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# Evaluation of Tractor Fuel Efficiency Parameters Variability during Ploughing Operations

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## ABSTRACT
*Fuel consumption is unavoidable in farm practices to boast mechanization of agriculture. In this study, field experiments were performed to evaluate the variability in tractor fuel efficiency parameters during ploughing operations. An experimental plot of 138 m by 50 m (6900m²) 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, ploughing depth, width of cut), time and tractor fuel efficiency parameters (hourly fuel consumption ($FC_h$) and tilled area fuel consumption ($FC_{ta}$)) during ploughing operations were evaluated. The field test data gotten 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) 0.07 % and (b) 07 %; and (a) 0.18 % and (b) 0.13 %, which inveterate that experimental error was low and dependable. In general, the variability in tractor fuel efficiency parameters during harrowing operations are influenced by differences in the soil-implement-machine parameters and thus become the decisive factors for reduction of fuel consumption.*

**KEYWORDS**: Hourly Fuel Consumption, Ploughing, Tillage, Tilled Area Fuel Consumption, Tractor.

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## 1. INTRODUCTION
Ploughing is a Primary tillage operation that involves the use of implement such as plough for physical and mechanical soil disturbance for preparing seedbed conducive for crop production. This can be done at sufficient soil moisture content and strength to permit ploughing and provide sufficient and well-organized traction. The useful and widely involvement of disc plough for tillage operation of virgin, stony and wet soils, cut through crop residues and roll over the roots (Boydas & Turgut, 2007). Moldboard plough creates an essential tillage, controls weeds, and buries fertilizers and remains of the preceding crops (Abrougui *et al*., 2013; Abrougui *et al*., 2014). Their findings were that a soil well tilled permits plants to accept more nutrient and water reserves inspiring their development and successively higher produces of fresh material. According to Pandy (2004) ploughing depth is a dependent of the crop to be cultivated, soil characteristics and also the source of power available. Research by Al-Suhaibani and Ghaly (2013) recommended that ploughing depth should be based on the crop type (depth of the root system) and shallow seed placement (less than

25 mm) is recommended for most crops that are directly sowed. Furthermore, they posited that the depth of the crop roots to be raised is a deterministic factor of ploughing depth, while the availability of time and implement width will determine the speed needed to finish the work on time. Results obtained from their studies showed that the depth has more significance on the draught. In addition, the ploughing depth have to to be determined based on the length of the root (Pandey, 2004; Al-Suhaibani & Ghaly, 2010; Ajav & Adewoyin 2012; Adewoyin 2013; Adewoyin & Ajav 2013; Al-Suhaibani & Ghaly, 2013).

There are significant changes in the physical situations of soil caused by variant levels of tractor forward speed (Ahaneku & Ogunjirin, 2005). They suggested a substantial forward speed of about 7km/h for tractor operation when using mouldboard plough in a sandy loam soil that would be suitable for soil structure correction as reflected in enhancements in the soil strength properties and maximum decrease in clod mean weight diameter. Ismail *et al*. (2009) reported that 47.81Kw of a tractor is appropriate at all plough width and at variant forward speed. Base on their recommendations, this can be used in tillage operations. In the same light, Nkakini (2015) in his study indicated that 1.94 m/s (7km/h) is the best ploughing forward speed for in loamy sand soil. Moreover, Ranjbarian *et al*. (2015) established that the results increment caused by forward speed also increased draught requirement. They stated that draught requirement for the implements ranged from 8.2 KN for the disc plough at velocity of 1.5 km/h to 13 KN and for the chisel plough at velocity of 4 km/h.

It has been in literature that tractor's fuel consumption is affected by many parameters during tillage operation, these include type and structure of soil, climate, tractor type, tractor size and tractor-implement relationship. The difference in soil texture influence fuel consumption during tillage operation and the highest fuel consumption was recorded for conventional tillage (81.83 L/ha) with the silty clay loam soil followed by conventional tillage on silty loam (68.38 L/ha) (Stajnko *et al*., 2009). According to Olatunji and Davis (2009) reported that soil moisture content, bulk density, soil texture and shear strength contribute to tillage energy requirement. Also, it has been reported in results obtained from studies by Ajav and Adewoyin (2012); Adewoyin (2013); and Adewoyin and Ajav (2013) that the ploughing depth has more effect on the fuel consumption of farm tractors than the ploughing speed. By this means, they suggested that the depth of ploughing should be determined based on the root length of crop in other to augment fuel cost. Also, Nkakini and Ekemube, (2020) suggested that forward speed and ploughing depth should be a determining factor to curtail expense on fuel consumption.

The right capable technique of saving fuel is to choose a suitable driving strategy, which specifies operation close to the optimal engine operating point (Moitzi *et al*., 2014). Leghari et al. (2016a) studied the relative efficiency of different tillage practices and their effect on soil physical properties under semi-arid climate of Tandojam, Pakistan observed that there was higher fuel consumption (23.3 L/h) in operating disc plough with less operating speed (4.1 km/h) and higher travel reduction (27.5%). Nevertheless, their observations were higher cultivator operating speed (4.76km $hr^{-1}$) with less travel reduction (21.8%) and fuel consumption (14.9 L/h). Fathollahzadeh *et al*. (2010) reported that the tractor attached with mouldboard plough and operates with depths of 15, 25 and 35cm consumed 27.446, 30.096 and 34.06 liters of fuel per hectare, respectively. Likewise, they reported that the increment in fuel consumption from 9.66 to 24.1% was due to increment in ploughing depth from 0.15 to 0.25 m and 0.15 to 0.35 m respectively. Kheiralla *et al*. (2004) carried out a study on measurement of fuel consumption of 64kw MF3060 tractor attached with a mouldboard plough with three shares in in different soil conditions. Their results revealed fuel

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consumption values of 21.2 and 24.6 L/ha for 0.18 and 0.235 m depths, respectively. Also, Filipovic et al. (2006) studied fuel consumption value for each applied implement in various tillage systems using a mouldboard plough attached to a four-wheel drive tractor of 92 Kw. They reported that mouldboard plough used for planting wheat and soybean tillage operations consume 28.16 and 34.45 L/h of diesel fuel. Taiwo (2015) stated that in order to lessen fuel consumption during primary and secondary tillage operations, the width of cut should be maximized. For this reason, there is dearth of information on the variability of tractor fuel efficiency parameters during ploughing 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 evaluate the variability in tractor fuel consumption ploughing operations.

## 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 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 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.

### 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 1.5mm$^2$/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 Plough (Baldan Implementos Agricolas, Brazil) used in this Study**

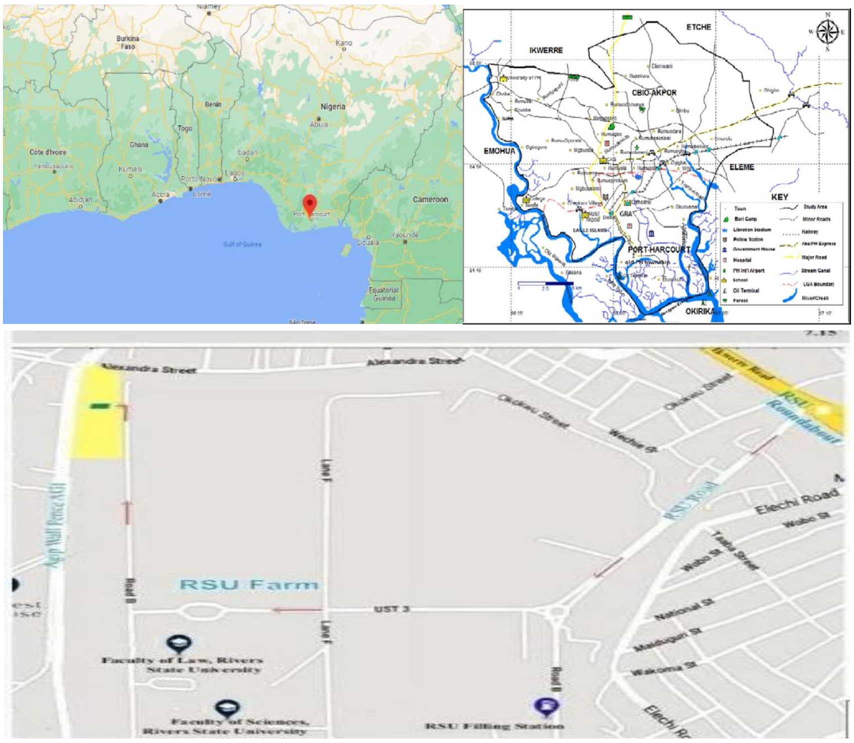


**Figure 1: Map of Nigeria, Port Harcourt Metropolis and River State University (Source: Googgle Map, 2021).**

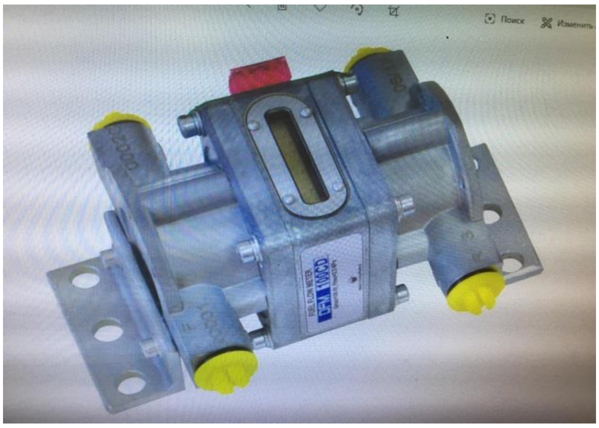

**Plate 3: DFM 100CD Fuel Flow Meter (Technoton Engineering, Belarus) used in this Study**

## 2.3 Methods

Preceding ploughing operation, soil core was used for obtaining the soil sample from the depth of 0 – 10, 10 – 20 and 20 - 30 cm respectively 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 ploughing depth. 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 ploughing depth measurement was done by placing the meter rule from furrow bottom to the surface of the ploughed 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):

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

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).

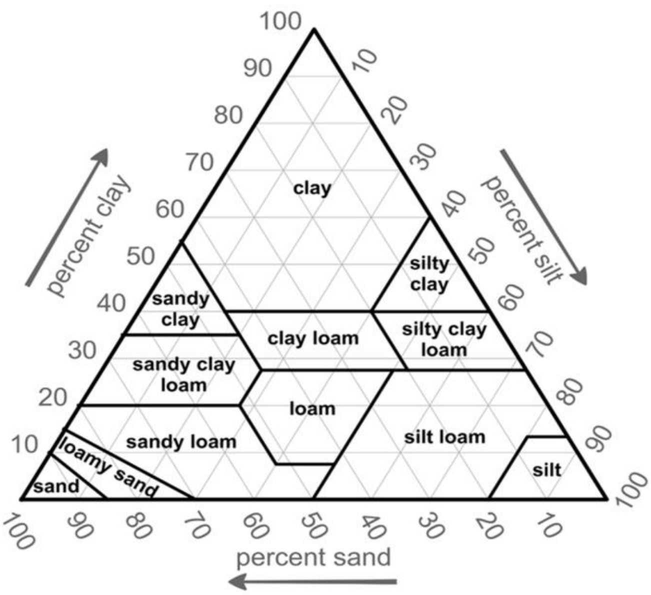


**Figure 2: USDA Soil Texture Triangle**

**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% | Tabular F 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 | | | | |

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

| Parameters | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| d, m | S, Km/h | W, m | $\rho_b$, g/cm$^3$ | CI, N/cm$^2$ | D, N | MC, % | $FC_h$, L/h | $FC_{ta}$, L/ha |
| 0.10 | 5.00 | 0.90 | 1.55 | 195.31 | 1435.82 | 17.92 | 2.93 | 6.08 |
| | 7.00 | 0.90 | 1.55 | 195.31 | 1553.64 | 17.92 | 4.14 | 6.59 |
| | 9.00 | 0.90 | 1.55 | 195.31 | 1671.45 | 17.92 | 4.24 | 6.78 |
| 0.20 | 5.00 | 0.90 | 1.69 | 234.38 | 2871.65 | 19.90 | 4.25 | 8.80 |
| | 7.00 | 0.90 | 1.69 | 234.38 | 3107.27 | 19.90 | 5.98 | 9.49 |
| | 9.00 | 0.90 | 1.69 | 234.38 | 3342.89 | 19.90 | 6.15 | 9.86 |
| 0.30 | 5.00 | 0.90 | 1.85 | 273.44 | 4307.47 | 21.05 | 6.36 | 13.16 |
| | 7.00 | 0.90 | 1.85 | 273.44 | 4660.91 | 21.05 | 8.95 | 14.23 |
| | 9.00 | 0.90 | 1.85 | 273.44 | 5014.34 | 21.05 | 9.19 | 14.64 |

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

The field experiment parameters include tractor draught (D), forward speed (S), ploughing depth (d), moisture content (MC), bulk density ($\rho_b$), and width of cut (W) were evaluated (Table 2). From table 2, 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 during ploughing operation. 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).

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**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% | Tabular F 1% |
|---|---|---|---|---|---|---|
| Replication | 2 | 0.00643 | 3.215E-05 | | | |
| Treatment group | 2 | 88.61965 | 44.309825 | 2,988,858.35** | 6.94 | 18.00 |
| Error (a) | 4 | 5.93E-05 | 1.4825E-05 | | | |
| Treatment within group A | 2 | 3.171489 | 1.5857445 | 106.904.15** | 3.88 | 6.93 |
| Treatment within group B | 2 | 6.6318 | 3.3159 | 223,543.87** | 3.88 | 6.93 |
| Treatment within group C | 2 | 14.7746 | 7.3873 | 498.020.34** | 3.88 | 6.93 |
| Error (b) | 12 | 0.000178 | 1.483333E-05 | | | |
| Total | 26 | 113.2042 | | | | |

*Significant, **Highly Significant, $^{ns}$ No significant, CV (a) = 0.07%, CV (b) = 0.07%

### 3.2 Hourly Fuel Consumption

The results of hourly fuel consumption during ploughing operation are shown in Figure 3. The hourly fuel consumption values presented in Table 2 during ploughing. Fuel consumption was measured with the use of fuel flow meter. Other field test parameters were draught, cone index, forward speed, tillage depth, bulk density and moisture content that affect the variability of fuel consumption during ploughing operation were measured. The results revealed that, there were differences in the fuel consumption during the ploughing operations that appeared as increment in fuel consumption that is caused by some parameters such draught, depth, speed, cone index, bulk density, and moisture content. The increase in the aforementioned parameters increase fuel consumption during the process of ploughing. Based on 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 Moitzi *et al*. (2014); Leghari *et al*. (2016b); Nasr (2016); Almaliki *et al*. (2016); Shafaei *et al*. (2018), Nkakini and Ekemube (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 treatment reliability. Also, ANOVA results showed that they were statistically significant at 95 % confidence level and highly significant at 99 % confidence and coefficient of variations (CV) of (a) is 0.07 % and (b) 0.07% respectively, which revealed that the experimental errors were low and reliable (Table 3).

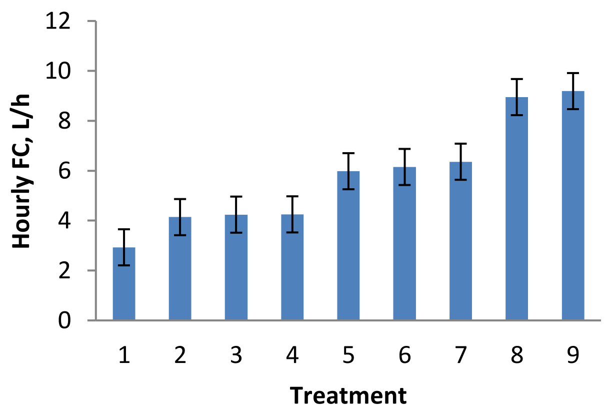


**Figure 3: Variability of Hourly Fuel Consumption during Ploughing**

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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 | 0.004356 | 2.178E-03 | | | |
| Treatment group | 2 | 259.4003 | 129.700015 | 729,676.60** | 6.94 | 18.00 |
| Error (a) | 4 | 0.000711 | 1.7775E-04 | | | |
| Treatment within group A | 2 | 0.7862 | 0.3931 | 2,211.53** | 3.88 | 6.93 |
| Treatment within group B | 2 | 1.7366 | 0.8683 | 4,884.95** | 3.88 | 6.93 |
| Treatment within group C | 2 | 3.5034 | 1.7517 | 9,854.85** | 3.88 | 6.93 |
| Error (b) | 12 | 0.002133 | 1.7775E-04 | | | |
| Total | 26 | 265.4337 | | | | |

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

### 3.3 Tilled Area Fuel Consumption

Fuel consumption could be attained based on fuel consumption per hectare measurement, which is the key technical indicator in the agricultural machinery efficiency use assessment (Serrano, 2007). The results of tilled area fuel consumption during ploughing operation are shown in Figure 4. The tilled area fuel consumption values presented in Table 1 during ploughing operation. These were measured using fuel flow meter. Other field test parameters were draught, cone index, forward speed, tillage depth, bulk density and moisture content that affect the variability of fuel consumption during ploughing operation were measured. The increase in the aforementioned parameters increased fuel consumption during the process of ploughing 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 influences fuel consumption more than any other parameters that were tested in this study. This is in line with the findings of Moitzi *et al.* (2014); Leghari *et al.* (2016b); Nasir (2016); Almaliki *et al.* (2016); Shafaei *et al.* (2018), Nkakini and Ekemube (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 treatment reliability (Figure 4). Also, ANOVA results showed that there is statistically significant at 95 % confidence level and highly significant at 99 % confidence and coefficient of variations (CV) of (a) is 0.13 % and (b) 0.13% respectively, which revealed that the experimental errors were low and reliable (Table 4).

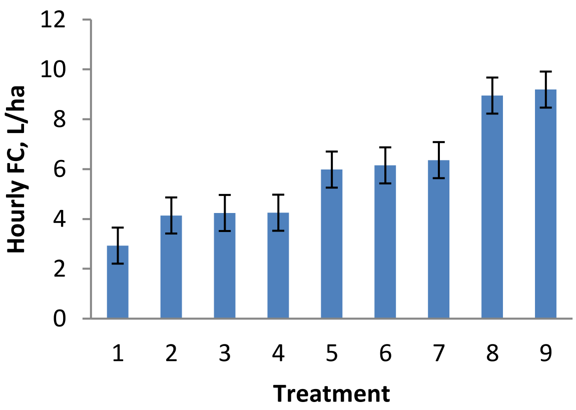


**Figure 4: Variability of Tilled Area Fuel Consumption during ploughing**

## 4. CONCLUSION

Evaluation of tractor fuel efficiency parameters (TFEP) variability during ploughing operation has been studied. The findings conclusions are as follows:

(i) The hourly fuel consumption increment in course of ploudging operation were caused by soil-implement-machine parameters (draught, forward speed, ploughing depth, width of cut, bulk density and moisture content);

(ii) In the same way, the incresae in tilled area fuel consumption in course of ploughing operation are caused by increment in soil-implement-machine parameters (draught, forward speed, ploughing depth, width of cut, bulk density and moisture content);

(iii) Furthermore, the incresae in working hour and tilled area during ploughing operations increases in line with tractor fuel consumption rate;

(iv) Differences in the soil-implement-machine parameters measurement cause the variability in hourly and tilled area fuel consumptions.

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