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DEVELOPMENT OF PREDICTIVE MODEL FOR FUEL CONSUMPTION DURING PLOUGHING OPERATION IN AGRICULTURAL SOIL

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ABSTRACT

Fuel plays a vital role in mechanized agricultural practices more especially during tillage operations. Fuel consumption is function of draught, tractor forward speed, ploughing depth, width of cut, cone index, bulk density and moisture content. This study was on development of predictive model for fuel consumption in respect of tillage operation using Buckingham pi theorem. The study was conducted in a loamy sand soil of 5200 m^2 of land in Rivers State Agricultural Development Programme Farm in School to Land Authority, Port Harcourt, Nigeria. The experimental fuel consumption was determined by amount of fuel used per unit time with the aid of graduated (measuring) cylinder and stop- watch to note the time taken after each operation. The field test parameters (draught, tractor forward speed, ploughing depth, moisture content, cone index and width of cut) were measured. The field data results were used in the development of the predictive model equation. The developed equation was validated by graphical comparison, also compared with root mean square error (RMSE) and paired t Test. The results showed that there was good agreement between measured and predicted fuel consumption, with corresponding RMSE value of 5.17E-7. And the t test result showed no significant difference with 95 and 99 % confidence. This developed equation is recommended to be used for envisaging fuel consumption in ploughing operations using disc plough.

Keywords: Tillage; Loamy Sand Soil; Disc Plough; Dimensional Analysis; Buckingham pi theorem.

INTRODUCTION

The use of a predictive model in the estimation of fuel consumption by a tractor during tillage operation considerably enhances the fuel utilization efficiency and economy. This reduces operational cost and increases agriculture productivity. It would be possible to estimate the amount of fuel consumed in different types of tillage operations preceding the field operations; and to predict the variation of dependent and independent variables involved in the process. All these ultimately result in increased profitability in crop production. Tillage is a preliminary land preparation which is essential in crop production. Over the years, prior to mechanization in agriculture, tilling the soil to boast production of food in agriculture has been in existence (McKyes, 1985). Ahaneku, Oyelade, and Faleye, (2011) states agricultural tillage involves soil cutting, soil turning, and soil pulverization which as a result, 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.

There are many parameters in tillage operation affecting fuel consumption of tractors, such as type and structure of soil, climate, tractor type, tractor size and tractor-implement relationship (Fathollahzadeh, Mobli, Rajabipour, Minaee, Jafari, and Tabatabaie 2010; Adewoyin, 2013; Adewoyin, and Ajav, 2013). Ahaneku et al. (2011) studied comparative field evaluation of three models of a tractor and found that the high fuel consumed by tractor could be ascribed to tractor forward speed with a higher wheel slip.

LITERATURE REVIEW

Several factors that affect fuel consumption fundamentally in tillage equipment use is the increase in power consumption by increasing the working speed, actual width of cut, soil strength, moisture content and the working depth (Cortez, Furlani, Silva, and Grotta, 2008; Kichler, Fulton, Raper, McDonald, and Zech, 2011; Silveira, Fernandes, Modolo, Silva, and Trogello, 2013; Moitzi, Wagentrist, Refenner, Weingartmann, Piringer, Boxberger, and Gronauer, 2014; Leghari, Oad, Shaikh, and Soomro, 2016; Nasr, Tayel, Abdelhay, Sabreen, and Dina, 2016). Investigation by Moitzi et al. (2014) revealed that increasing working depth, raises the drawbar pull and the slip and the effect is an increased fuel consumption rate (L h-1) and area-specific fuel consumption (L ha^{-1}). Cortez et al. (2008); Kichler et al. (2011); and Silveira et al. (2013) posited that within the same operating speed and varying the engine speed, there are significant increases in hourly fuel consumption. 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 call for extensive engine testing to verify the amount of fuel consumption (ASAE 2002a; 2002b; Grisso, Kocher, and Vaughan, 2004; Grisso, Perumpral, Vaughan, Roberson, and Pitman, 2010).

Persson, (1969, as cited in Macmillan, 2002) developed an equation for modelling engine performance based on power, speed, swept volume and heat value of the fuel, together with two constants estimated from the test data. On the other hand for an engine of given type and swept volume, Persson’s equation was reduced to the form given by Huynh and Brown (1981, as cited in Macmillan, 2002). Bowers, (2001, as cited in Grisso et al., 2004) developed model specified to assess average fuel consumption data the varying PTO power tests from the NTTL Reports. The fuel consumption in excess of the varying PTO power tests (approximately 100%, 85%, 65%, 45%, 20%, and 0% of rated PTO power) were averaged and then the average was divided by the rated PTO power (Grisso et al., 2004). Furthermore they stated that one implication of this method is that the estimated annual fuel consumption is based on operation of the tractor for equal amounts of time at each of these partial loads. Fuel consumption estimates for crop production and machinery financial plan are centred on the average annual fuel consumption from Agricultural Machinery Management engineering practice (ASAE Standards 2002a). ASAE (2002a) developed predictive model to predictive model for average gasoline consumption over a whole year of a tractor operating under a range of load conditions. In the time most tractors tested and used for agricultural purposes have had diesel engines they improved the equations developed for diesel engines. ASAE (2002b) developed equation for fuel consumption for a particular operation such as ploughing. Kheiralla, Yahya, Zohadie, and Ishak, (2003) developed a fuel consumption model from regression analysis. This was formulated based on linear tractor PTO power as well as linear equivalent. Hansson, Lindgren, Nordin, and Pettersson, (2003) developed a model base on the steady state fuel consumption as a function of engine speed and loading torque. Kheiralla, Yahya, Zohadie, and Ishak, (2004) formulated fuel consumption models for a number of implements. This revealed linear relationships between fuel consumption rates and drawbar power or PTO power. Furthermore, their development of fuel consumption models for tractors have need of the engine power be represented in its equivalent PTO shaft power. Grisso et al. (2004) developed a general model to predict fuel consumption for full and partial loads and for reduced throttle conditions when engine speeds are reduced from full throttle using data from Nebraska Tractor Test Laboratory (NTTL) in U.S.A. for a specific tractor models. With these, mathematical equations make it possible to predict fuel savings for different operating and loading tractor conditions (Grisso, Vaughan, and Roberson, 2008). Also Kheiralla et al. (2004) developed regression model for fuel consumption on various implements. The regression analysis results for the mould board plough, disk plough, disk harrow and the rotary tiller have shown linear relationships between fuel consumption rates and equivalent PTO power. Safa, Samarasinghe, and Mohssen, (2009) used an artificial neural network (ANN) approach to model fuel consumption of wheat production. They reported that the developed model is capable of predicting fuel consumption under different field conditions and can help farmers to reduce their expenditure. ASABE Standards (2006; 2009, as cited in Grisso et al., 2010) are generally used for estimating fuel consumption for financial plan preparations and fuel consumption equations for compression ignition engines. They developed most commonly used relationship for estimating fuel consumption in gallons per hour (gal/h). Grisso et al. (2010) also developed an equation for fuel consumption estimates for specific tractor models. They stated that the general equations are useful for predicting fuel consumption for diesel engines during full and partial loads and under conditions when engine speeds are reduced from full throttle. Also, they specified that the model has the capability to predict fuel consumption when the tractor is fully or partially loaded and when the engine speeds are reduced from full throttle. Fathollahzadeh et al. (2010) developed a fuel consumption model for a John Deere 3140 tractor at a number of working depths of mould board plough. Their results showed a linear relationship between fuel consumption and working depth of the mould board plough. Rahimi-Ajdadi and Abbaspour-Gilandeh, (2011) development models based on artificial neural network and stepwise multiple range regression for prediction of tractor fuel consumption. Fuel consumption was assumed to be a function of engine speed, throttle and load conditions, chassis type, total tested weight, drawbar and PTO powers. Results indicated that the artificial neural network and stepwise regression models gave similar determination coefficients (R^2 = 0.986 and R^2 = 0.973, respectively) while the artificial neural network provided relatively better prediction accuracy (R^2 = 0.938) compared to stepwise regression (R^2 = 0.910). Adewoyin, (2013); Adewoyin and Ajav, (2013); represented the linear relationship between tractor fuel consumption and ploughing depth as an equation and also reported that fuel consumption increased significantly with increase in tractor forward speed, the linear relationship is represented by fuel consumption equation. It was further revealed that the fuel consumption of farm tractors vary with changes in forward speeds and depths and the model that gives the best fit is a linear relationship represented in equations. Pelletier, Godbout, Belzile, and Li, (2014) developed a model predicting fuel consumption according to the different agricultural practices; the equation showed that land preparation and fertilizer consumed the highest amount of fuel. Karparvarfard and Rahmanian-Koushkaki, (2015) used dimensional analysis in Buckingham's pi theorem to develop fuel consumption equation for a tractor chisel-ploughing in a clay loam Soil. They reported that the fuel consumption rate can be effectively predicted by the model with good accuracy. Kumar and Pandy, (2015) used a visual basic program with multiple linear regression analysis for predicting gear and throttle position for best fuel economy. The collected data in excel spread sheet was fitted to the model structure formulae to determine the coefficients. Lee, Kim, and Kim, (2016) developed fuel consumption model with computer simulation using ASABE linear model to define a quadratic equation based on three fuel efficiencies. Almaliki, Alimardani, and Omid, (2016a) used acquired data to produce an accurate model for fuel consumption in three forms (Temporal Fuel Consumption, TFC; Area-specific Fuel Consumption, AFC; and Specific Fuel Consumption, SFC). Dahab, Kheiry, and Talha, (2016) developed a computer model of fuel consumption estimation for different agricultural farm operations. They reported that changing any of the component parameters could quickly affect the other parameters in the model resulting in quick decision-making and proper machinery management. It was realized that the sensitivity analysis showed that the change in any input parameters, for example speed, unit draught, engine power, affected directly the estimated fuel consumption rate. Subsequently, they stated that 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. Finally it was discovered that computer model is a useful tool for farmers to estimate the fuel consumption for any type of machine attached to the agricultural tractor and it enables the user to change any of the parameters (speed, unit draught, engine power, transmission efficiency and width) to have different outputs. Almaliki, Alimardani, and Omid, (2016b) developed a model using artificial neural network (ANN) based modeling of tractor performance at different field conditions. Results obtained indicated that the neural network can be able to pick up the relationships between the input variables and performance parameters of tractor, very well. Finally, It has been suggested that because of fast, accurate and reliable results and efficient of the ANN models this can be used to predict tractor's performance (Rahimi-Ajdadi, Abbaspour-Gilandeh, 2011; Almaliki et al., 2016b, Shafaei, Loghari, and Kamgar, 2018. Shafaei, et al. (2018) developed model on neurocomputing based intelligent simulation of tractor fuel efficiency parameters.

So far, there is dearth of researches about the use of Dimensional Analysis with Buckingham pi theorem in development of model equation for predicting tractor fuel consumption in ploughing operation. So, in this research the use of Dimensional Analysis with Buckingham pi theorem to develop predictive model equation for tractor fuel consumption in ploughing operation will be adopted.

The aim of this study was to develop an appropriate predictive equation for the determination of optimum tractor fuel consumption in ploughing operations.

METHODOLOGY

Tillage Site

The experiment was conducted at the Rivers Agricultural Development Programme farm in School to Land Authority, Port Harcourt, Nigeria (4° 49′ 27″ N, and longitude of 7° 2′ 1″ E). The experimental design adopted was factorial in randomized complete block design (RCBD) to evaluate fuel consumption during ploughing operations. A farm location, 160 m by 32.5m (5200 m^2) which was divided into three blocks of 9 plots each. Each plot was marked out 50m by 2.5 m each along with the paths alley dimension of 1m between each plot was provided for different treatment options and with a space of 4 m between each block and 1 m at the sides of the of the outer blocks.

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Tractor and Implement Specifications

Table 1: Tractor Specifications

Parameter	Description
Model	Swaraj 978 FE
Drive	2 Wheel drive
Engine horse power	72 hp
Lifting power	2200 kg
Hitch	3 point CAT III
Front tyres	7.5 - 16 ,8 – ply
Rear tyres	16.9 - 28,12 – ply
Width	2030 mm
Weight	3050 kg
Manufacturer	Swaraj, India.

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Table 2: Implements Specifications

Parameter	Plough
Number of Disc	3
Working Depth (330)	300
Frame Width (mm)	1180
Width of Cut (mm)	1120
Disc Diameter (mm)	660
Manufacturer	Swaraj, India

Table 1 shows a tractor specification that was used for this study. The two wheel drive tractor (model: Swaraj 978 FE, manufacturer: India) was the most common tractor in the part of the country. As well, Table 2 shows the implement specifications that were used for the study. A three gang disc plough was used to perform the tillage (plouhing) operations in the field. The disc plough was the common type of the farm implement suitable for the soil type in the region of the country. Farmers in this region usually use this implement for performing their primary tillage activities.

Experimental Procedure

Figure 1: Ploughing Operation

Figure 2: Measurement of Volume of Fuel Used

Certain soil samples were collected from the study area prior to tillage operations with implements. Soil auger was used for collecting the sample at the depth of 0 - 0.30 m at random in the field to determined textural classification of the soil and moisture content. The composite soil samples were put in well labelled polyethylene bags and were taken to the laboratory immediately.

The hydrometer method was used to determine the textural classification of the soil. The soil sample was 102 g of air dried soil and was weighed, placed in a 500 ml beaker filled in within 5 cm of the top with distilled water. Hence, the temperature reading taken was calculated and percentage of sand, silt and clay were determined. Finally, the textural class was determined using textural triangle. The gravimetric (i.e. oven dry method) was used to determined soil moisture content prior to tillage operation. The soil samples were collected randomly at depths of 0 – 30 cm soil using auger. 100g of wet soil was weighed and put into an aluminium pan and placed into an oven at 105oc. The soil was reweighed and the solid mass was noted.

Cone index (CI) was measured with simple measuring device called cone penetrometer having an enclosed angle of 30o, with a base area of 3.23cm2 (323mm2) mounted on a shaft of 45.72cm (457.20 mm). Cone index (soil resistance) to penetration of implements was taken at three different depths, 0-0.10, 0-0.20, 0-0.30m respectively before any of the tillage operations. During operation, the cone penetrometer was positioned between the operator's two legs and with his two hands on the handle pushed into the soil until the marked point on the shaft is reached, the reading was taken.

Prior to ploughing operation, the ploughing depths were determined by setting the controlling level of the lifting mechanism (three-point linkage height) to lower the disc plough corresponding to the desired ploughing depth. Ploughing speeds were determined by selecting a particular gear that will give the desired speed. This was done either at full or reduced throttle setting. The tractor was operated at the respective throttle and gear settings to gain the required ploughing speed at a ploughing depth (0.10, 0.20 and 0.30 m) corresponding to the required parameters at a gear best suited for targeted operational speed of 1.39, 1.94 and 2.50 ms-1 respectively. This was done in a practice area in advance entering to each main test plot for maintaining desired treatment. The ploughing depth was measured by placing the meter rule from furrow bottom to the surface of the unploughed land, while the width of cut was measured by placing a steel tape from one side of the furrow wall to the other end. Time was determined with stop watch setting at zero before each operation. The reading was taken at the end of each operation test.

Draught force was determined using the formula represented below (ASAE, 2000a):

$$D = F_i[A + B(S) + C(S)^2]WT \quad (1)$$

Where;

D = Draught force, N

F = dimensionless soil texture and adjustment parameter (table)

i = 1 for fine, 2 for medium 3 for coarse (table)

ABC = machine specific parameter (table)

S = speed

W = machine with or number of rows (table)

T = depth cm

The Direct method (topping up the tank) of determining fuel consumption was adopted for determining tractor fuel consumption. During this process the tractor fuel tank was filled to the brim before and after each operation test was performed. . The measurement of fuel consumption was taken using 1000 ml graduated cylinder to top up the fuel level in the tank after each operation test, thereby noting the volume of fuel consumed per time taken for the operation (Fig 2). The fuel consumption was determined mathematically by adopting equation (3) given as:

$$FC = \frac{V_{fc}}{T} \quad (2)$$

Where:

FC = fuel consumption (m^3/s)

V_{fc} = volume of fuel consumed, m^3;

T = Time, s.

Development of Model Equation

The significance of accurate prediction cannot be overemphasised in any field of engineering. Therefore, mathematical tool employed in this work is Dimensional Analysis using Buckingham pi theorem concerning dimensionally homogeneous equations. Dimensional analysis is a method that helps in determining functional relations providing a technique for combining various parameters that are thought to represent a system into group of dimensionless terms selected as pi terms, which reduces the number of variables in a multifaceted phenomenon to a smaller set of dimensionless ratio. This outcome is in considerable savings in both cost and labour during the experimental determination of the function (Srivastica, Goering, Rohrbach, and Buckmaster, 2006).

Table 3: Some Variables Affecting Fuel Consumption

Variables	Symbol	Unit	Dimension
Dependent Variable			
Fuel Consumption	Fc	m^3/s	$\mathbf{L^3\ T^{-1}}$
Independent Variables			
Forward Speed	V	m/s	$\mathbf{LT^{=1}}$
Tillage depth	D	m	**L**
Width of cut	W	m	**L**
Cone index	CI	N/m^2	$\mathbf{ML^{-1}T^{-2}}$
Bulk density	ρ_b	Kg/m^3	$\mathbf{ML^{-3}}$
Draught force	D	N	$\mathbf{MLT^{-2}}$
Moisture content	M	%	$\mathbf{M^0L^0T^0}$

Fuel consumption, Fc is a function of (d, W, V, CI, $\rho_{b,}$ D, S, and MC)

Mathematically;

$$Fc\ = f(d, W, V, CI, \rho_{b,} D, MC) \quad (3)$$

Or

$$Fc\ = (d, W, V, CI, \rho_{b,} D, MC) \quad (4)$$

Total number of variables, n = 8

Total number of fundamental dimensions, m = 3

Therefore, number of π- terms = n – m = 5

Equation (5) can be written as:

$$f_1 = (\pi_{1,}\pi_2, \pi_{3,}\pi_4, \pi_5) \quad (5)$$

Each π- term contains (m + 1) variables, where m = 3 and is also equal to repeating variable choosing from $\rho_{b,}$ d, V as repeating variables, we get five π- terms as:

$$\pi_1 = \rho_b^{a_3} . d^{b_3} V^{c_3} . Fc \quad (6)$$

$$\pi_2 = \rho_b^{a_4} . d^{b_4} V^{c_4} . W \quad (7)$$

$$\pi_3 = \rho_b^{a_5} . d^{b_5} V^{c_5} . CI \quad (8)$$

$$\pi_4 = \rho_b^{a_6} . d^{b_6} V^{c_6} . D \quad (9)$$

$$\pi_5 = M \quad (10)$$

The model fuel consumption equation developed is represented as:

$$\therefore Fc = \varphi \frac{DVdMc}{CIW} + C \quad (11)$$

Also, the equation can be written as:

$$Fc = \varphi Z + C \quad (12)$$

Where:

D is Draught force (N), W is Width of cut (m), V is ploughing speed (m/s), d is ploughing depth (m).CI is Cone index (N/m^2), MC is Moisture content (%) and Z = Mean field test results $\left(\frac{DVdMc}{CIW}\right)$.

Equation Validation

The developed equation was validated with regression curve to check if the measured and predicted results are in good agreement. Also, root mean square error (RMSE) was used to check the error difference as represented below:

$$RMSE = \sqrt{\frac{\frac{1}{N}\sum_{i-1}^{i-N}(FC_m - FC_p)^2}{N}} \quad (13)$$

Where:

N = number of samples; FC_m = measured fuel consumption; FC_p = predicted fuel consumption.

Furthermore, the t Test was used to compare the experimental and predicted data to determined significant difference at 0.05 and 0.01 level of significance (95 and 99 % confidence) as given in equation (14).

$$t = \frac{\sum D/N}{\sqrt{\frac{\sum D^2 - \left(\frac{(\sum D)^2}{N}\right)}{(N-1)(N)}}} \quad (14)$$

Where:

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$\sum D$ = summation of the differences; $\sum D^2$ = summation of the squared differences; $(\sum D)^2$ = summation of the differences squared.

RESULTS

Table 4: Soil Textural Class

Percentage (%) by Mass		
Clay	**Silt**	**Sand**
14.30	5.30	80.40

Table 5: Mean Results of Field Test Performed during Ploughing Operation

Parameter	Ploughing Depth, d_1 (m)			Ploughing Depth, d_2 (m)			Ploughing Depth, d_3 (m)		
	V_1 (m/s)	V_2 (m/s)	V_3 (m/s)	V_1 (m/s)	V_2 (m/s)	V_3 (m/s)	V_1 (m/s)	V_2 (m/s)	V_3 (m/s)
FC (m^3/s)	2.08E-06	2.33E-06	2.50E-06	3.41E-06	3.33E-06	4.76E-06	3.75E-06	4.87E-06	5.83E-06
W (m)	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
CI (N/m)	2900.00	2900.00	2900.00	4200.00	4200.00	4200.00	5050.00	5050.00	5050.00
D (N)	1435.82	1553.64	1671.45	2871.65	3107.27	3342.89	4307.47	4660.91	5014.43
MC (%)	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50

Table 6: Mean Values of Field Test and Z for Ploughing Operation

Treatment	D (N)	V (m/s)	d (m)	Mc (%)	CI (N/m)	W (m)	Z= $\left(\frac{DVdMc}{CIW}\right)$
d_1V_1	1435.82	1.39	0.10	17.50	2900.00	1.12	1.08E-02
d_1V_2	1553.64	1.94	0.10	17.50	2900.00	1.12	1.62E-02
d_1V_3	1671.45	2.50	0.10	17.50	2900.00	1.12	2.25E-02
d_2V_1	2871.65	1.39	0.20	17.50	4200.00	1.12	2.97E-02
d_2V_2	3107.27	1.94	0.20	17.50	4200.00	1.12	4.49E-02
d_2V_3	3342.89	2.50	0.20	17.50	4200.00	1.12	6.62E-02
d_3V_1	4307.47	1.39	0.30	17.50	5050.00	1.12	5.56E-02
d_3V_2	4660.91	1.94	0.30	17.50	5050.00	1.12	8.39E-02
d_3V_3	5014.43	2.50	0.30	17.50	5050.00	1.12	1.16E-01

Table 7: Validation of the Model Equation for Ploughing Operation

Treatment	D (N)	V (m/s)	d (m)	Mc (%)	CI (N/m)	W (m)	$FC = 4.00E05\left(\frac{DVdMc}{CIW}\right) + 2E\text{-}06$
d_1V_1	1435.82	1.39	0.10	17.50	2900.00	1.12	2.43E-06
d_1V_2	1553.64	1.94	0.10	17.50	2900.00	1.12	2.65E-06
d_1V_3	1671.45	2.50	0.10	17.50	2900.00	1.12	2.90E-06
d_2V_1	2871.65	1.39	0.20	17.50	4000.00	1.12	3.19E-06
d_2V_2	3107.27	1.94	0.20	17.50	4000.00	1.12	3.80E-06
d_2V_3	3342.89	2.50	0.20	17.50	4000.00	1.12	4.49E-06
d_3V_1	4307.47	1.39	0.30	17.50	5050.00	1.12	4.22E-06
d_3V_2	4660.91	1.94	0.30	17.50	5050.00	1.12	5.36E-06
d_3V_3	5014.43	2.50	0.30	17.50	5050.00	1.12	6.64E-06

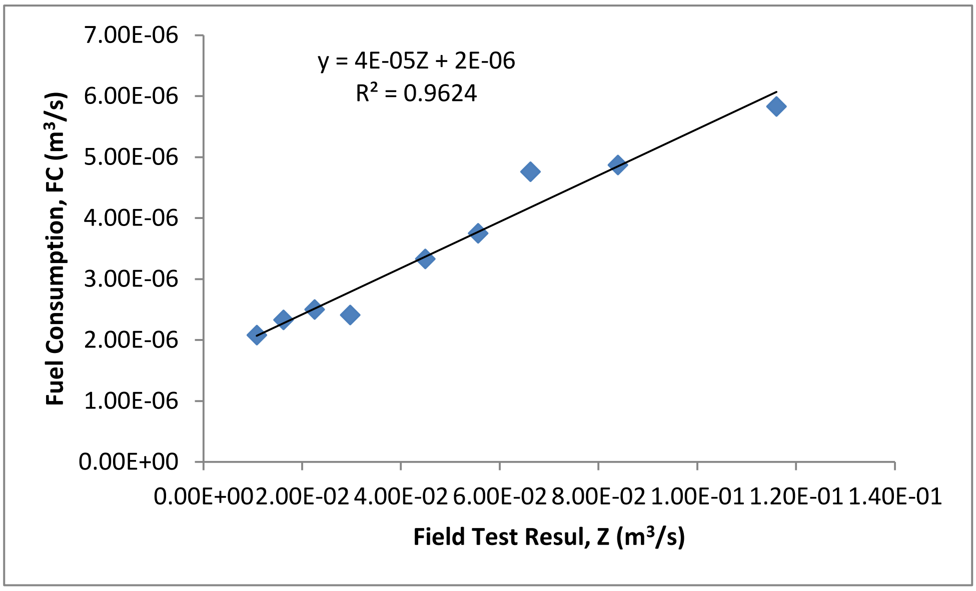

Figure 3: Fuel Consumption, FC (m^3/s) and Field Test Results, Z (m^3/s) Relationship

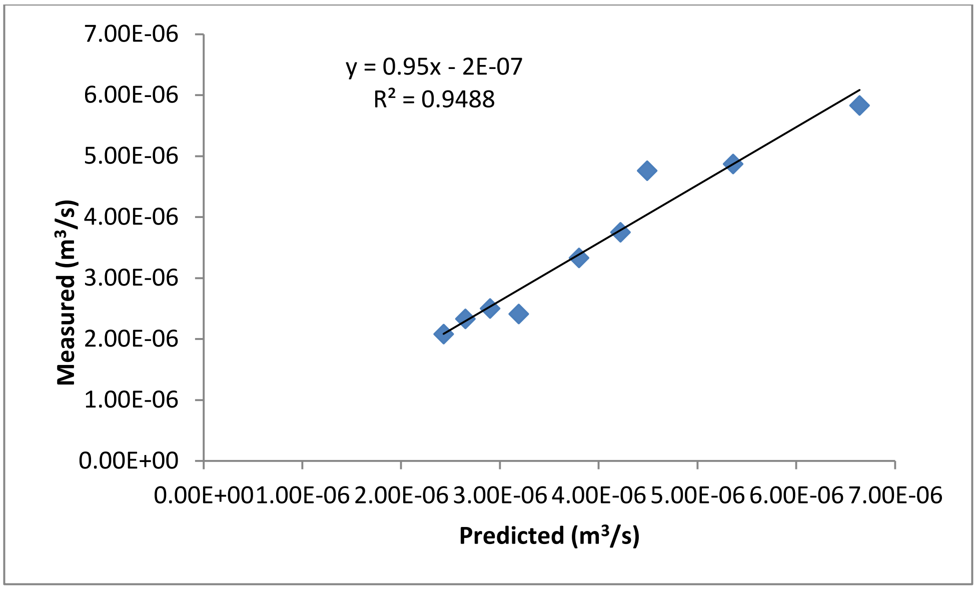

Figure 4: Measured (m^3/s) and Predicted (m^3/s) Fuel Consumption Relationship

DISCUSSION

Table 4 showed the soil textural classification as loamy sand soil (80.40 % sand, 5.30 % silt and 14.30 % clay). The field test parameters include the draught (D), tractor forward speed (V), ploughing depth (d), moisture content (MC), Cone Index (CI), and width of cut (W) that were evaluated and used as indices for assessment of the fuel consumption model equation preceding and during ploughing operation as presented in Table 5. Fuel consumption model equation was developed using Dimensional Analysis (Buckingham pi theorem) to analyze the result from field test. The mean field test results (Z) for the ploughing operations were presented in Table 6. From tables 5 and 6, regression graph was plotted for fuel consumption (FC, m^3/s) against mean field test results (Z, m^3/s) and the values for the constants (φ and C) were established for ploughing operation (Figure 3) and the linear regression equation was fitted into the model fuel consumption equation developed. This is similar to Nkakini, (2013) that used regression curve to established constants in his equation of modeling of tractive force on ploughed soil and also Kumar and Pandy, (2015) used multiple linear regression analysis with excel spread sheet and fitted to the model structure formulae to calculate the coefficient. The result showed acceptable agreement with coefficient of determination R^2 = 0.9624. As a result, the established predictive fuel consumption model equation for ploughing operations at speed of 1.39, 1.94 and 2.50 m/s with depth of 0.1, 0.2 and 0.3 m respectively is:

$$FC = 4.00 \times 10^{-5} Z + 2.00 \times 10^{-6} \text{ Or } FC = 4.00 \times 10^{-5} \left(\frac{DVdMc}{CIW}\right) + 2.00 \times 10^{-6} \quad (19)$$

The mean field test was used in the equation to predict the combine effect of soil-implement parameters on tractor fuel consumption performance. Accordingly, from equation (19) constants of of 4.00×10^{-5} and 2.00×10^{-6} for ploughing operation were established.

Authenticity of a developed model equation for solving a particular problem depends on its predictions and validation. Table 7 showed results of the developed model fuel consumption equation for ploughing operations by substituting the values of a number of experimental data which is being compared with the measured fuel consumption. As a result, the predicted fuel consumption values were close to measured fuel consumption. Figure 4 showed the graphical relationship between measured and predicted fuel consumption values. The result indicated acceptable agreement with coefficient of determinations R^2 = 0.9488. The error analysis which depicted the differences between the measured and predicted model results ranged between -3.30E-07 to 2.70E-07 while the RMSE was 5.17E-07 that is low compared to the mean. Also t Test was used to determine the significance difference between the means of measured and predicted fuel consumption at 0.05 and 0.01 significance (i.e. 95 and 99 % confidence) levels. The result of the paired t Test showed that $t_{calculated}$ (1.80) is less than t_{table} (2.306 and 3.355). This indicated that there were no significant differences between the measured and the predicted.

CONCLUSIONS

This study had developed model equations for fuel consumption during tillage operations (ploughing, The predictive model equaton established is:

$$FC = 4.00 \times 10^{-5}\left(\frac{DVdMc}{CIW}\right) + 2.00 \times 10^{-6} \text{ for ploughing;}$$

The constants for ploughing were obtained as $4.00 \times 10^{-5}, 2.00 \times 10^{-6}$. The equatons' ceofficient of determinations R^2 = 0.9624 was obtained for ploughing. The results reviewed acceptable agreement with the measured and predicted model equatons results. The RMSE value of 5.17E-07 was low and t Test result of $t_{calculated}$ (1.80) is less than t_{table} (2.306 and 3.355), showed highly significance difference between the measured and predicted fuel consumption at 0.05 and 0.01 significance (i.e. 95 and 99 % confidence) levels. This has ascertained that the model equation developed can precisely predict fuel consumption. Conclusively, the developed fuel consumption equation showed good treatments between experimental (measured) and predicted equation results. Hence, selecting the right parameters, required for ploughing operations and good soil condition will achieve good estimation, saving fuel and cost reduction, Also it can be used as a guide for decision making tool to farmers, agricultural engineers and those interested in machinery management.

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