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Assessment of Tractor Hourly and Tilled Area Fuel Consumptions Variability during Ridging Operation

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Abstract: *It is obvious that fuel consumption in farm practices to boast mechanization of agriculture is a major concern. This study field experiments were executed to assess the variability in tractor hourly and tilled area fuel consumptions during ridging operation. A 138 m by 50 m (6900m2) experimental plot was cleared and divided into three blocks of nine sub-blocks. For different treatments, each block was drawn out in 2 m by 50 m. Alleys to the plot of dimensions of 1m by 50m were provided. The tractor and equipment utilized in the tillage operations were DFM 100CD fuel flow meter, disc ridger and Swaraj 978FE. Soil-implement-machine parameters (draught, moisture content, bulk density, tractor forward speed, ridge height, width of cut), time and tractor fuel efficiency parameters (hourly fuel consumption (FC_h) and tilled area fuel consumption (FC_{ta})) during ridging operations were assessed. The data from the field experiment were statistically analyzed using analysis of variance (ANOVA) and coefficient of variation (CV). From the results, the FC_h and FC_{ta} increased in line with working time and tilled area. ANOVA results revealed a significant difference with 95 percent confidence levels and a highly significant difference with 99 percent confidence levels, as well as coefficients of variation (CV) of (a) 0.19 percent and (b) 0.16 percent; and (a) 0.13 percent and (b) 0.10 percent, indicating that experimental error was low and reliable. Generally, the variability in tractor hourly and tiled area fuel consumption during ridging operation are influenced by differences in the soil-implement-machine parameters and hence become the decisive factors for the management of fuel consumption.*

Keywords— Disc Ridger; Hourly Fuel Consumption; Ridging; Tillage; Tilled Area Fuel Consumption; Tractor

1. INTRODUCTION

Ridge is a long mound of tilled soil typically between two furrows with a precise shape, its length depends on the size and layout of the field while the width and height of the ridge depend on the implement adjustment and size of the disc used (Imonigie, 2007). Ridging is a type of tillage operation that takes place after plowing and harrowing. Nkakini and Fubara-Manuel (2012) define ridging as a tillage procedure that involves piling up tilled soil from two sides to generate lengthy stripes of mounds with a furrow in between. This is majorly for undulating, flat and low-lying flat fields that are susceptible to being wet and/or any other topography can be used. The permanent raised ridges are flat and usually 30 to 61 cm (12 to 24 inches) wide and 10 to 16 cm (4 to 6 inches) high and the operation is accomplished with the help of tillage implement called ridger (Igoni et al., 2020).

The type of crop to be planted, the type of soil, the depth of the ridger cut in the soil, and the tractor forward travel speed all influence the height and structure of ridges. The effect of the final three criteria on the amount of fuel spent during a ridging operation in a humid tropical environment on a sandy loam soil (Igoni et al., 2020). Fuel consumption rates climb linearly with duration and area covered for each of the tillage processes (ploughing, harrowing, and ridging), according to Ikpo and Ifem (2005). Igoni et al. (2020) in their study found that increase in tractor forward speed and ridging height increase fuel consumption. When compared to circuitous and direct alternation patterns, traditional tillage requires less fuel and time for tillage operation, lowering production costs (Sarkar et al., 2016).

According to Udo and Akubuo (2004) there are two different methods of measuring fuel consumption in agricultural field machinery. These consist of the introduction of an instrument to the machine to measure draught, fuel flow and other parameters under soil-bin (controlled) condition, and the other method is to measure fuel consumption in field operations by fixing supply tank fuel meter and depend on the operator to keep records. These aforementioned methods create different types of data with the first method usually present more useful and reliability of the results with respect to the machine design parameters (Schrock et al., 1985), and many more of the environmental variables and machine features which affect actual on-farm fuel consumption were considered the second technique.

Study by Fathollahzadeh et al. (2010) revealed that flow-time diagram points out that some important and operative factors on the spot upsetting fuel consumption during tillage operations differ continuously in the field. There by, recommended that the speedy fuel consumption data and positioning system may perhaps be adapted to develop fuel consumption map. A number of approaches to measure the suitability of fuel consumption of tractor engine have been adopted by several researchers such as Fathollahdeh, et al. (2010, 2011); Grisso et al. (2010); Rahimi-Ajdadi and Abbaspour-Gilandeh (2011); Spagnolo et al. (2012); Jokiniemi et al. (2012); Tayel et al. (2015); Leghari et al. (2016a; 2016b), Shafaei et al. (2018); Oyelade and Oni (2018); Nkakini et al (2019a, 2019b); Igoni et al. (2019); Igoni et al. (2020); Ekemube et al., (2020). These include: Direct method, cylindrical fuel container branched, Flow meters sensors, two flow sensors, Series sensors, volumetric system, instrumentation package and transducer system, and transparent fuel level indicator.

But different variables have been mentioned to affect tractor fuel consumption during tillage operations but there is dearth of information in literature on the assessment of tractor hourly and tilled area fuel consumptions variability during ridging operation**.** Therefore, the objective of this study is to assess the variability of tractor hourly and tilled area fuel consumptions during ridging operation.

2. Materials and Methods

2.1 Experimental Site

This experimental area map is shown in figure 1. The experiment was performed on May 11th, 2021 at the Rivers Institute of Agriculture Research and Training (RIART) farm at Rivers State University, Port Harcourt, Nigeria (latitude of 4° 49′ 27″ N, and longitude of 7° 2′ 1″ E). The experimental design used in this study is group balanced block design (GBBD). A farm size of 138 m by 50 m (6900 m^2) was divided into three plots of 9 sub-plots each. Each sub-plot of 50m by 2m was marked with a 1m alley. The sub-plot was provided for different treatment options and with a space of 2 m between each block and 1 m at the sides of the outer blocks.

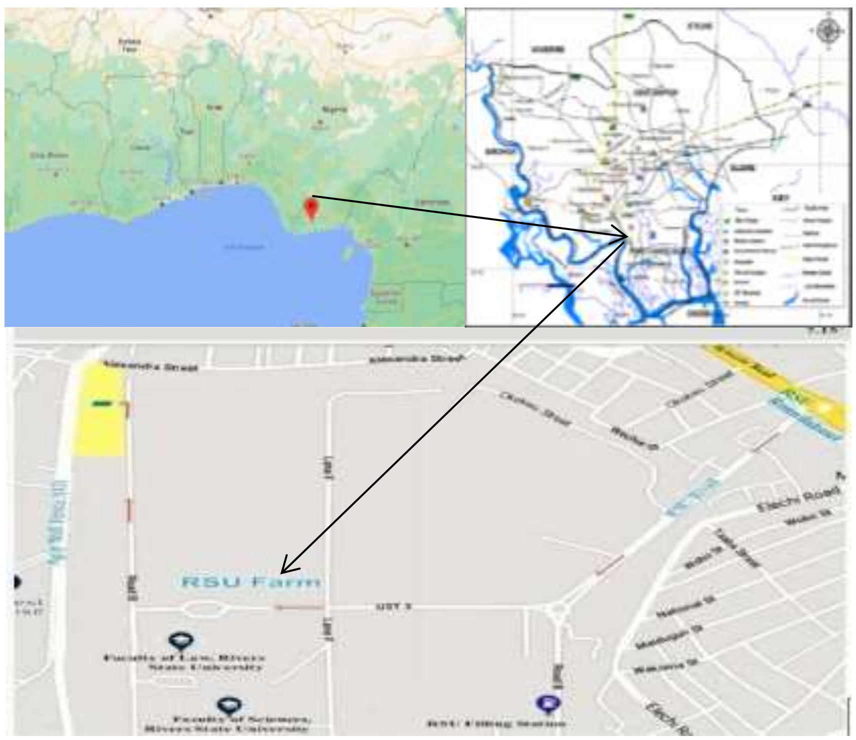

Figure 1: Map of Nigeria, Port Harcourt Metropolis and River State University (Source: Googgle Map, 2021).

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2.2 Tractor and Implement Specifications

The tractor used to perform the ploughing operation was A two-wheel drive tractor Swaraj 978 FE (Swaraj, India) was used for this study (Plate 1). The tractor has a total weight of 3015kg, engine horsepower of 72 hp and lifting power of 2200 kg. Front and the rear tyres were 7.5–16, 8 ply and 16.9 – 28, 12 radial respectively. A 1180 mm frame width mounted-type disc plough with disc diameter of 300 mm of disc plough (Baldan Implementos Agricolas, Brazil) with 3-disc bottom mounted on a gauge wheel was used for the experiments (Plate 2). Also, a DFM 100CD fuel flow meter (Technoton Engineering, Belarus) has nominal fuel pressure 0.2 MPa, maximum fuel pressure 2.5 MPa, minimum kinematic viscosity 1.5mm2/s, maximum kinematic viscosity 6.0 mm2/s, minimum supply voltage 10 V and maximum supply voltage 45 V (Plate 3).

Plate 1: The Swaraj 978 FE Tractor (Swaraj, India)

Plate 2: 2-Row Disc Ridger

Plate 3: DFM 100CD Fuel Flow Meter (Technoton Engineering, Belarus) used in this Study

2.3 Experimental procedure

Before ridging, a soil auger was used to collect soil samples from depths of 0 – 10, 10 – 20, and 20 – 30 cm at random in the field to evaluate the textural categorization of the soil, moisture content, and bulk density. The soil samples were collected and taken to a laboratory for analysis. The hydrometer method was used to evaluate soil textural classification, and the gravimetric (i.e., oven dry method) method was utilized to determine soil moisture content. Also, the bulk density was determined using core method preceding to ridging operation (Walter et al., 2016).

The disc ridger was attached to the tractor and levelled using the top links of the tractor in order to reduce parasitic forces. Then, ridging heights were determined by setting the level control of the lifting mechanism (three-point linkage height) to lower the disc ridger to the desired depth for ridge height. Tractor forward speeds were determined by choosing a gear ratio that provided the desired speed. This was done in a practice area in advance for each test plot to maintain the desired treatment. The ridge height measurement was done by placing the meter rule from furrow bottom to the surface of the ridge, while the width of cut was measured by placing a steel tape from one side of the furrow wall to the other end. Before each operation, a stopwatch was set to zero to determine the time. Draught force was calculated using the formula represented below (ASAE, 2002):

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

Where:

D = Implement Draught force, N;
F = dimensionless soil texture and adjustment parameter;
i = 1 for fine, 2 for medium 3 for coarse;
ABC = machine specific parameter;
S = speed (Km/h);

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W = machine with or number of rows (m);
T = depth (cm).

The digital method of measuring the amount of fuel used was adopted to determine tractor fuel consumption. During this process, the use of DFM fuel flow meter was employed to measure fuel consumption. The metre was mounted on the fuel line between the tractor's fuel tank and the pump. At the end of each test operation the data was taken from the fuel flow meter as display information, switching is performed by light touch to the top cover of fuel flow meter by iButton key. Mathematically, hourly and tilled area fuel consumptions were deduced by expression in Equations (2 and 3) (Shafaei et al., 2018):

$$FC_h = \frac{T_{fc}}{h} \quad (2)$$

Where:

FCh = Hourly fuel consumption (L/h);
= Tractor fuel consumption, L;
h = Working hour, h.

$$FC_{ta} = \frac{10T_{fc}}{V \times W \times E \times h} \quad (3)$$

Where:

FCta = Tilled area fuel consumption, L/ha;
= Tractor fuel consumption, L;
V = Forward speed, Km/h;
W = Implement width, m
E = Implement field efficiency, %;
h = Working hour h

2.4 Statistical analysis

The statistical method used to examine the data is analysis of variance (ANOVA) in this research based on the F-test and to help achieve suitable error terms with single probability risk to determine if the means measured are totally different and if the differences are away from what is ascribed to chance or experimental error (Table 1) (Gomez & Gomez, 1983):

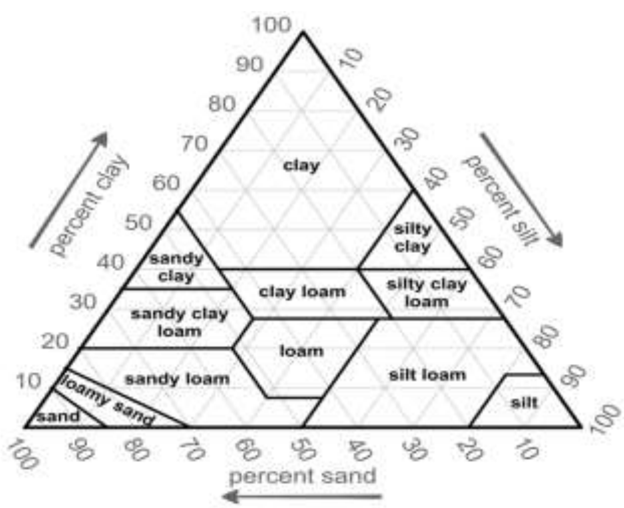
Table 1: Analysis of Variance of Data for Group Balanced Block Design

Sources of Variation	**Degree of Freedom (df)**	**Sum of Square (SS)**	**Mean Square (MS)**	**Computed F**	**Tabular F**	
					1%	**5%**
Replication	r – 1	Replication SS	Replication MS			
Group	s – 1	Group SS	Group MS	$\frac{Group\ MS}{Error\ (a)\ MSS}$		
Error (a)	(r – 1) (s-1)	Error (a) SS	Error (a) MS			
Group A	t/s – 1	Group A SS	Group A MS	$\frac{Group\ A\ MS}{Error\ (b)\ MS}$		
Group B	t/s – 1	Group B SS	Group B MS	$\frac{Group\ B\ MS}{Error\ (b)MS}$		
Group C	t/s – 1	Group C SS	Group C MS	$\frac{Group\ C\ MS}{Error\ (b)MS}$		
Error	s(r-1)(t/s-1)	Error (b) SS	Error (b) MS			
Total	(r)(t) -1	Total SS				

3. Results and Discussion

3.1 Soil textural class

A particle size distribution (PSD) air-dried soil revealed soil particles of varied sizes, including sand (9.60 %), silt (8.80 %), and clay (83.60 %). According to the United States Department of Agriculture (USDA) textural categorization of soil, the soil texture was loamy sand (Figure 2).



The field experiment variables include tractor draught (D), forward speed (S), ridge height (h), moisture content (MC), bulk density (ρ_b), and width of cut (W) were evaluated (Table 2). Considering table 2, results displayed that the increased in the values of the field test parameters increased the tractor fuel efficiency parameters (TFEPs) (hourly fuel consumption, FC_h), and tilled area fuel consumption, FC_{ta}). During the ridging operation, draught, tractor forward speed, ridge height, width of cut, bulk density, and moisture content all effect fuel usage. As a result, tractor fuel usage rises with time and tilled area. This is consistent with Ikpo and Ifem (2005).

Figure 2: USDA Soil Texture Triangle

Table 2: Hourly Mean Results of Field Test Performed during Ridging Operation

Parameters								
h, m	**S, Km/h**	**W, cm**	**ρ_b, g/cm^3**	**CI, N/cm^2**	**D, N**	**MC, %**	**FC_h, L/h**	**FC_{ta}, L/ha**
0.10	5.00	1.00	1.42	156.25	4533.75	17.92	3.30	6.27
	7.00	1.00	1.42	156.25	4904.25	17.92	4.27	6.80
	9.00	1.00	1.42	156.25	5274.75	17.92	4.38	6.90
0.20	5.00	1.00	1.56	195.31	9067.50	19.90	4.78	9.03
	7.00	1.00	1.56	195.31	9808.50	19.90	6.11	9.72
	9.00	1.00	1.56	195.31	10549.5	19.90	6.26	9.99
0.30	5.00	1.00	1.70	226.56	13601.25	21.05	7.15	13.46
	7.00	1.00	1.70	226.56	14712.75	21.05	8.86	14.61
	9.00	1.00	1.70	226.56	15824.25	21.05	9.40	14.93

h = ridge height (m), S = tractor forward speed (Km/h), W = width of cut (m). **ρ_b = (N/cm^2),** CI = cone index (N/cm^2), D = draught (N), MC = moisture content (%), FC_h (L/h), FC_{ta} (L/ha)

3.2 Variability of hourly fuel consumption

Figure 3 presented the results of hourly fuel consumption during ridging operation. The hourly fuel consumption data were presented in Table 2 during ridging operation were 3.30, 4.27, 4.38, 4.78, 6.11, 6.26, 7.15, 8.86 and 9.40 L/h respectively. These were measured with the use of fuel flow meter. Draught, cone index, forward speed, tillage depth, bulk density, and moisture content were all measured before, during, and after the ridging process to see how they affected fuel consumption variability. Their corresponding values with fuel consumption were 4,533.75, 4,904.25, 5,274.75, 9,067.50, 9,808.50, 10,549.50, 13,601.25, 14,712.75 and 15,824.25 N for draught; 156.25, 195.31, and 226.56 N/cm^2 for cone index; 1.42, 1.56 and 1.70 g/cm^3 for bulk density; 0.10, 0.20 and 0.30 m for tillage depths; 5.00, 7.00 and 9.00 Km/h for forward speed; 17.92, 19.00 and 21.05 %; and a constant width of 1.00 m respectively. The increase in the aforementioned parameters increased fuel consumption during the process of ridging but the draught influences the fuel consumption with the combinations of the tillage depth and forward speed in Table 2. From the experimental results, it can be observed that the depth influenced fuel consumption more than any other parameters that were tested in this study. This is in line with the findings of Igoni et al. (2020). The variation in fuel consumption was observed with increase in draught, cone index, tillage depth, forward speed, bulk density and moisture content. The standard error bar showed a statistically significant different which revealing its mean reliability treatment (Figure 3). Also, ANOVA results showed that they were statistically significant at 95 % confidence level and highly significant at 99 % confidence from different treatments mean. Moreover, coefficient of variations (CV) (a) is 0.19 % and (b) 0.16% respectively, which revealed that the experimental errors were low and reliable. This agrees with the findings of Igoni et al. (2020).

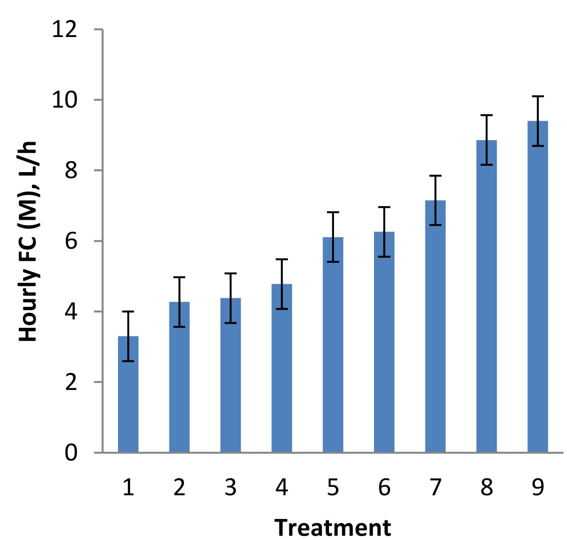


Figure 3: Variability of Hourly Fuel Consumption during Ridging using Fuel Flow Meter

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Table 3: Analysis of Variance (Group Balanced Block Design) for Tractor Hourly Fuel Consumption (FC_h)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F	
					5%	1%
Replication	2	0.00056	0.0028			
Treatment group	2	92.43627	46.21813	346,636.00**	6.94	18.00
Error (a)	4	0.000533	0.000133			
Treatment within group A	2	2.0726	1.0363	11,658.38**	3.88	6.93
Treatment within group B	2	4.0950	2.0475	23,034.38**	3.88	6.93
Treatment within group C	2	8.2782	4.1391	46,564.88**	3.88	6.93
Error (b)	12	0.0001067	8.89E-05			
Total	26	106,8893				

3.3 Variability of tilled area fuel consumption

The key technical indicator in the assessment of agricultural machinery efficiency for fuel consumption could be attained based on fuel consumption per hectare measurement (Serrano, 2007). Figure 4 presented the results of tilled area fuel consumption during ridging operation. The tilled area fuel consumption reading was presented in Table 2 during ridging operation were 6.27, 6.80, 6.90, 9.03, 9.72, 9.99, 13.46, 14.61 and 14.93 L/ha respectively. These were measured using fuel flow meter. Draught, cone index, forward speed, ridge height, bulk density, and moisture content were all measured before, during, and after the ridging operation to see how they affected fuel consumption variability. Their corresponding values with fuel consumption were 4,533.75, 4,904.25, 5,274.75, 9,067.50, 9,808.50, 10,549.50, 13,601.25, 14,712.75 and 15,824.25 N for draught; 156.25, 195.31, and 226.56 N/cm^2 for cone index; 1.42, 1.56 and 1.70 g/cm^3 for bulk density; 0.10, 0.20 and 0.30 m for tillage depths; 5.00, 7.00 and 9.00 Km/h for forward speed; 17.92, 19.00 and 21.05 %; and a constant width of 1.00 m respectively. The increased in the aforementioned parameters increase fuel consumption during the process of ridging but the draught influences the fuel consumption with the combinations of the ridge height and forward speed (Table 2). From the experimental results, it can be observed that the ridge height influences fuel consumption more than any other parameters that were tested in this study. This is in line with the findings of Igoni et al. (2020). The variation in fuel consumption was observed with increase in draught, cone index, ridge height, forward speed, bulk density and moisture content. The standard error bar showed a statistically significant revealing its mean reliability treatment (Figure 4). Also, ANOVA results showed that they were statistically significant at 95 % confidence level and highly significant at 99 % confidence for different treatments mean. Additionally, coefficient of variations (CV) (a) is 0.13 % and (b) 0.10% respectively, which showed that the experimental errors were low and reliable. This agrees with the findings of Igoni et al. (2020).

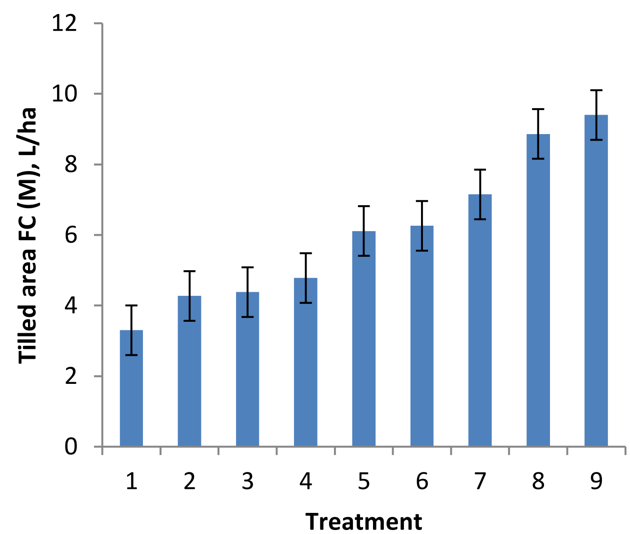

Figure 4: Variability of Tilled Area Fuel Consumption during Ridging using Fuel Flow Meter

Table 4: Analysis of Variance (Group Balanced Block Design) for Data in Table 1 (FC_h)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F	
					5%	1%
Replication	2	0.004356	0.002178			
Treatment group	2	270.2138	3135.1069	759,976.30**	6.94	18.00
Error (a)	4	0.000711	0.000178			
Treatment within group A	2	0.6878	0.3439	3,095.10**	3.88	6.93
Treatment within group B	2	1.4706	0.7353	6,617.70**	3.88	6.93
Treatment within group C	2	3.5858	1.7929	16,136.10**	3.88	6.93
Error (b)	12	0.001333	0.000111			
Total	26	275.9644				

4. Conclusion

The variability of tractor hourly and tilled area fuel consumption during ridging operations has been investigated. The foollowing conclusions were drawn:

(i) The hourly fuel consumption increment in during ridging operation were caused by soil-implement-machine parameters (draught, forward speed, ridge height, width of cut, bulk density and moisture content);

(i) Similarly, the incresae in tilled area fuel consumption during ridging operation are caused by increment in soil-implement-machine parameters (draught, forward speed, ridging depth, width of cut, bulk density and moisture content);

(ii) Furthermore, the incresae in working hour and tilled area in course ridging operation increases in line with tractor fuel consumption rate;

(iii) Variations in the soil-implement-machine variables measurement cause the variability in hourly and tilled area fuel consumptions during ridging.

References

[1] ASAE (2002). ASAE Standards, 49th Ed. 2002a. EP496.2. Agricultural Machinery Management Data. St. Joseph, Michigan: ASAE.

[2] Ekemube, R. A., Nkakini, S. O., & Igoni, A. H. (2020). Assessment of Tractor Fuel Consumption as Influence by Tractor Forward Speed and Depth during Harrowing Operation. International Journal of Academic Information Systems Research (IJAISR), 4(8), 57- 63.

[3] Fathollahzadeh, H., Mobile, H., Jafari, A., Mahdavinejhad, D., & Tabatabaie, S. M. H. (2011). Designn Band Calibration of A Fuel Consumption Measurement System for A Diesel Tractor. International Commission for Agricultural Engineering Journal, 13(2), 1 - 12.

[4] Fathollahzadeh, H., Mobli, H., Rajabipour, A., Minaee, S., Jafari, A., & Tabatabaie, S. M. H. (2010). Average and Instantaneous Fuel Consumption of Iranian Conventional Tractor with Moldboard plow in tillage. Asian Research Publishing Network, Journal of Engineering and Applied Sciences, 5(2), 30-35.

[5] Grisso, R. B., Perumpral, J. V., Vaughan, D., Roberson, G. T., & Pitman, R. (2010). Predicting Tractor Diesel Fuel Consumption. Virginia Cooperative Extension Publication VCE Publication 442-073. http://pubs.ext.vt.edu.edu/442-073 (accessed on December 5th, 2021).

[6] Igoni, A. H., Ekemube, R. A., & Nkakini, S. O. (2019). Predicting Tractor Fuel Consumption during Ridging on a Sandy Loam Soil in a Humid Tropical Climate. Journal of Engineering and Technology Research, 11(3), 29-40.

[7] Igoni, A. H., Ekemube, R. A., & Nkakini, S. O. (2020). Tractor Fuel Consumption Dependence on Speed and Height of Ridging on a Sandy Loam Soil.n ournal of Engineering and Technology Research, 12(1), 47 - 54.

[8] Ikpo, I., & Ifem, J. L. C. (2005). Fuel Consumption of Tractors – Steyr 768 & 8075 during Tillage Operations in Makurdi, Benue State. Proceedings of the Nigerian Institution of Agricultural Engineers, 27, 60 – 63.

[9] Imonigie, P. S. (2007). Basic Principles of Farm Mechanization and Machinery. Stirling-Horden Publisher (Nigeria) Limited, Lagos, Ibadan, Benin City,Jattu-Uzairua.

[10] Jokiniemi, T., Rossner, H., & Ahokas, J. (2012). Simple and Cost-Effective Method for Fuel Consumption Measurements of Agricultural Machinery. Agronomy Research Biosystem Engineering Special Issue 1, 97-107.

[11] Leghari, N., Ali, A., & Mangrio, M. A. (2016a). Relative Efficiency of Different Tillage Practices and Their Effect on Soil Physical Properties Under Semi-Arid Climate of Tandojam, Pakistan. Mehran University Research Journal of Engineering & Technology, 35(2): 239-246.

[12] Leghari, N., Oad, V. K., Shaikh, A. A., & Soomro, A. A, (2016b). Analysis of Different Tillage Implements with Respect to Reduced Fuel Consumption, Tractor Operating Speed and its Wheel Slippage. Sindh University Resources Journal, (Science Series) 48(1), 37 - 40.

[13] Nkakini, S. O., & Ekemube, R. A. (2020). Evaluation of the Effects of Tractor Forward Speed and Tillage Depth on Fuel Consumption during Ploughing Operation. Journal of Newviews in Engineering and Technology (JNET), 2(2), 60 – 69.

[14] Nkakini, S. O., & Fubara-Manuel, I (2012). Modlling Tractive Force Requirements of Wheel Tractors for Disc Ridging in Loamy Sand Soil. International Journal of Engineering and Technology, 2(10), 1657-1665.

[15] Nkakini, S. O., Ekemube, R. A., & Igoni, A. H. (2019a). Development of Predictive Model for Fuel Consumption During Ploughing Operation in Agricultural Soil. European Journal of Engineering and Technology, 7(1), 16 – 30.

[16] Nkakini, S. O., Ekemube, R. A., & Igoni, A. H. (2019b). Modeling Fuel Consumption Rate for Harrowing Operations in Loamy Sand Soil. European Journal of Agriculture and Forestry Research, 7(2), 1 – 12.

[17] Oyelade, O. A., & Oni, K. C. (2018). Modelling of Tractor Fuel Consumption for Harrowing Operation in A Sandy Loam Soil. Arid Zone Journal of Engineering, Technology and Environment, 14(I4), 8-19.

[18] Rahimi-Ajdadi, F., & Abbaspour-Gilandeh, Y. (2011). Artificial Neural Network and Stepwise Multiple Range Regression Methods for Prediction of Tractor Fuel Consumption. Journal of Measurement, (2011), 1 – 8. doi:10.1016/j.measurement.2011.08.006

[19] Sarkar, S., Mahmud, M. S., Kabir, A. B. M. H., Sarker, M. K. U., & Munnaf, M. A. (2016). Selection of Suitable Tillage Pattern for Fuel Economy. Research Journal of Agriculture and Forestry Sciences, 4(4), 1- 4.

[20] Schrock, M. D., Kramer, J. A., & Clark, S. J. (1985). Fuel Requirements for Field Operation in Dansas. Transactions of the American Society of Agricultural Engineers, 28, 669 – 764.

[21] Shafaei, S. M., Loghari, M. S., & Kamgar, S. (2018). On the Neurocomputing Based Intelligent Simulation of Tractor Fuel Efficiency Parameters. Information Processing in Agriculture, 5(2018), 205 – 223. (Accessed on July 6th, 2021) (Available at www.sciencedirect.com)

[22] Tayel, M. Y., Shaaban, S. M., Mansour, H. A. (2015). Effect of Plowing Conditions on the Tractor Wheel Slippage and Fuel Consumption in Sandy Soil. International Journal of Chemical Techechnology Research, 8(12): 151-159.

[23] Udo DU, Akubuo, CO (2004). Fuel Consumption in Tillage Operations for Sandy Loam Soil. Proceedings of the Nigerian Institution of Agricultural Engineers, 26: 74 – 82.