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Determination of Variability in Hourly and Tilled Area Tractor Fuel Consumption during Harrowing Operations

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ABSTRACT
Fuel is an essential product used by all farm machinery during their operations. In this study, field experiments were carried out to determine the variability in hourly and tilled area tractor fuel consumption during harrowing operations. An experimental plot of 138 m by 50 m (6900m^2) area was cleared and divided into three blocks of nine sub-blocks. Each of the blocks was marked out in 2 m by 50m for different treatments. Alleys to the plot of dimensions of 1m by 50m were provided. The equipment and tractor used for the tillage operations were DFM 100CD fuel flow meter, disc harrow and Swaraj 978FE. Soil-implement-machine parameters (draught, moisture content, bulk density, tractor forward speed, harrowing depth, width of cut), time and tractor fuel efficiency parameters (hourly fuel consumption (FC_h) and tilled area fuel consumption (FC_{ta}) during harrowing operations were determined. The experimental data obtained were analysed statistically by means of analysis of variance (ANOVA), and Coefficient of variation (CV). The results obtained revealed that increased in the soil-machine-implement parameters increased in line with hourly and tilled area fuel consumption (FC_h and FC_{ta}). ANOVA results also showed significant difference with 95 % and highly significant at 99 % confidence levels and coefficient of variation (CV) of (a) 0.55 % and (b) 11 %; and (a) 0.18 % and (b) 0.13 %, which confirmed that experimental error was low and reliable. Generally, the variability in tractor fuel consumption during harrowing operations are influenced by variations in the soil-implement-machine parameters and thereby become the determining factors to reduce fuel consumption.

KEYWORDS Farm Mechanization, Harrowing, Hourly Fuel Consumption, Tillage, Tilled Area Fuel Consumption.

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1. INTRODUCTION
Harrowing is a process of tilling the soil after ploughing operations. This is a secondary tillage operation that can be accomplished with the aid of a secondary tillage implement called disc harrow. It is projected to create a refined soil condition. According to Ekemube *et al*. (2020) reported that for optimum crop yield in agricultural mechanization, pulverization by harrowing. This secondary implement reduces operating depth and is less aggressive than primary tillage implement. The utmost used implement types for tillage in the preparation for planting are harrows in conventional field operations (Stolf *et al.*, 2010). In most cases, these secondary implements are functional as both in primary and secondary provision. Furthermore, the most often considerable used for soil preparation with disc harrow is the weed control, plant residues management, soil aeration and improvement of porosity, a good preparation of seedbed and improving soil physical conditions (Stolf *et al.*, 2010).

Peça *et al.* (1998) reported that the 24-disc implement performed better both in terms of work rate and fuel consumption per unit of worked area, though by a small difference, relative to the 20-disc harrow, making the larger implement a better choice. Also, engine rotational speed and the effective work speed may be decision making questions in the harrowing operation (Correia *et al.*, 2015).

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Also, from their finding that the increase in effective speed reduces harrow work depth up to 26%, going from 17. 7 to 13.1 cm. This result is tillage with compromised value, being only rapidly equipped. Serrano and Peça (2008) carried out a field test under real conditions of field work revealed that the draught required for trailed disc harrows increased as the forward speeds increased from 3 and 9 km/h. Nkakini and Douglas (2013) recommended tillage speed of 2.22 m/s as the best forward speed for harrowing in loamy sand soil for drawbar pull.
Ekemube *et al.* (2020) recommended that forward speed and harrowing depth should be a determining factor to curtail expenses on fuel consumption during harrowing operation. It has been observed in literature, that for each of tillage operations (ploughing, harrowing and ridging), fuel consumption rates rise linearly with time and area covered (Ikpo & Ifem, 2005). They reported that ploughing operation which has need of more energy than others used up the highest fuel consumption and the lowest work rate.

The traditional tillage pattern needs a smaller amount fuel and time for tillage operation compared to circuitous and straight alternation pattern that would reduce the cost of production (Sarkar *et al.*, 2016). The research by Shah *et al.* (2016) has shown that fuel consumption and operation cost was more by disc harrow as compare to combination of cultivator + disc harrow. From their findings, they recommended that the use of combination of cultivator + disc harrow followed by disc harrow could make better seedbed in clay loam soil. Abbouda *et al.* (2001) reported that the wider track widths combinations and higher water ballast levels showed no significant differences (at 5% level) of fuel consumption with trailed disc harrow, that this might be caused by the absence of the dynamic load transfer to the rear wheels during work by the freely floating disc harrow. According to Correia *et al.* (2015) the choice of 220 rad/s (2100 rpm) rotation and 3.65 km/h permits fuel economy and higher worked area amount per unit time, which are desirable outcomes to lessen operational costs.
Similarly, Correia *et al.* (2015) uses 220 rad/s (2100 rpm) engine rotation with disc harrow in performance tillage operation in clay soil to enhance lower fuel consumption and higher effective field capacity.

They observed that the difference is that, there was a reduction in depth of work and the power required on the bar improved and lower engine rotation speed makes available higher working depth and decrease power in the traction bar.
Serrano (2007) stated that as with other implements, fuel consumption in harrowing operation could be attained based on fuel consumption per hectare measurement, which is the key technical indicator in the agricultural machinery efficiency use assessment. So, he stated that this demonstrated the contribution of the several variables that affect fuel supplied to the engine transformation effectiveness, during the work done by the implement. Tavares *et al.* (2012) used a harrow in conventional tillage system to describe the operating fuel consumption is 20.9% lesser when compared to reduce tillage system using chisel. Ekemube *et al.* (2020) researched on the assessment of tractor fuel consumption as influenced by tractor forward speed and depth during harrowing operation, their result revealed that increase in both forward speed and harrowing depth causes fuel consumptions increase during harrowing. Kheiralla *et al.* (2003, 2004) in their studies of an evaluation of power and energy requirements for both powered and draught implements. They posited that the disc harrow was the best energy efficient implement in terms of fuel consumption and specific energy followed by the rotary tiller, disc plough and mouldboard plough.
It has been in literature that tractor's fuel consumptions are affected by many parameters during tillage operation, these include type and structure of soil, climate, tractor type, tractor size and tractor-implement relationship. There is dearth of information on the variability of tractor's fuel consumption during harrowing operation;

there is still work to be done on this area considering two aspects of tractor fuel efficiency parameters (TFEPs) (hourly fuel consumption (FC_h), and tilled area fuel consumption (FC_{ta}). The aim of this study is to determine the variability in tractor fuel efficiency parameters during harrowing.

2. MATERIALS AND METHODS:

2.1 Experimental Site

The map of the experimental area is displayed in figure 1. This experiment was carried out on May 12th, 2021 at the Rivers State Institute of Agricultural 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 group balanced block design (GBBD) was the experimental design used. 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.

2.2 Tractor and Implement Specifications

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 1800 mm wide mounted-type disc harrow with disc diameter of 508 mm of disc plough (Baldan Implementos Agricolas, Brazil) with 9-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 1.5mm^2/s, maximum kinematic viscosity 6.0 mm^2/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: The Disc Harrow (Baldan Implementos Agricolas, Brazil) used in this Study

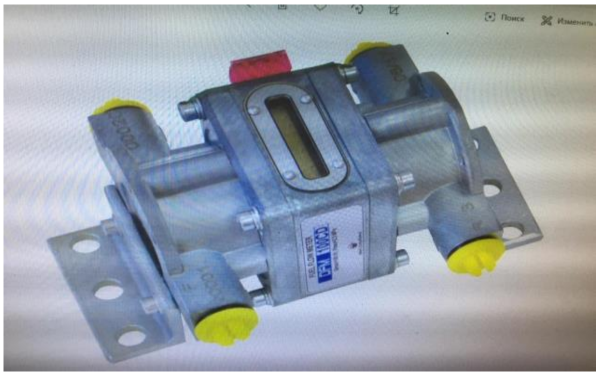

Plate 3: DFM 100CD Fuel Flow Meter (Technoton Engineering, Belarus) used in this Study

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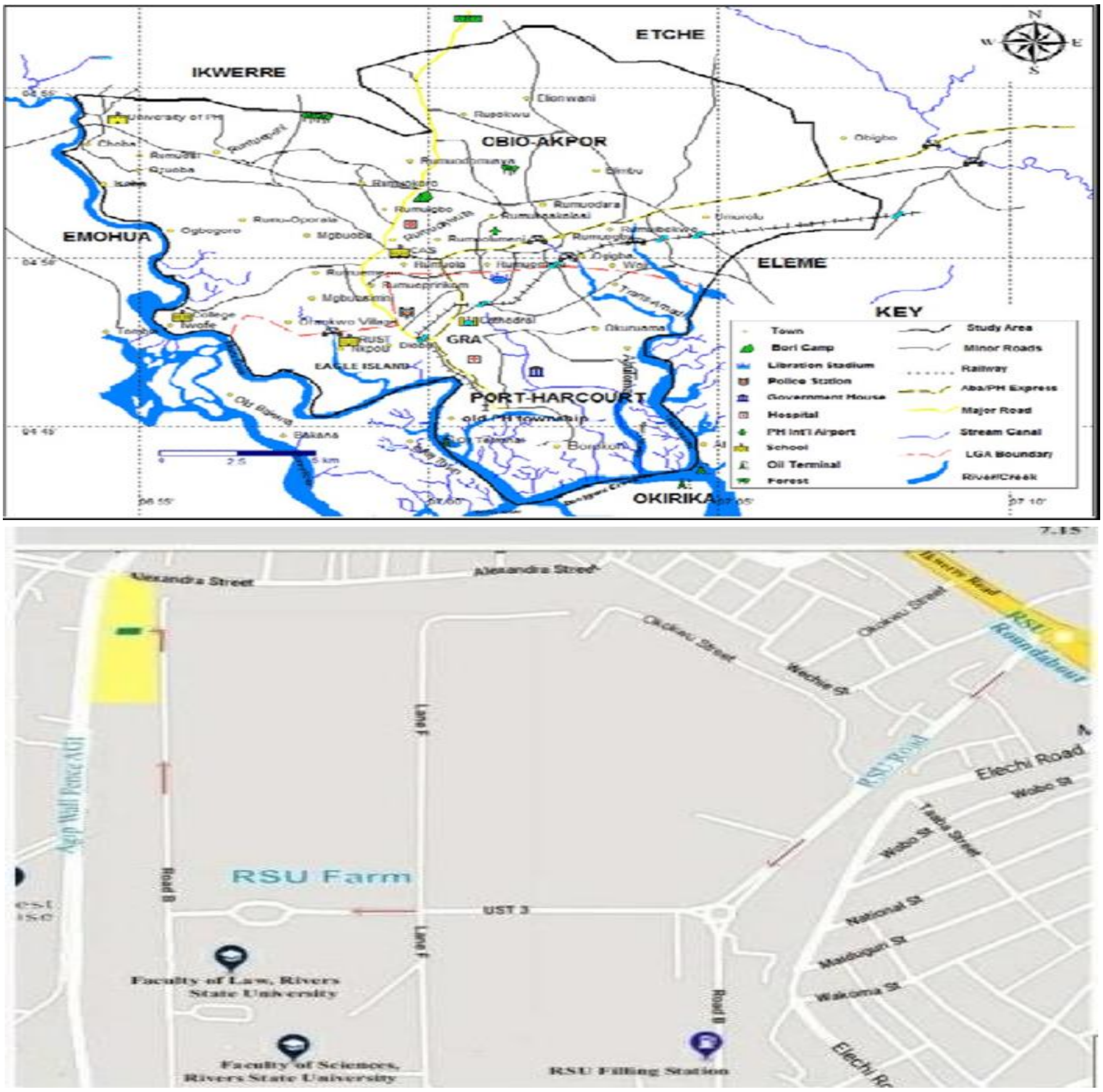

Figure 1: Map of Nigeria, Port Harcourt Metropolis and River State University (Source: Googgle Map, 2021).

2.3 Experimental Procedure

Prior to harrowing operations, soil core was used for obtaining the soil sample from the depth of 0 - 15 cm at random in the field to determined textural classification of the soil, moisture content and the bulk density. The collected soil samples were taken to the laboratory for analysis. The parameters such as textural classification of the soil was determined by hydrometer method and the gravimetric (i.e., oven dry method) was used for soil moisture content determination (Nkakini, 2015). Also, the bulk density was determined using core method prior to tillage operation (Walter et al, 2016).

The disc harrow was attached to the tractor and levelled using the top links of the tractor in order to reduce parasitic forces. Then, harrowing depths were determined by setting the level control of the lifting mechanism (three-point linkage height) to lower the disc harrow to the desired harrowing depth.

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Tractor forward speeds were determined by selecting a particular gear that gave the desired speed. This was done in a practice area in advance for each test plot to maintain the desired treatment. The harrowing depth measurement was done by placing the meter rule from furrow bottom to the surface of the harrowed 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 a stopwatch set at zero before each operation. Draught force was determined using the formula represented below (ASAE, 2000):

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

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

The digital method of measuring the quantity 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. Similar method has been adopted by Sumer *et al*. (2010); Spanolo *et al* (2012); Lopez-Vazquez *et al.* (2019); Ivanov (2019). 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:
FC_h = Hourly fuel consumption (L/h);
T_{fc} = Tractor fuel consumption, L;
h = Working hour, h.

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

Where:
FC_{ta} = Tilled area fuel consumption, L/ha;
T_{fc} = 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

Analysis of variance (single factor ANOVA) is the statistical method used to analyze the data 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).

3. RESULTS AND DISCUSSION:

3.1 Soil textural class

The particle size distribution (PSD) analysis of a 102g air-dried soil before tillage operations indicated soil particles of various sizes, including sand (9.60 %), silt (8.80 %) and clay (83.60 %) in the soil. Result showed that the soil texture was loamy sand according to the United State Department Agriculture (USDA) textural classification of soil (Figure 2).

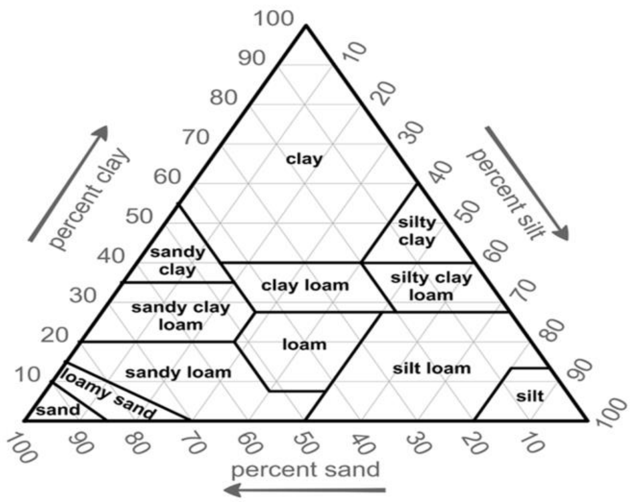

Figure 2: USDA Soil Texture Triangle

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Field test parameters including tractor draught (D), forward speed (S), harrowing depth (d), moisture content (MC), bulk density (ρ_b), and width of cut (W) were evaluated (Table 1). From table 1, results showed that the increase 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}). Therefore, fuel consumption is affected by draught, tractor forward speed, harrowing depth, width of cut, bulk density and moisture content. Therefore, tractor fuel consumption rate increases in line with time and tilled area. This is in agreement with the findings of Ikpo and Ifem (2005).

Table 2: Mean Results of Field Test Performed during Harrowing Operation

Parameters								
d, m	S, Km/h	W, m	ρ_b, g/cm^3	CI, N/cm^2	D, N	MC, %	FC_h, L/h	FC_{ta}, L/ha
0.0 9	5.00	1.50	1.42	164.06	3818.88	17.92	3.04	6.15
	7.00	1.50	1.42	164.06	4133.38	17.92	4.19	6.67
	9.00	1.50	1.42	164.06	4447.87	17.92	4.29	6.80
0.12	5.00	1.50	1.53	214.84	5346.43	18.50	4.37	8.86
	7.00	1.50	1.53	214.84	5786.73	18.50	6.08	9.61
	9.00	1.50	1.53	214.84	6227.02	18.50	6.20	9.85
0.15	5.00	1.50	1.65	253.91	6873.98	18.60	6.54	13.33
	7.00	1.50	1.65	253.91	7440.08	18.60	9.09	14.52
	9.00	1.50	1.65	253.91	8006.17	18.60	9.30	14.76

d (depth), S (speed), W (width), ρ_b (bulk density), CI (cone index), D (draught), MC (moisture content), FC_h (hourly fuel consumption), FC_{ta} (tilled area fuel consumption)

Table 3: 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	0.002489	1.2445E-03			
Treatment group	2	91.5678	45.7839	43,8333.32**	6.94	18.00
Error (a)	4	0.0004178	1.0445E-03			
Treatment within group A	2	2.895	1.4475	32,589.12**	3.88	6.93
Treatment within group B	2	6.2874	3.1437	70,777.48**	3.88	6.93
Treatment within group C	2	14.1642	7.0821	159,446.89**	3.88	6.93
Error (b)	12	0.000533	4.441667E-05			
Total	26	25376.49				

*Significant, **Highly Significant, ^{ns} No significant, CV (a) = 0.55%, CV (b) = 0.11%

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3.2 Hourly Fuel Consumption

Figure 3 shows the results of hourly fuel consumption during harrowing operation. The hourly fuel consumption readings were presented in Table 1 during harrowing operation. These were measured with the use of fuel flow meter. Parameters such as draught, cone index, forward speed, tillage depth, bulk density and moisture content that affect the variability of hourly fuel consumption during harrowing operation were measured before, during and after the operation. The increase in the aforementioned parameters increase fuel consumption during the process of harrowing 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 was observed that increasing the tractor forward speed, travel time for an assumed distance reduces and as a result, time reduction will result in the hourly fuel consumption increase.

Also, depth influenced hourly fuel consumption more than any other parameters that were tested in this study. This is in line with the findings of Leghari *et al.* (2016b); Nasir (2016); Almaliki *et al.* (2016a).; Shafaei et al. (2018); Nkakini and Ekemube (2020) and Ekemube et al. (2020). The variation in hourly 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 show that there are statistically significant at 95 % confidence level and highly significant at 99 % confidence and coefficient of variations (CV) (a) is 0.55 % and (b) 0.11% respectively, which revealed that the experimental errors were low and reliable (Table 3).

3.3 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 shows the results of tilled area fuel consumption during harrowing operation. The tilled area fuel consumption readings were presented in Table 1 during harrowing operation.

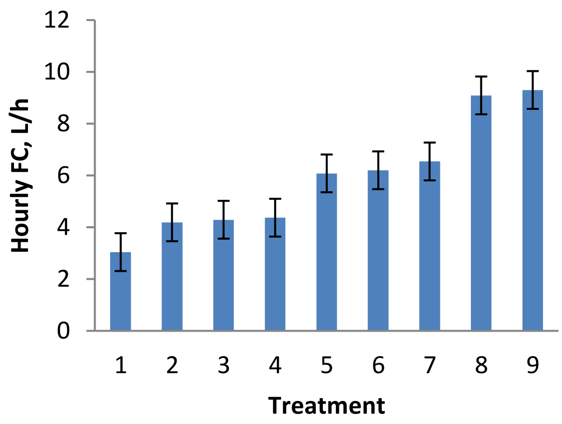

Figure 3: Variability of Hourly Fuel Consumption during Harrowing

These were measured using fuel flow meter. Parameters such as draught, cone index, forward speed, tillage depth, bulk density and moisture content that affect the variability of fuel consumption during harrowing operation were measured before, during and after the operation. The increase in the aforementioned parameters increased fuel consumption during the process of harrowing but the draught influenced the fuel consumption with the combinations of the tillage depth and forward speed (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 Leghari *et al.* (2016b); Nasir (2016); Almaliki *et al.* (2016a); Nkakini and Ekemube (2020); and Ekemube *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 revealed its mean reliability treatment (Figure 4). Also, ANOVA results shows that there is statistically significant at 95 % confidence level and highly significant at 99 % confidence and coefficient of variations (CV) of (a) is 0.18 % and (b) 0.13% respectively, which revealed that the experimental errors were low and reliable (Table 4).

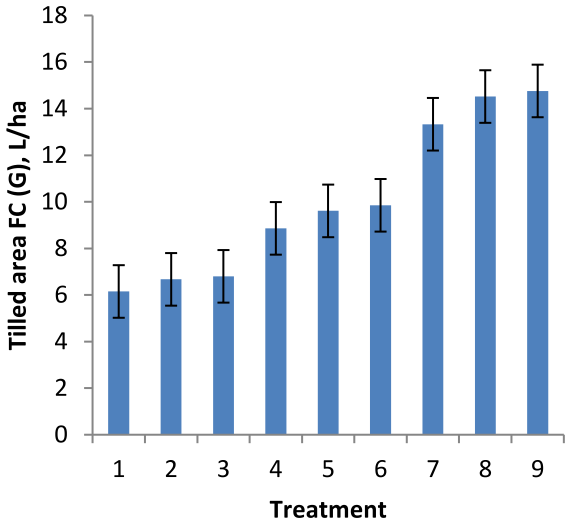

Figure 4: Variability of Tilled Area Fuel Consumption during Harrowing

4. CONCLUSION:

Determination of the variability in tractor fuel efficiency parameters (TFEP) (hourly and tilled area fuel consumption) in the course of harrowing operation has been studied. The findings led to the following conclusions:

(i) The increase in soil-implement-machine parameters (draught, forward speed, harrowing depth, width of cut, bulk density and moisture content) in course of harrowing operations cause increment in hourly fuel consumption;

(ii) Similarly, increase in soil-implement-machine parameters (draught, forward speed, harrowing depth, width of cut, bulk density and moisture content) in course of harrowing operation causes increment in tilled area fuel consumption;

(iii) In addition, the increase in tractor fuel consumption rate increases in line with working hour and tilled area;

Variations in the soil-implement-machine parameters cause the variability in hourly and tilled area fuel consumptions.

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Table 4: Analysis of Variance (Group Balanced Block Design) for Data in Table 1 (FC_{ta})

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F	Tabular F 5%	Tabular F 1%
Replication	2	0.003822	0.001911			
Treatment group	2	269.4781	134.739	433,089.70**	6.94	18.00
Error (a)	4	0.001244	0.000311			
Treatment within group A	2	0.7098	0.3549	1,998.31**	3.88	6.93
Treatment within group B	2	1.6002	0.8001	4,500.56**	3.88	6.93
Treatment within group C	2	3.5186	1.7593	9,896.06**	3.88	6.93
Error (b)	12	0.002133	0.000178			
Total	26	275.3139				

*Significant, **Highly Significant, ^{ns} No significant, CV (a) = 0.18%, CV (b) = 0.13%