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# Assessment of Tractor Fuel Consumption as Influence by Tractor Forward Speed and Depth during Harrowing Operation

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***Abstract**: Harrowing has high pulverization effects for optimum crops yield in agricultural mechanization. Mechanization practice involves use of tractors and implements for tillage operations. Tractors and implements depend on fuel as the major sources of energy for its operation. Therefore, with tractor application in all farm operations fuel plays an active role. Fuel consumption field tests were conducted to assess the influence of speed and depth of cut on tractor fuel consumption during harrowing operation. The experimental field layout for the study was 160m by 32.5m (5200m$^2$) area, which was divided into three blocks of nine sub-blocks. Each of the blocks was marked out in 50 m by 5 m for different treatments. The alleys dimensions of 50 m by 2 m to the plot were provided. The equipment and tractor used for the tillage operations were Swaraj 978FE (tractor) model mounted with disc harrow. The parameters measured were moisture content, bulk density, tractor forward speed, harrow width, harrow depth, time and amount of fuel used during harrowing operation were measured and employed for the evaluation of the fuel consumption. The fuel consumption was estimated by amount of fuel used per unit time to complete each treatment. The experimental data obtained were analysed statistically using analysis of variance (ANOVA), coefficient Variation (CV) and Duncan multiple range test (DMRT). Results showed coefficient of determination $R^2$ = 0.9939; 0.9952 and 0.9454 for speed of 1.39, 1.94 and 2.50 m/s respectively and also, coefficient of determination $R^2$ = 0.9976; 0.9984 and 0.9996 for depths of 10, 13 and 16 cm. ANOVA and DMRT showed significant difference with 95 confidence levels on effect of speed, depth and their combined effects of speed and depth. In addition, coefficient of variation (CV) of 0.42 % confirmed that the experiment was reliable due to negligible experimental error. Therefore, suggested that forward speed and harrowing depth should be a determining factor to curtail expense on fuel consumption.*

**Keywords**: Harrowing depth; forward speed; fuel consumption; percentage composition of fuel consumption

## 1. Introduction

Harrowing is a secondary tillage operation projected to create a refined soil condition. This tillage process is achieved with the aid of secondary tillage implement known as disc harrow [1]. In conventional field operations, harrows are mostly used implement for tillage operation during land preparation for planting [2] and they are functional in both primary and secondary soil preparation. Studies have shown that, it is the most frequently used validations for soil preparation in terms of weed control, plant residues management, soil aeration and porosity improvement, a good seedbed preparation and making physical conditions of the soil better [2]. Peça et al. [3] revealed that the disc implement with larger width and higher number of discs performed better than the one smaller with and lesser number of discs in terms of work rate and fuel consumption per unit of worked area. By this reason of difference in work rate and fuel consumption, the larger implement has become better choice for harrowing operations [3]. Correia et al. [4] assumed that the rotation speed of the engine and the effectiveness of the rate of work may be decision tools in the harrowing operation. Serrano and Peça [5] assessed that the field tests carried out under real situations of work demonstrates that the draught necessary for trailed disc harrows tends to increase to some extent with forward speeds between 3 and 9 kmh-1. Shah et al. [6] reported that the overall performance of cultivator with disc harrow is satisfactory and can be more effective for tillage operations in clay loam soils. Nkakini and Douglas [7] indicated that the sensitivity coefficient of 0.2331 for drawbar pull at 2.22 ms-1 tillage speed, is recommended as the best speed for harrowing in loamy sand soil.

The study by Shah et al. [6] revealed that fuel consumption and cost of operation was found more by disc harrow as compare to cultivator + disc harrow. In the light of Shah et al. [6] findings, they suggested that the use of cultivator + disc harrow followed by disc harrow can make better seedbed in clay loam soil. Abbouda et al. [8] observed that combinations of wider track widths and higher water ballast levels have no influence on fuel consumption with trailed disc harrow during operation. This could be caused due to lack of transfer of dynamic load to the rear wheels in the course of work by the floating disc harrow without obstruction.

Disc harrow operating performance in clay soil when using 220 rad s-1 (2100 rpm) engine rotation speed aided reduction in fuel consumption and higher effective field capacity [4]. They reported that the variance is that, depth of work was reduced and the required power on the bar improved and lower the rotation speed of the engine which provides higher working depth and a reduced amount of power in the traction bar.

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The research by Serrano [9] indicated that fuel consumption per hectare measurement is the key assessment used for technical indicator in the agricultural machinery efficiency. Thus, the effectiveness of the engine transformation was demonstrated by the contribution of several variables that affect fuel supplied during the work done by the implement. Harrow when used in conventional tillage system, indicates that the operating fuel consumption is 20.9% lower when related to decrease in tillage system using chisel [10]. Gulsoylu et al. [11] reported that increasing speed reduced the fuel consumptions and increasing tillage depth increased fuel consumptions in their study of different types of chisel legs to determine their performances. Kheiralla et al. [12, 13] opined that disc harrow was the best energy efficient implement in relations to fuel consumption and specific energy compared to rotary tiller, disc plough and mouldboard plough on evaluation of power and energy requirements for both powered and draught implements.

As reported by Ikpo and Ifem [14], fuel consumption ratesincreases linearly with time and area covered for each oftillage operation (ploughing, harrowing and ridging). Sarkar et al. [15] further stated that the application of appropriate tillage pattern during could reduce fuel consumption and tilling time during tillage operation. Thus, the traditional tillage pattern requires less fuel and time for tillage operation compared to circuitous and straight alternation pattern that would reduce the production cost [15].

It has been observed that the factors which fundamentally affect fuel consumption in tillage equipment use is the increase in power consumption by increasing the forward speed, width of cut, soil strength of soil, soil moisture content and the tilling depth [16 - 20]. But the depth and the forward speed have more influence on tractor's fuel consumption [11, 18, 21 - 23]. Moitzi et al. [18] suggested that chosen an appropriate driving strategy, which indicates operation close to the optimal engine operating point, is the right proficient way of saving fuel. Taiwo [24] assessed that possibility of reduction of fuel consumption during primary and secondary tillage operations, the width of cut should be maximized. Serrano et al. [25] in their studies results demonstrated that selection of an engine speed of approximately 70-80% of the nominal speed, and using a higher gear ("shift-up throttle-down" concept) could minimized fuel consumption during tillage operations.

The use of digital and manual appliance to measure fuel consumption has been adopted by several researchers [21, 23, 26 - 31]. Also the method of topping up the tank (direct method) by using graduated cylinder manually to top-up the fuel tank of a tractor immediately after each operation has been adopted by several researchers [6, 22, 32 - 35].

In light of previous findings, there is insufficiency of researches about the assessment of tractor fuel consumption as influenced by tractor forward speed and depth during harrowing operation. The aim of this study was to assess the effects of forward speed and depth on tractor fuel consumption.

## 2. MATERIALS AND METHODS:

### 2.1 Experimental Site

This experiment was carried out during the raining season (July 2018) at the Rivers State Agricultural Development Programme (ADP) farm in School to Land Authority, Rumuodomaya, Obio Akpor Local Government Area of Rivers State, Nigeria (4° 49′ 27″ N, and longitude of 7° 2′ 1″ E). The map of the experimental area is shown in figure 1.

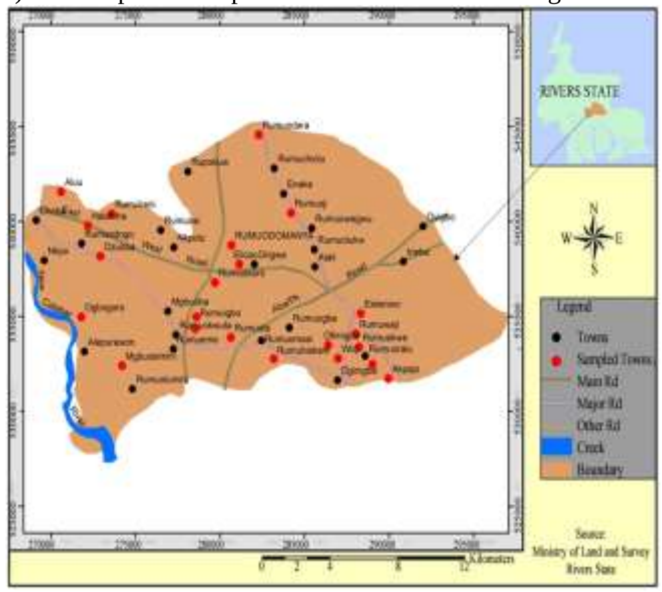


Figure 1: Map of Obio Akpo Local Government Area, Rivers State, Nigeria. Source: Rivers State Ministry of Land Survey

The randomized complete block design (RCBD) was adopted for this study. A farm site, 160 m by 32.5m (5200 $m^2$) that was split up into three blocks of 9 sub-blocks each. Each plot was marked out 50 m by 2 m each along with the alley dimension of 1m in between. The sub-blocks were provided with variable treatment options and with 4 m space in between each block.

### 2.2 Specifications of Tractor and Implement Used

A two wheel drive tractor (Model: 978 FE, manufacturer: Swaraj, country: India) was used for this study (see Plate 1). The tractor was one of the commonly used tractors in farm operations in Rivers State. The tractor total weight 3015 Kg. Front and the rear tyres were 7.5 – 16, 8 ply and 16.9 – 28, 12 radial respectively. A disc harrow of 1390 mm wide mounted-type (manufacturer: Swaraj, country: India) with fourteen disc bottom mounted on a guage wheel was used for this study (see Plate 2). The disc harrow amounted on the tractor was lowered using top links of the tractor together for reduction of parasitic forces.

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**Plate 1: Tractor (Swaraj 978 FE)**

**Plate 2: Disc Harrow**

## 2.3 Experimental Procedure

Prior to harrowing operations, soil auger was used for collecting the soil sample at the depth of 0 - 16 cm at random in the field to determined textural classification, moisture content and the bulk density of the soil. The collected soil samples from the experimental in well labelled polyethylene bags were taken to the laboratory for analysis. The hydrometer method and the gravimetric (i.e. oven dry method) were used to determine textural classification and moisture content of the soil respectively, also the bulk density was determined using excavation method prior to tillage operation.

Proceeding to harrowing operation, the harrowing depths were determined by setting the controlling level of the three-point linkage height (lifting mechanism) to lower the disc harrow conforming to the desired depth for harrowing. Tractor forward speeds were determined by selecting a particular gear that will give the desired speed. This was done in a practiced area before entering to each main test sub-block for maintaining desired treatment. The meter rule was placed from furrow bottom to the surface of the harrowed land to measure harrowing depth, and the width of cut was determined by placing a steel tape at both ends of the furrow wall. Time was determined with stop watch setting at zero before each operation.

The topping up the tank method of determining the quantity of fuel used was adopted in the determination of tractor fuel consumption. The topping up is the process of filling the tank of the tractor fuel tank to its brim before and after each operation test performed. The fuel consumption measurement was taken using 1000 ml graduated cylinder to fill up the fuel level in the tank after each operation test, by this means, the volume of fuel consumed per time taken for the operation was noted. Mathematically, fuel consumption was determined by adopting equation (1) which is mathematically expressed as:

$$FC = \frac{V_{fc}}{T} \quad (1)$$

Where:
FC = fuel consumption ($m^3/s$), $V_{fc}$ = volume of fuel consumed, $m^3$, T = Time, s.

## 2.4 Statistical Analysis

The statistical method used to analyze the data in this study was analysis of variance (ANOVA). This is based on the F-test and to help achieved a suitable error terms with single probability risk determined. Also, the Coefficient of Variation (CV) was calculated adopting equation (2)

$$CV = \frac{\sqrt{Error\ MS}}{Grand\ mean} \times 100 \quad (2)$$

The same way, the Duncan's Multiple Range Test (DMRT) as an unplanned pair comparison technique is used to compare all possible pairs of treatment means to check which pair yields significant difference at a chosen significance level. It was considered as significant difference at 0.05 levels of significance. This was followed by computing the standard deviation ($S_d$) and the (t – 1) values of the shortest significant range ($R_p$) as given below:

$$S_d = \sqrt{\frac{2S^2}{r}} \quad (3)$$

Where:
$S^2$ = Error Mean Square (EMS)
r = number of replication

$$R_p = \frac{(r_p)(S_d)}{\sqrt{2}} \text{ for } p = 2,3,\ldots\ldots.t \quad (4)$$

Where:
$R_p$ = shortest significant range,
$r_p$ = tabular values of the significant studentized ranges.

## 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 (14.30 %), silt (5.30 %) and clay (80.40 %) in the soil. Result showed that the soil texture was loamy sand according to the United State Department Agriculture (USDA) textural classification of soil. Field test parameters including tractor forward speed (V), tillage depth (d), moisture content (MC), bulk density ($\rho_b$), 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 fuel consumption. Therefore, fuel consumption is affected by tractor forward speed, tillage depth, width of cut and moisture content. Table 1 shows the field experimental results prior and during harrowing operations.

**Table 1: Result of Field Test Performed Prior and during Harrowing Operation**

| Parameter | $d_1$ (cm) | | | $d_2$ (cm) | | | $d_3$ (cm) | | |
|---|---|---|---|---|---|---|---|---|---|
| | $V_1$ (m/s) | $V_2$ (m/s) | $V_3$ (m/s) | $V_1$ (m/s) | $V_2$ (m/s) | $V_3$ (m/s) | $V_1$ (m/s) | $V_2$ (m/s) | $V_3$ (m/s) |
| $F_C$ ($m^3$/s) | 2.38E-06 | 2.60E-06 | 2.77E-06 | 2.72E-06 | 3.22E-06 | 3.62E-06 | 3.45E-06 | 3.76E-06 | 4.53E-06 |
| W (m) | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| MC (%) | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 | 17.50 |
| $\rho_b$ (g/$cm^3$) | 1.83 | 1.83 | 1.83 | 1.83 | 1.83 | 1.83 | 1.83 | 1.83 | 1.83 |

Harrowing speed, $V_1$ = 1.39 m/s; Harrowing speed, $V_2$ = 1.94 m/s; Harrowing speed, $V_3$ = 2.50 m/s for all operations. Harrowing depth, $d_1$, = 10 cm; Harrowing, $d_2$ = 13 cm; Harrowing depth, $d_3$ = 16 cm, W = Width of cut; MC = Moisture content; and $\rho_b$ = Bulk density.

**Table 2: Analysis of Variance of Data in a 3 X 3 Factorial Experiment in RCB Design**

| Sources of Variation | Degree of Freedom (df) | Sum of Square (SS) | Mean Square (MS) | Computed F | Tabular F 1% | Tabular F 5% |
|---|---|---|---|---|---|---|
| Replication | 2 | 6.00E-16 | 3.00E-16 | 1.60$^{ns}$ | 6.23 | 3.63 |
| Treatment | 8 | 1.12877E-11 | 1.410963E-12 | 7525.133** | 3.89 | 2.59 |
| Depth, d | 2 | 7.988114E-12 | 3.9405E-12 | 21016.16** | 6.23 | 3.63 |
| Speed, V | 2 | 2.8248E-12 | 1.4124E-12 | 7532.89** | 6.23 | 3.63 |
| d x V | 4 | 4.748E-13 | 1.187E-13 | 633.07** | 4.77 | 3.01 |
| Error | 8 | 3.00E-15 | 1.875E-16 | | | |
| Total | 26 | 7.9881E-12 | | | | |

*Significant, **Strongly Significant, ns = No significant, CV = 0.42 %

3.2 Influence of Forward Speed on FC during Harrowing

The influence of forward speed of the fuel consumption (FC) by tractor is shown in Figure 2. The influence of tractor forward speed (1.39, 1.94 and 2.50 m/s respectively) as it influences fuel consumption during harrowing operation is exemplified in Figure 2. The linear regression equations at various harrowing depths (10, 13 and 16 cm respectively) give the relationships as represented in equations (5), (6) and (6) as:

$$FC = 4.00 \times 10^{-7} V + 2.00 \times 10^{-6} \quad \text{(5) (10 cm depth)}$$

$$FC = 8.00 \times 10^{-6} V + 2.00 \times 10^{-6} \quad \text{(6) (13 cm depth)}$$

$$FC = 1.00 \times 10^{-6} V + 2.00 \times 10^{-6} \quad \text{(7) (16 cm depth)}$$

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Where:
FC = Fuel consumption ($m^3$/s); and
V = Forward speed, (m/s)

The resulted coefficient of determination $R^2$ = 0.9938, 0.9952 and 0.9454 respectively at the three speeds used in this study. The ANOVA result (Table 2) for the influence of forward speed on the FC during harrowing operation indicated that there were highly significant different at 0.05 significance (95 % confidence) levels as the forward speed increased (86 %) from 1.39 to 2.50 m/s which resulted to rise in FC to 14.08, 24.86 and 23.84 % respectively at the three used depths. Furthermore, the DMRT results showed that at the forward speed of 2.5m/s was the most significant from other treatment and least significant at forward speed of 1.39m/s treatment means at 0.05 significance differences. These findings are in perfect correlation with Adewoyi and Ajav [22], Shafaei et al. [23], Almaliki et al. [31], Ahaneku et al. [32], Balami et al. [36].

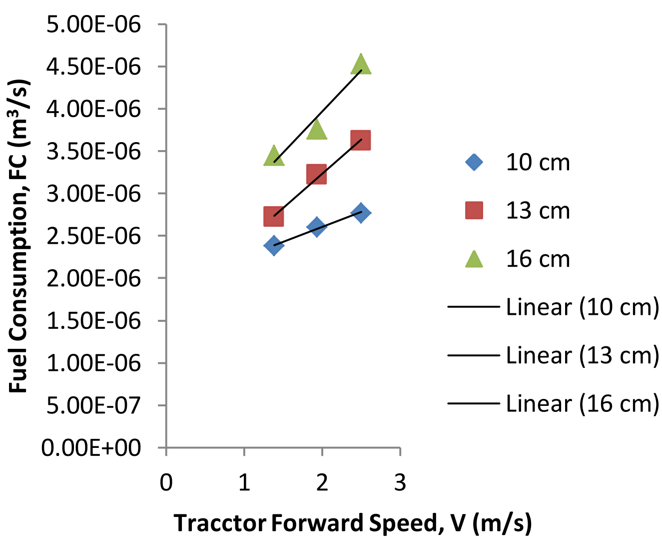


**Figure 2: Influence of Harrowing Speed, V (m/s) on FC ($m^3$/s)**

### 3.3 Influence of Harrowing Depth on FC during Harrowing

The influence of harrowing depth on the fuel consumption (FC) by tractor is shown in Figure 3. Figure 3 showed the effect of harrowing depth (10, 13 and 16 cm) on FC during harrowing operation. The linear regression equations at various forward speeds (1.39, 1.94 and 2.50 m/s respectively) give the relationships as represented in equations (8), (9) and (10) as:

$FC = 5.00 \times 10^{-6} d + 2.00 \times 10^{-6}$ (8) (1.39 m/s speed)
$FC = 6.00 \times 10^{-6} d + 2.00 \times 10^{-6}$ (9) (1.94 m/s speed)
$FC = 9.00 \times 10^{-6} d + 2.00 \times 10^{-6}$ (10) (2.50 m/s speed)
Where,
FC = Fuel consumption, $m^3$/s, and
d = harrowing depth, m.

The resulted coefficients of determinations $R^2$ = 0.9976, 0.9984 and 0.9996 respectively at the three depths used in this study. The ANOVA result (Table 2) for the influence of harrowing depth on the FC during harrowing operation indicated that there were highly significant different at 0.05 significance (95 % confidence) levels as the harrowing depth percentage increase (60 %) from 10 to 16 cm led to notable change in the FC of 31.01, 30.85 and 40.40 % respectively at the three respective depths of study. The results of the DMRT showed that at the tillage depth of 16cm was the most significant from other treatment and least significant at tillage depth of 10cm treatment means at 0.05 significance differences. This agrees with the findings of Gulsoylu et al. [11], Moitzi et al. [18], Fathollahzadel et al. [21], Adewoyin and Ajav [22], Shafaei et al. [23].

### 3.4 Combined Influences of Tractor Forward Speed and Depth on FC during Harrowing Operation

Figure 4 shows the combined influences of tractor forward speed and harrowing depth on fuel consumption during harrowing Operation. The interaction influences of forward speeds and depths on FC are shown in Figure 4. An exact examination of the figure shows that forward speed increased (86 %) from 1.39 to 2.50 m/s along with harrowing depth variations (60 %) from the lowest (10 m) to the highest depth (16 cm) 47.46 % FC change. The ANOVA result (table) for the combined influences of speed and depth on the FC during harrowing operation indicated that there were highly significant different at 0.05 significant (95 and 99 % confidence) levels and a coefficient variation (CV) of 0.42 % indicated that the experimental error was negligible and reliable. In addition, the results of DMRT showed that at the combined forward speed of 2.5m/s with 16cm was the most significant from other treatment and least significant at the combined forward speed of 1.39 and tillage depth of 10cm treatment means at 0.05 significance differences. This agrees with the findings of Adewoyin and Ajav [22], Shafaei et al. [23].

## 4 CONCLUSION

This study was on the assessment of the effects of tractor forward speeds and depths of cut on tractor fuel consumption during harrowing. It was found that the increse in tractor forward speed and harrowing during harrowing operation increased the fuel consumption in which more were recorded in harrowing depths. In addition, the same observation was applicable in the case of combined effects of harrowing speeds and depths; It is therefore, recommended that harrowing depth should depend on the depth of crop root to be cultivated, this can minimise fuel consumption.

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