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Modeling of energy requirement for tillage operations in a sandy loam soil

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Abstract

Tillage, the mechanical manipulation of soil, demands a huge amount of energy in order to accomplish various tasks during field operation. Field tests and evaluation were conducted on 40 different tractor makes and models with matching implements on a sandy loam soil between 2005 and 2011 by the officials of the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. Implements used for the trials were tractor mounted disc plough and off-set disc harrow. Each tractor was operated on an area of 0.25 hectare (25 m × 100 m) in a randomized complete block design (RCBD). Parameters measured include travel speed, actual and total time of operation, field efficiency, field capacities (effective and theoretical), depth and width of cut, average soil moisture content, average soil bulk density and average soil cone index in order to determine the energy requirement for each tractor-implement combination. Two models for predicting energy requirement during ploughing and harrowing operations were developed using 36 tractor test data. The multiple linear regression method was used for developing the two models. The remaining 4 tractor test data were used for cross-validation. The resulting model equations for ploughing and harrowing operations gave R-squared values of 0.859 and 0.776, respectively. Results obtained from the predicted energy requirement values when compared to that of the observed energy requirement values for both ploughing and harrowing operations gave correlation coefficient values of 0.927 and 0.881, respectively. Cross-validation results for the models developed for energy requirement during ploughing and harrowing operations gave test error values of 4672.3 J m^{-3} and 2721.1 J m^{-3}, respectively.

Keywords: Tillage; Energy; Operation; Width; Depth; Speed

1. Introduction

Tillage operation in a conventional farming system involving the use of the tractors results in high energy costs. The sustainability of such system requires a well-controlled resource management leading to a significant reduction in crop production costs derived from savings in fuel consumption [1]. Farm managers and consultants use draught and power requirements of tillage implements in specific soil types to evaluate implement performance and energy requirements, and to determine requisite tractor sizes [2].

Tillage is a basic step for any agricultural production which demands a huge amount of energy. In tillage operation, energy can be expressed in terms of energy per unit area or per unit volume of disturbed soil [3]. Energy requirement can be expressed as the rate of energy per depth of operation. The most important factors in determining energy requirement of a tillage tool are draught and the amount of disturbed soil [4]. In other words, energy can be derived from the product of draught and length of disturbed soil. The report of energy requirement for a tillage operation should therefore include the depth of operation as well. Energy has also been defined as the product of force and the distance the soil has been moved. According to Mckey [5], energy requirement per unit volume has the same unit as draught per unit area, as it can be shown as the draught requirement to cut a furrow in an exact cross section.

Tillage operation further involves soil cutting, soil turning and soil pulverization. These three soil actions demand high energy, not just due to large amount of soil mass that must be moved, but also due to inefficient methods of energy transfer to the soil [6]. Energy is used in two ways during tillage operations. The first is in driving the tractor which constitutes traction, rolling resistance and wheel slip, and the second in pulling the implement, which is the draught. The most widely used energy-transfer method is pulling tillage tool through the soil.

A tillage implement moving at a constant speed is subject to the forces of weight of implement, soil forces acting upon the implement and the forces acting between the implement and the tractor. The resultant of all these three forces is the pull of the tractor upon the implement. Depth of cut, width of cut, tool shape, tool arrangement and travel speed are factors that affect draft and energy utilization [7]. According to Bukhari et al. [8], disc implement can cut through crop residues, will roll over roots and other obstructions and can be operated in non-scouring soils by using scrapers. The disc provides incomplete coverage of trash which may either be an advantage or a disadvantage depending upon the tillage objectives.

Crop production activities in Nigeria are done at small-scale, subsistence levels. Consequently, human labour is the predominant source of power. Human labour utilizes human muscular energy for certain operations in such areas as farm irrigation using traditional tools, transportation of goods on head or shoulder, etc. With the use of human energy, land and labour productivities cannot be increased to the levels obtainable in developed countries. Presently, Japan, does not employ animal power for all their agricultural operations and as of 1975, about 99 per cent of farm power was derived from mechanical source [9].

During tillage operations various factors such as soil parameters (soil physical, mechanical and dynamic properties); tool parameters (tool type, tool shape and size, tool rake angle, tool sharpness

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and tool material) and operational parameters (speed of operation and depth of cut) can affect energy requirement of a tool. Soil parameters have significant influence on the amount of energy requirement of a tillage operation. Soil moisture content and soil texture affect mechanical behavior and strength of soil. Soil of same mechanical and environmental conditions but of different texture behaves differently. Camp and Grill [10] and Smith [11] observed that shear strength parameters of fine grained soils decreased with increasing moisture content. As moisture content increases, the soil changes from brittle solid to a plastic solid and eventually to a viscous liquid.

Bulk density of a soil is a function of soil moisture at any amount of compactive effort. As the soil wetness increases, the moisture weakens the inter-particle bonds, causing swelling and reducing internal friction making the soil more workable and compactible [12]. The optimum moisture content is the point at which the moisture is just enough to expel all the air from the soil, and the corresponding density is the maximum dry density.

Cone index of agricultural soils is a very important factor that is measured in most tillage studies and it indicates the resistance of soil to penetration. Cone index taken at different depths of the various soil types helps researchers to elevate and compare soil mechanical strength and forces engaged in tillage operations. The ASAE Standards [13] emphasizes that cone index does not provide specific soil values such as soil cohesion, angle of friction or coefficient of soil-metal friction. Other soil parameters of use in tillage studies include soil cohesion, soil-soil friction, soil shear strength and soil compaction.

Draught and energy requirements, based on soil and operating conditions, are considered important parameters for design and manufacture of improved tillage implements. Thus, quantification of these parameters with respect to different soil failure patterns necessitates having good knowledge of soil-tool interaction. Tillage tools apply forces to soil resulting in soil failure for enhanced seedling emergence, improved plant rooting, increased infiltration rate, and controlled soil erosion [14,15]. The primary interest in tillage operations is the application of mechanical forces by machines to change the soil condition for agricultural production purposes [16]. Factors such as soil texture, soil moisture content, soil compaction, tool geometry, tool operating depth, tool forward speed and tool rake angle obviously affect energy requirement of a tillage operation. There has been much research that discusses the effect of these factors for different soil and tool conditions on tool energy requirement although each of them has some limitations in their applications [17,18,19].

According to Uke [20], draught and energy requirement of mouldboard, disc and chisel ploughs differ depending on the situation in which they are used. Summers et al. [21] reported that draught is linear with speed for chisel, disc and sweep ploughs and is quadratic with speed for mouldbaord ploughs. They further asserted that draught was linear with depth for mouldboard ploughs. Rotary tillers are known to have a very low or negligible draught requirement but the total power requirement are quite high. Depth of cut, width of cut, tool shape (including cutting edge), tool arrangement and travel speed are factors that may affect draught and energy utilization efficiency for specific soil condition. The effects of these parameters vary with different types of implements and with different soils [22]. Implement width, operating depth and speed are factors that affect draught of a tillage implement. Draught also depends on soil conditions and geometry of the tillage implements [23]. The effect of speed on implement draught depends on soil type and the type of implement. It has been widely reported that draught forces on implements increase significantly with speed and the relationship varies from linear to quadratic [24].

It is important to note that for many tractors used along with matching implements in Nigeria, hardly could tractor owners give records of the amount of energy expended by such tractor-implement combinations in performing a particular tillage operation. In view of this, a model is needed to be developed for predicting energy requirement for tillage operations from the various data generated during ploughing and harrowing operations in a sandy loam soil. The objective of this study is to develop a statistical model for predicting energy requirement during ploughing and harrowing operations in a sandy loam soil.

2. Data and Methods

This investigation involves making use of available data gathered during field evaluation of several farm tractors in predicting energy requirement for ploughing and harrowing operations in a sandy loam soil. These farm tractors were tested by the officials of the National Centre for Agricultural Mechanization (NCAM), Ilorin as part of the Centre's mandate in testing all kinds of agricultural machinery, tools and equipment imported into the country for use in Nigerian agriculture. The study was conducted on a sandy loamy soil between 2005 and 2011. The implements used for the trials were tractor mounted, disc plough and off-set disc harrow. Each tractor was tested on an area of 0.25 hectare (25 m × 100 m) in a randomized complete block design (RCBD).

Parameters measured include travel speed, theoretical and effective field capacities, draught, depth and width of cut, soil cone index, soil moisture content on dry weight basis and soil bulk density. The three soil properties, namely, soil cone index, soil moisture content and soil bulk density were all measured at depths 0 - 7 cm, 7 – 14 cm and 14 – 21 cm. The resulting average values of these three soil properties were part of the data collated. All the parameters of the tractor-implement performance were measured and recorded in line with the recommendations of RNAM [25] test codes and procedures for farm machinery technical series.

For the purpose of this study, it should be noted that disc plough and offset disc harrow are the two commonest tillage implements used in Nigeria for carrying out ploughing and harrowing operations, respectively, on the field.

2.1. Test parameters

The following parametric equations were used for the various evaluations:

2.1.1. Soil Bulk Density

Soil bulk density measured in g/cm^3 was expressed mathematically as:

$$S_{\text{bd}} = \frac{M_T}{V_T} \tag{1}$$

where,
S_{bd}: Soil bulk density (g/cm^3)
M_T: Mass of oven dried soil (g)
V_T: Total volume of soil (cm^3)

2.1.2. Soil Moisture Content

Soil moisture content obtained in dry weight basis was expressed mathematically as:

$$MC_{d.b} = \frac{M_w}{M_s} x\ 100\% \tag{2}$$

where,
$MC_{d.b}$: Soil moisture content in dry basis (%)
M_w: Mass of water (g)
M_s: Mass of dried soil (g)

2.1.3. Theoretical field capacity

Theoretical field capacity measured in ha/h was expressed mathematically as:

$$A = \frac{B\,(3600)}{C} \tag{3}$$

where,
A: Theoretical field capacity (ha/h)
B: Area of field (ha)
C: Effective time taken in doing the main tillage work (seconds)

2.1.4. Effective field capacity

Effective field capacity measured in ha/h was expressed mathematically as:

$$D = \frac{B\,(3600)}{C_1} \tag{4}$$

where,
D: Effective field capacity (ha/h)
B: Area of field (ha)
C_1: Total time taken in completing the whole tillage operation (seconds)

2.1.5. Field efficiency

Field efficiency measured in (%) was expressed mathematically as:

$$E = \frac{D\,(100\%)}{A} \tag{5}$$

where,
E: Field efficiency (%)
A: Theoretical field capacity (ha/h)
D: Effective field capacity (ha/h)

2.2. Regression Analysis

The multiple linear regression method was used for developing the model for predicting energy requirement for tillage operations from the test results of tractors tested by the National Centre for Agricultural Mechanization (NCAM), Ilorin during ploughing and harrowing operations in a sandy loam soil. The model equations were generated using the SPSS statistical tool of version 25.0.0.0. package.

3. Model Development

3.1. Deriving Observed values for Energy Requirement for Tillage Operations

Energy as conceived for this study is a function of draught, speed of operation, effective field capacity and depth of cut. Energy requirement for tillage operation (J/m^3) can be defined in terms of energy per unit volume of disturbed soil. This is to say work done over a given volume of disturbed soil. Therefore, energy can be expressed as:

$$E = 10^2 \frac{D_f \cdot S_o}{D \cdot D_c} \tag{6}$$

where,
E: Energy requirement for tillage operation (J/m^3)
D_f: Draught (kN)
S_o: Speed of operation (km/h)
D: Effective field capacity (ha/h)
D_c: Depth of cut (m)
The above expression can also be re-expressed as:

$$E = 10^6 \left(\frac{D_f \cdot S_o}{\text{Volume of disturbed soil}} \right) \tag{7}$$

Since volume of disturbed soil is expressed as:
$V_s = 10000(D \cdot D_c)$
where,
V_s: Volume of disturbed soil (m^3/h)
D: Effective field capacity (ha/h)
D_c: Depth of cut (m)
The compiled tractor test data of the National Centre for Agricultural Mechanization (NCAM), Ilorin which has the following set of test parameters as contained in Equation (6) were used to obtain the observed energy requirement values during ploughing and harrowing operations. Presented in Table 1 is the observed energy requirement for the 40 different tractors tested by NCAM on a sandy loam soil during ploughing and harrowing operations.

3.2. Model developed for ploughing operation

The first list of 36 tractors as presented in Table 1 which has their tractor test data as contained in NCAM's Tractor Test Reports were used for developing the model used for predicting the energy requirement for ploughing operation in a sandy loam soil. Likewise, the last 4 tractors which is also contained in Table 1 using their tractor test data as contained in NCAM's Tractor Test Reports were used for validating the model developed using the 10-fold cross-validation method. Employing SPSS in developing the model for predicting energy requirement for ploughing operation in a sandy loam soil gave the results presented in Table 2.

From Table 2, the model equation developed for predicting energy requirement for tillage operation during ploughing operation (J/m^3) in a sandy loam soil is presented as:

$$\begin{aligned} ER_p = {} & 50439.946 - 1145.626\, D_c + 4992.283\, D_f \\ & - 17128.176\, T_{fc} + 12.789\, A_{mc} - 7408.903\, A_{bd} \\ & + 25.564\, A_{ci} \end{aligned} \tag{8}$$

where,
ER_p: Energy requirement for ploughing operation (J/m^3)
D_c: Depth of cut (cm)
D_f: Draught (kN)
T_{fc}: Theoretical field capacity (ha/h)
A_{mc}: Average moisture content (%)
A_{bd}: Average bulk density (g/cm^3)
A_{ci}: Average cone index (N/cm^2)
The model expression expressed in Equation (8) had a coefficient of multiple of determination (R^2) value of 0.859. The model developed for predicting energy requirement during ploughing operation explains a very high proportion of variance of 86% in the mean squared errors of energy requirement for tillage operation during ploughing operation in a sandy loam soil with depth of cut, draught and theoretical field capacity contributing statistically significantly to the model.

During 10-fold cross-validation using the test data of the last four tractor as presented in Table 1, the test error obtained was 4672.3 J/m^3 which accounts for 16.62% of the observed energy requirement value during ploughing operation in a sandy loam soil.

3.3. Model developed for harrowing operation

Adopting the same SPSS method used for developing the model for predicting energy requirement for ploughing operation using the tractor test data compiled during harrowing operation on a sandy loam soil as contained in NCAM's Tractor Test Reports gave

Table 1: Results of observed energy requirement for ploughing and harrowing operations in a sandy loam soil.

S.No.	Tractor make and model	Year of test	Observed energy consumed (J/m^3)	
			Ploughing	Harrowing
1.	MAHINDRA B-275 DI	2005	21972.31	16099.03
2.	MAHINDRA 575 DI	2005	26104.09	18461.35
3.	MAHINDRA 585 DI	2005	14639.52	23200.00
4.	SWARAJ 978FE	2005	9097.66	9599.49
5.	URSUS 5312	2006	24597.12	15930.26
6.	CLASS CELTIS 426 RA	2007	23122.03	18964.11
7.	FARMTRAC 60	2007	28663.60	23240.31
8.	FARMTRAC 70	2007	44831.42	26754.70
9.	FARMTRAC 80	2007	26563.67	15279.90
10.	POWERTRAC 455	2007	36901.66	26291.49
11.	BALWAN 500	2007	25669.98	19026.06
12.	BELARUS 82.1	2008	13976.87	17001.05
13.	KAMA 550	2008	6850.51	5628.92
14.	YTO-704	2008	9102.70	6136.19
15.	FOTON EUROPARD 704	2008	39382.18	9465.56
16.	FOTON EUROPARD 600	2008	50593.28	13796.07
17.	DONFENG 700	2008	54266.22	11914.86
18.	WEITUO SWT-854	2008	23777.81	10754.86
19.	MAHINDRA 585 DI	2008	23211.03	9673.39
20.	MAHINDRA B-275 DI	2008	25892.12	16708.28
21.	MAHINDRA 605 DI	2008	29490.27	15334.47
22.	MAHINDRA 705 DI	2008	32506.55	22062.35
23.	MAHINDRA 8000 2WD	2008	17688.31	18696.53
24.	TAK 750 DI	2009	15680.99	7943.64
25.	TAK 75 DI	2009	22072.23	18895.11
26.	TAK 90 DI	2009	21245.43	11623.66
27.	ZETOR (PROXIMA 75)	2009	27119.60	14906.88
28.	FARMTRAC 80E	2009	26630.43	13886.57
29.	AGROLUX 75e	2009	33926.60	8774.78
30.	SONALIKA DI – 75 (4WD)	2010	35358.19	28775.78
31.	YTO – 750	2010	32687.65	23926.02
32.	YTO – 754	2010	25530.50	18525.80
33.	LANDINI 7860	2010	48348.28	10270.11
34.	LANDINI GLOBALFARM 100	2010	51096.54	13686.49
35.	MILLAT MF 375	2011	45206.35	24876.16
36.	BULL 55 UTILITY	2011	18123.69	12032.97
37.	SWARAJ 855	2005	32915.27	23407.63
38.	FT 650	2006	17154.12	25258.08
39.	FT 824	2006	26242.99	22137.47
40.	SONALIKA DI-75 (2WD)	2006	6595.40	12998.36

the result presented in Table 3 for the model developed for predicting energy requirement during harrowing operation in a sandy loam soil.

From Table 3, the model expression generated for predicting energy requirement for tillage operation during harrowing operation (J/m^3) is presented as:

$$ER_h = 31961.004 - 952.873\, D_c + 4586.26 D_f - 8293.068\, T_{fc} + 50.850\, A_{mc} - 3639.79\, A_{bd} + 37.351\, A_{ci} \quad (9)$$

where,
ER_h: Energy requirement for harrowing operation (J/m^3)
D_c: Depth of cut (cm)
D_f: Draught (kN)
T_{fc}: Theoretical field capacity (ha/h)
A_{mc}: Average moisture content (%)
A_{bd}: Average bulk density (g/cm^3)
A_{ci}: Average cone index (N/cm^2)

The model expression expressed in Equation (9) had a coefficient of multiple determination (R^2) value of 0.776. The model developed for predicting energy requirement for harrowing operation explains a very high proportion of variance of 78% in the mean squared errors of energy requirement during harrowing operation in a sandy loam soil with depth of cut, draught and theoretical field capacity contributing statistically significantly to the model.

During 10-fold cross-validation using the test data of the last four tractor as presented in Table 1, the test error obtained was 2721.1 J/m^3 which accounts for 16.94% of the observed energy requirement value during harrowing operation in a sandy loam soil.

4. Results and discussion

4.1. Ploughing operation

The experimental results showing the observed against the predicted energy requirement values during ploughing operation in a sandy loam soil is presented in Table 4.

4.1.1. Energy Requirement for Ploughing Operation in a Sandy Loam Soil

The results in Table 4 was used for plotting the graphs presented in Fig. 1. The graph showed the graph trend of observed and predicted energy requirement values for the 36 different tractor makes and models tested during ploughing operation in a sandy loam soil. It can be deduced from Table 4 and Fig. 1 that the highest energy requirement values recorded for both observed and predicted during ploughing operation in a sandy loam soil was 54266.22 J/m^3 and 54289.03 J/m^3, respectively using DONFENG 700 tractor of 69 hp (51.47 kW) and FOTON EUROPARD 600 tractor of 59 hp (44.01 kW). Likewise from Table 4 and Fig. 1 it can also be deduced that the lowest energy requirement values recorded for both observed and predicted during ploughing operation in a sandy loam soil was 6850.51 J/m^3 and 5991.47 J/m^3, respectively using KAMA 550 tractor of 54.3 hp (40.51 kW) and SWARAJ 978FE tractor of 78 hp (58.19 kW). The results obtained for both observed and predicted energy requirement values as presented in Table 4 were also used in establishing the linear relationship that exist between them during ploughing operation by plotting the graph which is shown in Fig. 2. The graph recorded a R-squared value of 0.835. This signifies a correlation coefficient value of 0.927 exist between the observed and predicted energy requirement values as shown in Table 5. According to the rule of thumb as provided in `http://www.westgard.com/lesson42.htm` for evaluating correlation coefficient, simply tells us that the predicted energy requirement values for ploughing operation in a sandy loam soil have

Table 2: Parameter estimates for model of ploughing operation.

Coefficients	Estimates	Std. Error	t value	P-value
(Intercept)	50439.946	14701.854	3.431	0.002*
Depth of cut (cm)	-1145.626	252.971	-4.529	0.0001*
Draught (kN)	4992.283	466.625	10.699	0.0001*
Theoretical field capacity (ha/h)	-17128.176	6533.866	-2.621	0.014*
Average moisture content (%)	12.789	340.307	.038	0.970
Average bulk density (g/cm^3)	-7408.903	8050.800	-.920	0.365
Average cone index (N/cm^2)	25.564	40.755	.627	0.535

*significant at 5% level
Multiple R-squared: 0.859, Adjusted R-squared: 0.830

Table 3: Parameter Estimates for Model of Harrowing Operation.

Coefficients	Estimates	Std. Error	t value	P-value
(Intercept)	31961.004	9997.421	3.197	0.003*
Depth of cut (cm)	-952.873	150.945	-6.313	0.0001*
Draught (kN)	4586.260	589.134	7.785	0.0001*
Theoretical field capacity (ha/h)	-8293.068	2547.130	-3.256	0.003*
Average moisture content (%)	50.850	237.692	.214	0.832
Average bulk density (g/cm^3)	-3639.791	5474.973	-.665	0.511
Average cone index (N/cm^2)	37.351	52.835	.707	0.485

*significant at 5% level
Multiple R-squared: 0.776, Adjusted R-squared: 0.730

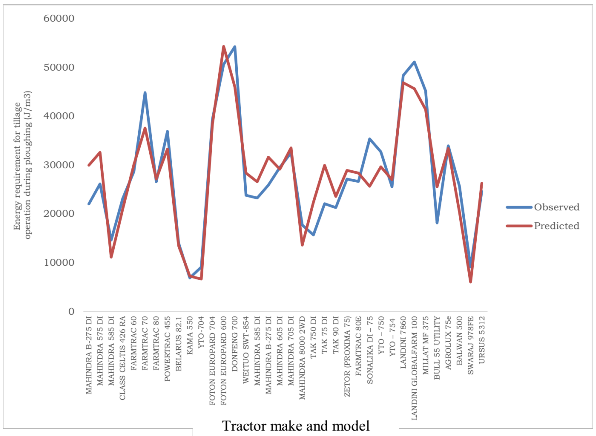

Figure 1: Trend of observed versus predicted energy requirement for tillage operation during ploughing operation in a sandy loam soil.

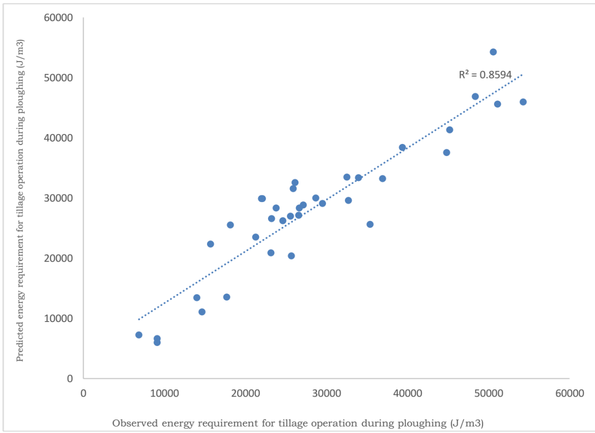

Figure 2: Observed and predicted energy requirement values obtained during ploughing operation.

very high relationship with the observed energy requirement values.

4.2. Harrowing Operation

The experimental results showing the observed against the predicted energy requirement values during harrowing operation in a sandy loam soil is presented in Table 6.

4.2.1. Energy Requirement for Harrowing Operation in a Sandy Loam Soil

The results presented in Table 6 was used for plotting the graph presented in Fig. 3. The graph showed the graph trend of observed and predicted energy requirement values for the 36 different tractor makes and models tested during harrowing operation in a sandy loam soil. It can be deduced from Table 6 and Fig. 3 that the highest energy requirement values recorded for both observed and predicted during harrowing operation in a sandy loam soil was 28775.78 J/m^3 and 23114.14 J/m^3 , respectively using SONALIKA DI-75 tractor of 75 hp (55.95 kW) and MILLAT MF 375 tractor of 72 hp (53.71 kW). Likewise from Table 6 and Fig. 3, it can also be deduced that the lowest energy requirement values recorded for both observed and predicted during harrowing operation in a sandy loam soil was 5628.92 J/m^3 and 5635.32 J/m^3 , respectively using KAMA 550 tractor of 54.3 hp (40.51 kW). The results obtained for both observed and predicted energy requirement values as presented in Tables 6 were also used in establishing the linear relationship that exist between the observed and predicted energy requirement values during harrowing operation by plotting their graphs which is shown in Fig. 4. The R-squared value obtained was 0.776. This signifies a correlation coefficient value of 0.881 exist between the observed and predicted energy requirement values as shown in Table 7. According to the rule of thumb as provided in `http://www.westgard.com/lesson42.htm` for evaluating correlation coefficient, simply tells us that the predicted energy requirement values for harrowing operation in a sandy loam soil have a high correlation relationship with the observed energy requirement values.

Table 4: Table 4. Results of observed against predicted energy requirement values during ploughing operation in a sandy loam soil.

Tractor Make and Model	Energy Requirement (J/m^3)		Difference between observed and predicted energy requirement values (J/m^3)
	Observed	Predicted	
MAHINDRA B-275 DI	21972.31	29919.55	-7947.24
MAHINDRA 575 DI	26104.09	32566.23	-6462.14
MAHINDRA 585 DI	14639.52	11103.06	3536.46
CLASS CELTIS 426 RA	23122.03	20924.86	2197.17
FARMTRAC 60	28663.60	30028.82	-1365.22
FARMTRAC 70	44831.42	37587.71	7243.71
FARMTRAC 80	26563.67	27128.96	-565.29
POWERTRAC 455	36901.66	33228.55	3673.11
BELARUS 82.1	13976.87	13472.28	504.5861
KAMA 550	6850.51	7240.28	-389.77
YTO-704	9102.70	6633.16	2469.54
FOTON EUROPARD 704	39382.18	38443.62	938.56
FOTON EUROPARD 600	50593.28	54289.03	-3695.75
DONFENG 700	54266.22	45987.16	8279.06
WEITUO SWT-854	23777.81	28359.18	-4581.37
MAHINDRA 585 DI	23211.03	26573.75	-3362.72
MAHINDRA B-275 DI	25892.12	31573.37	-5681.25
MAHINDRA 605 DI	29490.27	29113.72	376.55
MAHINDRA 705 DI	32506.55	33488.86	-982.31
MAHINDRA 8000 2WD	17688.31	13558.22	4130.09
TAK 750 DI	15680.99	22344.70	-6663.71
TAK 75 DI	22072.23	29936.73	-7864.50
TAK 90 DI	21245.43	23517.04	-2271.61
ZETOR (PROXIMA 75)	27119.60	28867.49	-1747.89
FARMTRAC 80E	26630.43	28341.84	-1711.41
SONALIKA DI – 75 (4WD)	35358.19	25653.04	9705.15
YTO – 750	32687.65	29627.60	3060.05
YTO – 754	25530.50	27011.99	-1481.49
LANDINI 7860	48348.28	46879.87	1468.41
LANDINI GLOBALFARM 100	51096.54	45595.20	5501.34
MILLAT MF 375	45206.35	41365.27	3841.08
BULL 55 UTILITY	18123.69	25530.83	-7407.14
AGROLUX 75e	33926.60	33403.26	523.34
BALWAN 500	25669.98	20419.20	5250.78
SWARAJ 978Fe	9097.66	5991.47	3106.19
URSUS 5312	24597.12	26221.11	-1623.99

Table 5: Correlation table showing relation between observed and predicted energy requirement values during ploughing operation.

	Observed	Predicted
Observed	1	
Predicted	0.927063	1

Table 6: Results of observed against predicted energy requirement values during harrowing operation in a sandy loam soil.

Tractor Make and Model	Energy Requirement(J/m^3)		Difference between Observed and Predicted Energy Requirement values (J/m^3)
	Observed	Predicted	
MAHINDRA B-275 DI	16099.03	19531.03	-3432.00
MAHINDRA 575 DI	18461.35	20659.61	-2198.26
MAHINDRA 585 DI	23200.00	20702.64	2497.36
CLASS CELTIS 426 RA	18964.11	19798.94	-834.83
FARMTRAC 60	23240.31	20829.73	2410.58
FARMTRAC 70	26754.70	23039.86	3714.84
FARMTRAC 80	15279.90	14604.20	675.70
POWERTRAC 455	26291.49	22198.86	4092.63
BELARUS 82.1	17001.05	18312.28	-1311.23
KAMA 550	5628.92	5635.32	-6.40
YTO-704	6136.19	6074.83	61.36
FOTON EUROPARD 704	9465.56	7255.48	2210.08
FOTON EUROPARD 600	13796.07	15723.91	-1927.84
DONFENG 700	11914.86	11303.89	610.97
WEITUO SWT-854	10754.86	16314.48	-5559.62
MAHINDRA 585 DI	9673.39	9190.93	482.46
MAHINDRA B-275 DI	16708.28	20606.24	-3897.96
MAHINDRA 605 DI	15334.47	15524.72	-190.25
MAHINDRA 705 DI	22062.35	22176.86	-114.51
MAHINDRA 8000 2WD	18696.53	14172.46	4524.07
TAK 750 DI	7943.64	9873.18	-1929.54
TAK 75 DI	18895.11	21439.44	-2544.33
TAK 90 DI	11623.66	13816.55	-2192.89
ZETOR (PROXIMA 75)	14906.88	17957.59	-3050.71
FARMTRAC 80E	13886.57	12750.17	1136.40
SONALIKA DI – 75 (4WD)	28775.78	21875.04	6900.74
YTO – 750	23926.02	22802.21	1123.81
YTO – 754	18525.80	19181.74	-655.94
LANDINI 7860	10270.11	7944.45	2325.66
LANDINI GLOBALFARM 100	13686.49	12627.91	1058.58
MILLAT MF 375	24876.16	23114.14	1762.02
BULL 55 UTILITY	12032.97	17491.58	-5458.61
AGROLUX 75e	8774.78	7259.20	1515.58
BALWAN 500	19026.06	15001.28	4024.78
SWARAJ 978Fe	9599.49	13034.93	-3435.44
URSUS 5312	15930.26	18317.93	-2387.67

Table 7: Correlation table showing relation between observed and predicted energy requirement values during harrowing operation.

	Observed	Predicted
Observed	1	
Predicted	0.881144	1

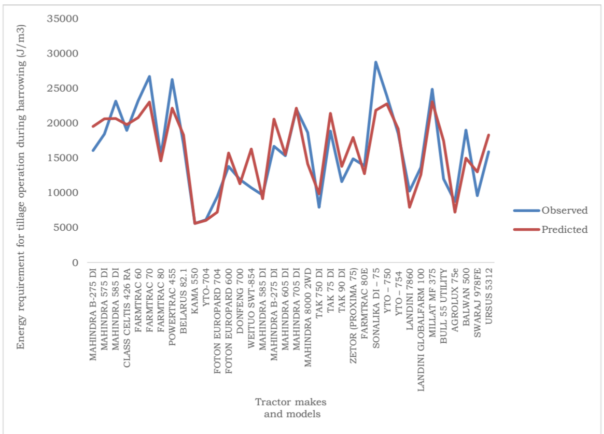

Figure 3: Trend of observed versus predicted energy requirement for tillage operation during harrowing operation in a sandy loam soil.

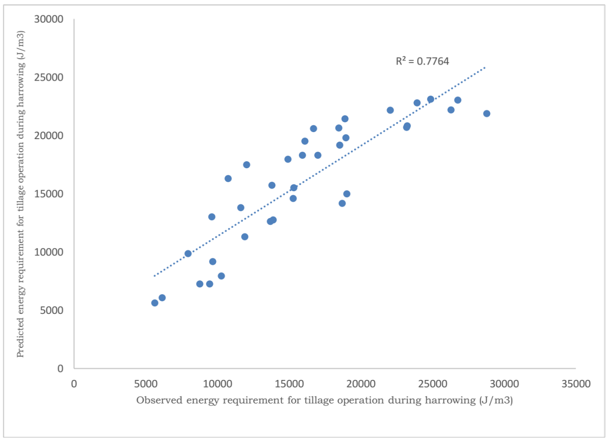

Figure 4: Graph of observed and predicted energy requirement values obtained during harrowing operation.

4.3. Sensitivity of the Model developed for Energy Requirement for Ploughing and Harrowing operations

It can be deduced from the models developed for predicting energy requirement during ploughing and harrowing operations in a sandy loam soil as contained in Tables 2 and 3, respectively, that out of the six independent variables involved in the model building that a total of three significant variables each, namely depth of cut, draught and theoretical field capacity which were found significant at 5% level. This signifies that these three significant variables strongly determines the energy requirement for both ploughing and harrowing operations in a sandy loam soil.

The presence of these two variables, namely, depth of cut and draught which were found to be significant at 5% level in the two developed models agrees with the study of Ashrafi Zadeh [26] that reported that draught and the amount of disturbed soil are two significant factors that are considered for the determination of energy requirement of a tillage tool. With the presence of these two variables, energy requirement can be determined. In the case of tillage, the study of energy requirement should as well include the depth of operation. To further buttress the point on the usefulness of depth of operation which is also known as depth of cut in the two models developed is considered as a very useful factor needed for determining the volume of soil disturbed.

In Tillage operation, energy is also expressed in terms of energy per volume of soil disturbed. According to Ahaneku et al. [27], the volume of soil disturbed is simply the product of effective field capacity and depth of cut. With the relationship that exist between field efficiency and effective field capacity in obtaining theoretical field capacity makes the use of theoretical field capacity relevant to this study of tillage energy.

The three other variables such as average soil cone index, average soil moisture content and average soil bulk density which were found not be significant at 5% level in the two developed models, however, contributed in their own small measures as none of the two generated models could stand on their own without the involvement of these three variables in predicting the values obtained for energy requirement during ploughing and harrowing operations in a sandy loam soil. Ashrafi Zadeh [26] noted that during tillage operation various factors can affect energy requirement of a tool. These factors can be categorized in three main groups: (1) soil parameters (2) tool parameters and (3) operational parameters. To evaluate energy requirement of a tillage tool, energy requirement resulting from each group of factors should be taken into account in order to have an estimation of total energy requirement.

5. Conclusion and Recommendation

5.1. Conclusion

The introduction of new machinery systems into agriculture have eased production thereby increasing the demand for energy. Tillage as one of the preliminary and basic step for any agricultural production also demand huge amount of energy for accomplishing its various tasks. At the National Centre for Agricultural Mechanization, Ilorin, Nigeria, field tests and evaluation were conducted on 40 different tractor makes and models with matching implements on a sandy loam soil between 2005 and 2011. The results gathered during ploughing and harrowing operations were subjected to multiple linear regression for the purpose of developing a statistical model for predicting energy requirement during ploughing and harrowing operations in a sandy loam soil. The generated model equations as provided in Equations (8) and (9) were found useful for predicting energy requirement during ploughing and harrowing operations, respectively, in a sandy loam soil. From this study, it was observed that depth of cut, draught and theoretical field capacity are predominant factors needed in determining the energy requirement for tillage operations in a sandy loam soil.

5.2. Recommendation

The models generated for predicting energy requirement for tillage operations in a sandy loam soil as provided in Equations (8) and (9) are recommended for use in knowing the amount of energy used by a tractor-implement combination during ploughing and harrowing operations in a sandy loam soil.

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