting tractor fuel consumption in litres per hectare using both speed of operation and depth of cut as independent variables. Likewise in the study of Nkakini and Ekemube (2020), there exist a very strong positive linear relationship between speed of operation and tractor fuel consumption and as well as between depth of cut and tractor fuel consumption which showed that this present study is in agreement with their work. This simply indicates that whenever there is an increase in either of the two independent variables with all other factors kept constant, the tractor fuel consumption value in litres per hectare will increase and vice versa.

3.2.1.2 Model 2 of ploughing operation

Model 2 of ploughing operation consist of speed of operation and width of cut as the two independent variables involved in the model developed. The model developed which gave a p-value of 0.118 as shown in Table 5 had a R^2-value of 0.510 and Adjusted R^2-value of 0.346. Also shown in Table 5 is the residual standard error of the model developed which gave a value of 0.48494 l/ha. Model 2 of ploughing operation was considered a regression model not fit for the dataset as the p-value of the model developed was greater than 0.05.

The model expression for Model 2 of ploughing operation as contained in Table 5 is expressed as:

$$\hat{y}=1.945+0.493E+0.009Wc \quad (13)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

E = Speed of operation (km/h)

Wc = Width of cut (cm)

The predicted fuel values of Model 2 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7.

3.2.1.3 Model 3 of ploughing operation

Model 3 of ploughing operation consist of speed of operation and draught force as the two independent variables involved in the model developed. Model 3 of ploughing operation as shown in Table 5 had a p-value of 0.012, R^2-value of 0.770 and Adjusted R^2-value of 0.693. According to Table 5, the residual standard error of the model developed gave a value of 0.33217 l/ha. It was observed from the model developed that speed of operation was found to be significant at 1% level as draught force was found to be significant at 5% level. This simply signifies that both speed of operation and draught force contributed in one way or the other to the model developed.

The model expression for Model 3 of ploughing operation as presented in Table 5 is expressed as:

$$\hat{y}=-0.912+0.737D+0.461E \quad (14)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

D = Draught force (kN)

E = Speed of operation (km/h)

The predicted fuel values of Model 3 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7. The positive coefficient obtained for draught force is in agreement with the study of Plouffe et al. (1995) where it was observed that fuel consumption increases with draught force requirement as deeper penetration of an implement requires more engine torque. Operating at a shallow depth can significantly reduce fuel consumption since a smaller volume of soil is turned over.

3.2.1.4 Model 4 of ploughing operation

Model 4 of ploughing operation consist of speed of operation and effective field capacity as the two independent variables involved in the model developed. The model developed which gave a p-value of 0.151 as shown in Table 5, had a R^2-value of 0.468 and Adjusted R^2-value of 0.291. Also shown in Table 5 is the residual standard error of the model developed which gave a value of 0.50514 l/ha. Model 4 of ploughing operation was considered a regression model not fit for the dataset as the p-value of the model developed was greater than 0.05.

The model expression for Model 4 of ploughing operation as contained in Table 5 is expressed as:

$$\hat{y}=-2.969+0.352D+1.681E \quad (15)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

E = Speed of operation (km/h)

F = Effective field capacity (ha/h)

The predicted fuel values of Model 4 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7.

3.2.1.5 Model 5 of ploughing operation

Model 5 of ploughing operation consist of speed of operation and tractive efficiency as the two independent variables involved in the model developed. Model 5 of ploughing operation as shown in Table 5, had a p-value of 0.00067, R^2-value of 0.913 and Adjusted R^2-value of 0.883. Also shown in Table 5, is the residual standard error of the model developed which gave a value of 0.20475 l/ha. It was observed in the model developed that speed of operation and tractive efficiency were both found to be significant at 1% level. This simply signifies that both speed of operation and tractive efficiency greatly contributed to the model developed.

The model expression for Model 5 of ploughing operation, according to Table 5, is expressed as:

$$\hat{y}=-1.293-1.809E+0.936R \quad (16)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

E = Speed of operation (km/h)

R = Tractive efficiency (%)

The predicted fuel values of Model 5 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7. Tractive efficiency going by its definition in a way tends to dictate if a tractor is underutilized or well utilized. But due to the improper selection or matching of implement size with tractor size in Nigeria and other developing nations make researchers to believe that tractors used in the developing nations are underutilized compared to the way they are being used in the developed nations where we have more of agricultural related works on the field. Having seen the significance of both variables (speed of operation and tractive efficiency) to this study implies that when a high value is obtained for tractive efficiency this tends to reduce the speed of operation so as to give room for better traction on the field. This is expected to happen because when tractors are handling heavy implements on the field they are expected to move at a low speed so that the implement they are working with would not easily get damaged. This is why the speed of operation during harrowing operation is always higher than that of ploughing operation regardless of the soil type. With the positive and negative coefficient values obtained for tractive efficiency and speed of operation, respectively, makes this model developed applicable to what happens in the actual field.

3.2.1.6 Model 6 of ploughing operation

Model 6 of ploughing operation consist of speed of operation and field efficiency as the two independent variables involved in the model developed. Model 6 of ploughing operation as shown in Table 5, had a p-value of 0.0011, R^2-value of 0.897 and Adjusted R^2-value of 0.863. Also shown in Table 5, is the residual standard error of the model developed which gave a value of 0.22218 l/ha. In the model developed, it was observed that speed of operation was found to be significant at 5% level while field efficiency was found to be significant at 1% level. This signifies that both speed of operation and field efficiency contributed in one way or the other to the model developed.

The model expression for Model 6 of ploughing operation, according to Table 5, is expressed as:

$$\hat{y}=-1.292+0.202E+0.081I \quad (17)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

E = Speed of operation (km/h)

I = Field efficiency (%)

The predicted fuel values of Model 6 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7. Oyelade (2016) observed that during ploughing operation in a sandy loam soil that the effects of speed of operation and field efficiency within a particular tractor horsepower group are significantly different implying that within that particular tractor horsepower group they have different impact on tractor fuel consumption. This was also the same thing observed in the study carried out by Okoro and Olosunde (2023) where both speed of operation and field efficiency had significant effect on tractor fuel consumption in litres per hectare. Though, their study had the involvement of a 4-bottom disc plough used in a clay loam soil as against a 3-bottom disc plough used in a sandy loam soil as contained in the study of

Oyelade (2016). This is to say that having both independent variables involved in the development of a model for predicting tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil makes a meaningful impact to this present study.

3.2.1.7 Model 7 of ploughing operation

Model 7 of ploughing operation consist of speed of operation and wheel slippage as the two independent variables involved in the model developed. The model developed which gave a p-value of 0.164 as shown in Table 5, had a R^2-value of 0.453 and Adjusted R^2-value of 0.271. Also shown in Table 5, is the residual standard error of the model developed which gave a value of 0.51226 l/ha. Model 7 of ploughing operation was considered a regression model not fit for the dataset as the p-value of the model developed was greater than 0.05.

The model expression for Model 7 of ploughing operation as contained in Table 5 is expressed as:

$$\hat{y}=4.359\text{-}0.15A+0.345E \tag{18}$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

A = Wheel slippage (%)

E = Speed of operation (km/h)

The predicted fuel values of Model 7 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7.

3.2.1.8 Model 8 of ploughing operation

Model 8 of ploughing operation consist of speed of operation and time of operation as the two independent variables involved in the model developed. Model 8 of ploughing operation as shown in Table 5, gave a p-value of 0.00012, R^2-value of 0.950 and Adjusted R^2-value of 0.934. Also shown in Table 5, is the residual standard error of the model developed which gave a value of 0.15413 l/ha. It was observed in the model developed that time of operation was found to be significant at 1% level. This simply signifies that time of operation greatly contributed to the model developed.

The model expression for Model 8 of ploughing operation, according to Table 5, is expressed as:

$$\hat{y}=-1.178+0.046E+4.542P \tag{19}$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

E = Speed of operation (km/h)

P = Time of operation (h/ha)

The predicted fuel values of Model 8 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7. Achieving timeliness in operation is one of the main objectives of agricultural mechanization. The positive coefficient obtained for the time of operation in the model developed when other factors are kept constant indicates that the more time the tractor spent doing ploughing operation on the field the more fuel it consumes. Having noticed the importance of time of operation going by the model ANOVA result where the p-value obtained for time of operation was found to be significant at 1% level, it is important to ensure that the time used for ploughing operation on the field should be maintained within its time range in order to minimize tractor fuel consumption during ploughing operation in a sandy loam soil which will significantly reduce the cost of production and thereby lead to huge profit for both the farmer and tractor owner.

3.2.1.9 Model 9 of ploughing operation

Model 9 of ploughing operation consist of speed of operation and drawbar power as the two independent variables involved in the model developed. Model 9 of ploughing operation as shown in Table 5, gave a p-value of 0.00031, R^2-value of 0.932 and Adjusted R^2-value of 0.909. Also shown in Table 5, is the residual standard error of the model developed which gave a value of 0.18059 l/ha. In the model developed, it was observed that speed of operation and drawbar power were both found to be significant at 1% level. This simply signifies that both speed of operation and drawbar power greatly contributed to the model developed.

The model expression for Model 9 of ploughing operation, according to Table 5, is expressed as:

$$\hat{y}=-1.220+1.646C-1.459E \quad (20)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

C = Drawbar power (kW)

E = Speed of operation (km/h)

The predicted fuel values of Model 9 of ploughing operation is presented in Table 6 while its residual fuel value is presented in Table 7. Tractor fuel consumption is directly related to energy requirement for tillage operations. Drawbar power is the direct product of draught force and speed of operation which according to Oyelade and Oni (2013b) in the study of tillage energy is a strong factor that determines energy requirement for tillage operations. The existence of a strong positive linear relationship between drawbar power and tractor fuel consumption in this study make this developed model involving both speed of operation and drawbar power as independent variables useful for the prediction of tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil.

3.2.1.10 Model 10 of ploughing operation

Model 10 of ploughing operation consist of speed of operation and average soil moisture content as the two independent variables involved in the model developed. Model 10 of ploughing operation as shown in Table 5, gave a *p*-value of 0.000023, R^2-value of 0.972 and Adjusted R^2-value of 0.962. Also shown in Table 5 is the residual standard error of the model developed which gave a value of 0.11650 l/ha. It was observed in the model developed that speed of operation and average soil moisture content were both found to be significant at 1% level. This simply signifies that both speed of operation and average soil moisture content greatly contributed to the model developed.

The model expression for Model 10 of ploughing operation, according to Table 5, is expressed as:

$$\hat{y}=-0.921+0.686ASMC+0.175E \quad (21)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

$ASMC$ = Ave. soil moisture content (%)

E = Speed of operation (km/h)

The predicted fuel values of Model 10 of ploughing operation is presented in Table 6 while its residual fuel values is presented in Table 7. Tractor fuel consumption and drawbar power have a strong positive linear relationship in this study thereby making this study to conform with the work of Ahaneku et al. (2004) were both variables (tractor speed and moisture content) were used for predicting draught and power requirement of a disc plough.

3.2.1.11 Model 11 of ploughing operation

Model 11 of ploughing operation consist of speed of operation and average soil bulk density as the two independent variables involved in the model developed. Model 11 of ploughing operation as shown in Table 5, gave a p-value of 0.061, R^2-value of 0.606 and Adjusted R^2-value of 0.475. It was observed in Table 5 that the residual standard error of the model developed was 0.43456 l/ha. Though, it was discovered that speed of operation contributed to the model developed with a p-value of 0.05 but resulting from the p-value of the model developed which was found to be greater than 0.05, considered Model 11 of ploughing operation as a model regression not fit for the dataset.

The model expression for Model 11 of ploughing operation as contained in Table 5 is expressed as:

$$\hat{y}=0.537+2.475ASBD+0.332E \quad (22)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

$ASBD$ = Ave. soil bulk density (g/cm^3)

E = Speed of operation (km/h)

The predicted fuel values of Model 11 of ploughing operation is presented in Table 6 while its residual fuel value is presented in Table 7.

3.2.1.12 Model 12 of ploughing operation

Model 12 of ploughing operation consist of speed of operation and average soil cone index as the two independent variables involved in the model developed. Model 12 of ploughing operation as shown in Table 5, gave a p-value of 0.069, R^2-value of 0.590 and Adjusted R^2-value of 0.453. Also shown in Table 5, is the residual standard error of the model developed which gave a value of 0.44372 l/ha. Though, it was observed that speed of operation contributed to the model developed with a p-value of 0.035 but resulting from the p-value of the model developed which was found to be greater than 0.05, considered Model 12 of ploughing operation as a regression model not fit for the dataset.

The model expression for Model 12 of ploughing operation as contained in Table 5 is expressed as:

$$\hat{y}=0.713+0.031ASCI+0.602E \quad (23)$$

Where,

$\hat{y}$ = Fuel consumption of tractor (l/ha)

$ASCI$ = Ave. soil cone index (N/cm^2)

E = Speed of operation (km/h)

The predicted fuel values of Model 12 of ploughing operation is presented in Table 6 while its residual fuel value is presented in Table 7.

3.2.2 Best model developed

Out of the 12 models developed during this study, 7 were considered as regression models that fits the dataset based on the fact that their p-values were < 0.05, while the remaining 5 were considered as regression models that does not fit the dataset based on the fact that their p-values were > 0.05. The results obtained in this study supports the earlier assertion of Ajav and Adewoyin (2011); Fathollahzadeh et al. (2010); Gulsoylu et al. (2012); Adewoyin and Ajav (2013); Moitzi et al. (2014); Oyelade (2016); Shafaei et al. (2018); and Okoro and Olosunde (2023) that speed of operation is considered a very strong factor in determining tractor fuel consumption. This was evident in Models 1, 3, 5, 6, 9, 10, 11 and 12 of plouging operation developed in the study as shown in Table 5. Though, Models 11 and 12 which were termed not good models due to their model p-values > 0.05 had speed of operation as significant variable in their models. This is to show how important speed of operation can be in contributing to the model developed for tractor fuel consumption in litres per hectare during ploughing operation in a sandy loam soil.

Among the seven models developed with p-values < 0.05, Model 10 of ploughing operation with the highest R^2-value of 0.972 and least residual standard error of 0.11650 l/ha was chosen as the best model developed for ploughing operation using a 74 and 75 horsepower tractor with a 3-bottom disc plough in a sandy loam soil. This does not mean to say that other models developed with p-values < 0.05 are not good, they are also good for predicting tractor fuel consumption of a 74 and 75 horsepower tractor using a 3-bottom disc plough during ploughing operation in a sandy loam soil.

Model 10 of ploughing operation which was picked as the best model in this study is in agreement with the study of Ahaneku et al. (2004) were both variables (tractor speed and moisture content) were used for predicting draught and power requirement of a disc plough. Power requirement otherwise known as drawbar power is related to tractor fuel consumption which this study also confirmed resulting from a correlation coefficient ‘r’ value of 0.795 obtained between fuel consumption and drawbar power values. This shows that there exist a strong linear relationship between fuel consumption and drawbar power in this study which also justified the importance of the research work of Ahaneku et al. (2004) in this study.

3.2.3 The importance of speed of operation to the study

Previous studies (Ajav and Adewoyin, 2011; Fathollahzadeh et al., 2010; Gulsoylu et al., 2012; Adewoyin and Ajav, 2013; Moitzi et al., 2014; Oyelade, 2016; Shafaei et al., 2018; Okoro and Olosunde, 2023) have shown that speed of operation was considered as a very strong factor that determine tractor fuel consumption during tillage operation. As a result of this, each measured parameter was paired with speed of operation in establishing fuel predictive models for use in predicting tractor fuel consumption for 74 and 75 horsepower tractors during ploughing operation in a sandy loam soil.

4 Conclusion

Three different tractor models of similar horsepower capacities were tested at the experimental field of the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. All test parameters measured during ploughing operation were in accordance with the recommendation of RNAM Test Codes and Procedures for Farm Machinery (1983). The data obtained during ploughing operation of the three tractors were subjected to multiple linear regression in order to develop models for predicting tractor fuel consumption. A total of 12 statistical models were developed out of which 7 were considered regression models fit for the dataset. The model with the highest R^2-value and least residual standard error was chosen as the best model which favoured Model 10 of ploughing operation which gave a p-value of 0.000023, R^2-value of 0.972, Adjusted R^2-value of 0.962 and residual standard error of 0.11650 l/ha.

The implications of the results obtained in this study to farmers include (i) for better fuel control and by implication, the cost of tillage operation, soil moisture conditions must be appropriate; (ii) the speed of operation is also critical. Therefore, adjusting both the speed of operation and soil moisture will help minimize fuel consumption and hence the cost of the field operation; and (iii) the optimum soil moisture and speed required to achieve the desired results in terms of fuel consumption can be obtained by keeping one of the parameters constant and evaluating the second parameter with the model equation and vice versa.

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