Journal of Newviews in Engineering and Technology (JNET)
Vol 2, Issue 2, June, 2020
Available online at http://www.rsujnet.org/index.php/publications/2020-edition

Evaluation of the Effects of Tractor Forward Speed and Tillage Depth on Fuel Consumption during Ploughing Operation

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ABSTRACT:

Fuel as the major sources of energy in the life of every power unit plays energetic role in all farm operations requiring tractor application. Field tests were conducted to compare the dependency of fuel consumption on speed and depth of plough during ploughing operation. An experimental field of 160m by 32.5m (5200m^2) area was cleared and divided into three blocks of nine sub-blocks. Each of the blocks was marked out in 5m by 50m for different treatments. Alleys to the plot of dimensions of 2m by 50m were provided. The equipment and tractor used for the tillage operations were disc plough and Swaraj 978FE. Properties such as moisture content, bulk density, tractor forward speed, depth and width of cut, time and amount of fuel used during ploughing operation were measured and employed in fuel consumption evaluation. Fuel consumption was estimated by quantity of fuel consumed per time taken to complete each treatment. The experimental data obtained were analysed statistically using analysis of variance (ANOVA), and Coefficient of variation (CV). From the results, the fuel consumptions for the combined forward speeds and depths of 10cm and 1.39m/s; 10cm and 1.94m/s; 10cm and 2.50m/s; 20cm and 1.39m/s; 30cm and 1.94m/s; 20cm and 2.50m/s; 30cm and 1.39m/s; 30cm and 1.94m/s; 30cm and 2.50m/s, were 2.08E-06 m^3/s, 2.33E-06 m^3/s, 2.50E-06 m^3/s, 3.41E-06 m^3/s, 3.33E-06 m^3/s, 4.76E-06 m^3/s, 3.75E-06 m^3/s, 4.78E-06 m^3/s, and 5.83E-06m^3/s respectively. Also, coefficient of determination R^2 of 0.9869; 0.9858 and 0.9975 for speeds of 1.39, 1.94 and 2.50 m/s respectively and as well, tillage depth coefficient of determination R^2 = 0.8913; 0.9852 and 0.9292 for depth of 10, 20 and 30 cm. ANOVA showed significant differences with 99 and 95 confidence levels on effect of forward speeds, tillage depths and their combined effects. Also, CV of 0.37 % confirmed that experimental error was low and reliable. Hence, it is recommended that the tractor forward speed and crop roots' depth should be the determining factors to minimize cost on fuel consumption.

KEYWORDS: Energy Use; Farm Power and Machinery; Farm Mechanization; Tillage; Fuel Consumption; Ploughing.

Cite This Article: Nkakini, S. O. and 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

1. INTRODUCTION:

Ploughing is a primary tillage operation aimed at opening of compact soil with implements. Disc plough is useful and widely engaged in primary tillage of virgin, stony and wet soils, as well as cutting through crop residues and rolling over the roots (Boydas & Turgut, 2007). Abrougui *et al*. (2013) and Chehaibi *et al*. (2013), as cited in Abrougui *et al*. (2014), stated that moldboard plough creates a desirable tillage, controls weeds, and buries fertilizers and residues of the previous crops. They observed that a well tilled soil allows plants to receive more nutrients and water reserves stimulating their development and subsequently higher yields of fresh material. The depth of ploughing depends on the root of the crop to be cultivated, characteristics of the soil and the available source of power (Pandey, 2004).

Al-Suhaibani and Ghaly (2013) compared the kinetic parameters of three chisel ploughs operating at different depths and forward speeds in a sandy soil and recommended that ploughing depth should be anchored on the crop type (root depth system) and shallow placement of seed (less than 25 mm) is suggested for most crops that are sown directly. Alternatively, they reported that the depth of the roots of the crop to be raised determines ploughing depth, while the speed needed to complete the work on time is determined by the availability of time as well as implement width. Therefore, the ploughing depth ought to be determined from the root length of the crop (Pandey, 2004; Al-Suhaibani & Ghaly, 2010; Adewoyin & Ajav, 2013; Al-Suhaibani & Ghaly, 2013).

Ahaneku and Ogunjirin (2005) reported that the substantial changes in soil physical conditions result from difference in the tractor forward speed. They recommended that the tractor forward speed of approximately 7km/h for a sandy loam soil was considerable for amendment of soil structure used for the enhancements in the soil strength properties and maximum reduction in clod mean weight diameter when using mouldboard plough. Ismail *et al*. (2009) found that 47.81kW of tractor was suitable at all plough width and at different forward speeds. Ahaneku and Ogunjirin (2005), and Nkakini (2015) specified 1.94m/s (7km/h) as the best forward speed for ploughing in a loamy sand soil. Also, Olatunji (2011) revealed that increased soil moisture content, draught for disc plough and a higher tool speed cause an increase in the depth of cut. Ranjbarian *et al*. (2015) concluded that increase in forward velocity results in an increase in draught requirement, wheel slippage, drawbar power, and overall energy efficiency, but results in a decrease in traction efficiency of the tractor and fuel consumption.

Fuel is the sources of energy for every farm mechanized operation. It plays a major role in every tractor's life. It has been reported by Ikpo and Ifem (2005) that fuel consumption rates increase linearly with time and area covered for each of tillage operations (ploughing, harrowing and ridging). According to Sarkar *et al*. (2016), the application of appropriate tillage pattern during tillage operation reduces fuel consumption and tilling time. Thus, they concluded that lesser fuel consumption and time were required for traditional tillage pattern compared to circuitous and straight alternation patterns that would reduce the cost of production.

According to Olatunji and Davis (2009), soil moisture content texture, bulk density, and shear strength contribute to energy requirement during tillage operations. Also, some parameters in tillage operation affecting fuel consumption of tractors were type and structure of soil, climate, tractor type, tractor size, and tractor-implement relationship (Fathollahzadeh *et al*., 2010; Adewoyin & Ajav, 2013). Similarly, in the literature, factors that fundamentally affect fuel consumption by tillage equipment use is the increment in power used by increasing the speed, width of cut, soil strength, moisture content and the depth of cut (Cortez *et al*., 2008; Kichler *et al*., 2011; Silveira *et al*., 2013; Moitzi *et al*., 2014; Leghari *et al*., 2016; Nasr, 2016). But the depth and forward speed have more influence on tractor's fuel consumption (Fathollahzadeh *et al*., 2009, 2010; Gulsoylu et al., 2012; Adewoyin & Ajav, 2013; Moitzi *et al*., 2014; Shafaei *et al*., 2018).

Study by Moitzi *et al*. (2014) recommended that the right proficient technique of saving fuel is by choosing an appropriate driving strategy, which indicates operation close to the optimal engine operating point. Fuel consumption during primary and secondary tillage operations can be reduced by minimizing the width of cut (Taiwo, 2015). Serrano *et al*. (2005; 2008) demonstrated that the selection of an engine speed of 70-80% of the nominal speed, and using a higher gear ("shift-up throttle-down" concept) can reduce fuel consumption in tillage operations. Correia *et al*. (2015) reported that the desirable outcomes to reduce operational costs is by selection of 220 rad s^{-1} (2100 rpm) rotation and 3.65km/h that enables fuel economy and higher worked area per unit time.

The use of digital and manual appliance to measure fuel consumption has been adopted by several researchers such as Karparvarfard and Rahmanian-Koushkaki (2015), Almaliki *et al*. (2016a; 2016b), and Shafaei *et al*. (2018). The method of topping up the tank (direct method) by using graduated cylinder has been adopted by several researchers such as Ahaneku *et al*. (2011), Adewoyin and Ajav (2013), Shah *et al*. (2016), Nkakini *et al*. (2019a, 2019b), and Igoni *et al*. (2019).

Therefore, there is shortage of information on the effects of tractor forward speed and depth of tillage on tractor fuel consumption in the course of ploughing operation in loamy-sand soil in Rivers State. The aim of the current study was to evaluate the effects of tractor forward speed and tillage depth on tractor's fuel consumption.

2. MATERIALS AND METHODS:

2.1 Experimental Site

The map of the experimental area is shown in figure 1. This experiment was carried out on July 30th, 2018 at the Rivers State Agricultural Development Programme (ADP) farm at School

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to Land Authority, Port Harcourt, Nigeria (4° 49′ 27″ N, and longitude of 7° 2′ 1″ E). The experimental design used was randomized complete block design (RCBD). A farm size of 160 m by 32.5m (5200 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 in between. The sub-plot was provided for different treatment options and with a space of 4 m between each block and 1 m at the sides of the outer blocks.

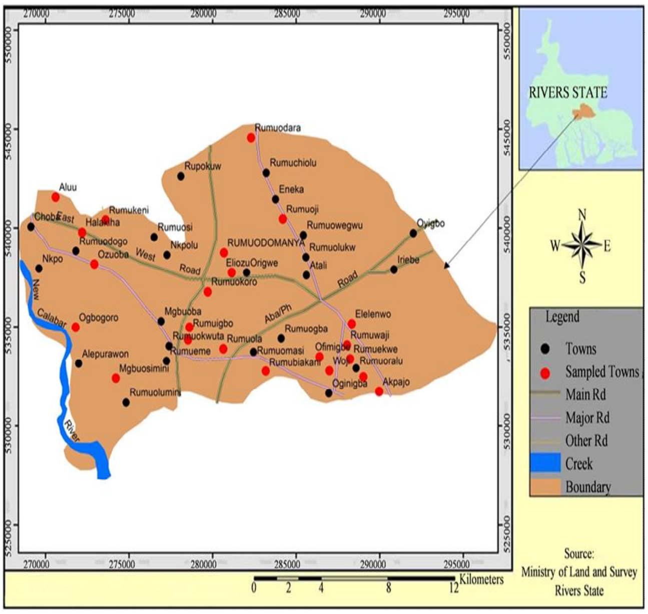

Figure 1: Map of Obio Akpo Local Government Area, Rivers State, Nigeria. Source: Rivers State Ministry of Land and Survey

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 and engine horsepower of 72 hp. Front and the rear tyres were 7.5–16, 8 ply and 16.9 – 28, 12 radial respectively. A 1180mm wide mounted-type disc plough with disc diameter of 660 mm of disc plough (Swaraj, India) with three-disc bottom mounted on a gauge wheel was used for the experiments (Plate 2)

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

Plate 2: The Disc Plough (Swaraj, India) used in this Study

2.3 Experimental Procedure

Prior to ploughing operations, soil auger was used for obtaining the soil sample from the depth of 0 - 30 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 excavation method prior to tillage operation (Al-Shammary *et al*., 2018).

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

The topping up the tank method of determining the quantity of fuel used was adopted to determine tractor fuel consumption. Prior to each operation, the tractor fuel tank was filled to the brim for test performance. The volume of fuel used was measured using a 1000ml graduated cylinder to top up the fuel level in the tank after each operation and observing the amount of fuel consumed per time taken for the operation. Mathematically, fuel consumption was deduced by expression in Equation (1):

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

Where:

FC = fuel consumption (m^3/s), V_{fc} = volume of fuel used (m^3), and T = Total time taken (s).

2.4 Statistical Analysis

Analysis of variance (two ways 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 (Equations 2 - 18) (Gomez & Gomez, 1983):

$$\text{Replication degree of freedom (df)} = r - 1 \quad (2)$$

$$Treatment\ degree\ of\ freedom\ (df) = ab - 1 \quad (3)$$

$$Depth\ (d)\ degree\ of\ freedom(df) = a - 1 \quad (4)$$

$$Speed\ (V)\ degree\ of\ freedom(df) = a - 1 \quad (5)$$

$$d\ x\ V\ degree\ of\ freedom\ (df) = (a - 1)\ (a - 1) \quad (6)$$

$$Error\ degree\ of\ freedom\ (df) = (r - 1)\ (ab - 1) \quad (7)$$

$$Total\ degree\ of\ freedom\ (df) = rab - 1 \quad (8)$$

Compute Sum of Square (SS)

$$C.F = \frac{G^2}{rab} \quad (9)$$

$$Total\ SS = \sum X^2 - C.F \quad (10)$$

$$Replication\ SS = \frac{\sum R^2}{ab} - C.F \quad (11)$$

$$Treatment\ SS = \frac{\sum T^2}{r} - C.F \quad (12)$$

$$Error\ SS = Total\ SS - Replication\ SS - Treatment\ SS \quad (13)$$

Compute the three factorial components of treatment sum of square (SS) as

$$R\ SS = \frac{\sum d^2}{rb} - C.F \quad (14)$$

$$VSS = \frac{\sum V^2}{ra} - C.F \quad (15)$$

$$d \times V\ SS = Treatment\ SS - dSS - VSS \quad (16)$$

Compute the mean square (MS) for each source of variation dividing by its df as:

$$dMS = \frac{dSS}{a-1} \quad (17)$$

$$VMS = \frac{VSS}{b-1} \quad (18)$$

$$d \times VMS = \frac{d \times VSS}{(a-1)(b-1)} \quad (19)$$

$$Error\ MS = \frac{ESS}{(r-1)(ab-1)} \quad (20)$$

Compute the F value for each of the three factorial components as:

$$F(d) = \frac{RMS}{Error\ MS} \quad (21)$$

$$F(V) = \frac{VMS}{Error\ MS} \quad (22)$$

$$F(d \times VMS) = \frac{d \times VMS}{Error\ MS} \quad (23)$$

Where:

a = Basic value number of levels of factor d (depth),

b = Number of levels of factor V (speed),

r = Number of replications ,

R = Replication total,

X = Treatment

d = depth,

V= speed

Also, Coefficient of Variation (CV) was computed using Equation (2):

$$CV = \frac{\sqrt{Error\ MS}}{Grand\ mean} \times 100 \quad (19)$$

Grand Mean was determined using Equation (20) (Gomez & Gomez, 1983):

$$Grand\ mean = Summation\ of\ treatment\ mean \quad (20)$$

$$Treatment\ mean = \frac{Treatment\ total}{Number\ of\ samples} \quad (21)$$

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 (Figure 2).

Figure 2: USDA Soil Texture Triangle

Field test parameters including tractor forward speed (V), tillage 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 fuel consumption. Therefore, fuel consumption is affected by tractor forward speed, tillage depth, width of cut and moisture content.

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Table 1: Variation of studied properties with tillage depth and tractor forward speed during ploughing operation in a loamy-sand soil

Studied Property	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)	2.08E-06	2.33E-06	2.50E-06	3.41E-06	3.33E-06	4.76E-06	3.75E-06	4.87E-06	5.83E-6
W (m)	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
MC (%)	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50	17.50
ρ_b (g/cm^3)	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83

Tractor forward speed, V_1 = 1.39 m/s; Tractor forward speed, V_2 = 1.94 m/s; Tractor forward speed, V_3 = 2.50 m/s for all operations. Tillage depth, d_1, = 10 cm; Tillage depth, d_2 = 20 cm; Tillage depth, d_3 = 30 cm, FC = Fuel consumption W = Width of operation; MC = Moisture content; and ρ_b = Bulk density.

Table 2: Analysis of Variance of Data for 3 X 3 Factorial Experiments 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	1.4E-15	7E-16	4.148148^{ns}	6.23	3.63
Treatment	8	4.36315E-11	5.453938E-12	32319.63**	3.89	2.59
Depth, d	2	2.84474E-11	1.42237E-11	84288.59**	6.23	3.63
Speed, V	2	1.17734E-11	5.8867E-12	34884.15**	6.23	3.63
d x V	4	3.4107E-12	8.52675E-13	5052.29**	4.77	3.01
Error	8	2.7E-15	1.6875E-16			
Total	26	4.36356E-11				

*Significant, **Highly Significant, ^{ns} No significant, CV= 0.37%

3.2 Effect of Tractor Forward Speed on Fuel Consumption during Ploughing

Figure 3 shows the effect of tractor forward speed on fuel consumption during ploughing operation. It can be observed that at different depths fuel consumption increased with forward speed of the tractor during ploughing operation. It can be observed that at different depths fuel consumption increased with forward speed of the tractor during ploughing operation. Figure 3 also shows a linear relationship between fuel consumption and tractor forward speed. This relationship is shown by the linear regression equations at varying tillage depths of 10, 20 and 30cm (Figure 3).

The ANOVA result (Table 2) for the effect of forward speed on the fuel consumption during ploughing operation indicated that there were highly significant different at 0.01 and 0.05 significance (99 and 95% confidence) levels as the tractor forward speed increased from 1.39 to 2.50 m/s, the fuel consumption rise of 16.80, 28.36 and 35.68 % at the three depths adopted in this research. This is supported by the outcomes of Ahaneku *et al.* (2011), Adewoyi and Ajav (2013), Balami *et al.* (2015), Almaliki *et al.* (2016a), and Shafaei *et al.* (2018).

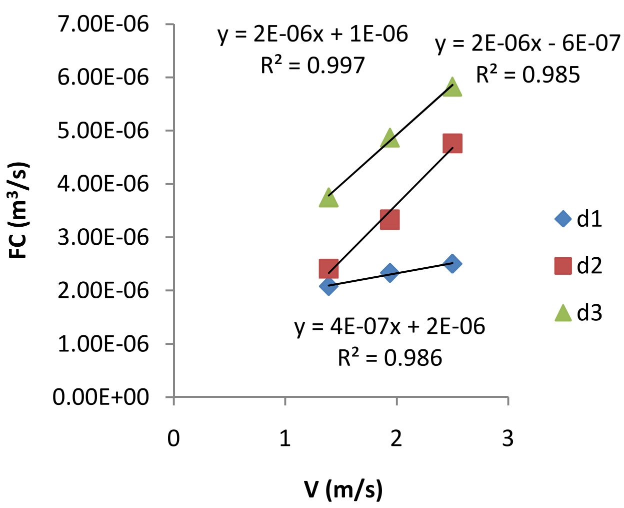

Figure 3: Effect of Forward Speed (m/s) on Fuel Consumption (m^3/s) during Ploughing at Stated Depths

3.3 Effect of Tillage Depth on Fuel Consumption during Ploughing

Figure 4 shows the effect of tillage depth of 10, 20 and 30 cm on fuel consumption during ploughing operation. It can be observed that at different forward speeds fuel consumption increased with depth of the tillage during ploughing operation. The relationship between the fuel consumption and depth is given by linear regression equation at different forward speeds of 1.39, 1.94 and 2.50m/s (Figure 3).

The ANOVA result (Table 2) for the effect of depth on the fuel consumption during ploughing operation indicated that there were highly significant different at 0.01 and 0.05 significance (99 and 95% confidence) levels as the tillage depths increased from 10 to 30cm, the fuel consumption rise of 44.53, 52.16 and 57.12% at the three forward speeds adopted in this research. This agrees with the outcomes of Fathollahzadel *et al.* (2009, 2010), Gulsoylu *et al.* (2012), Adewoyin and Ajav (2013), Moitzi *et al.* (2014), and Shafaei *et al.* (2018).

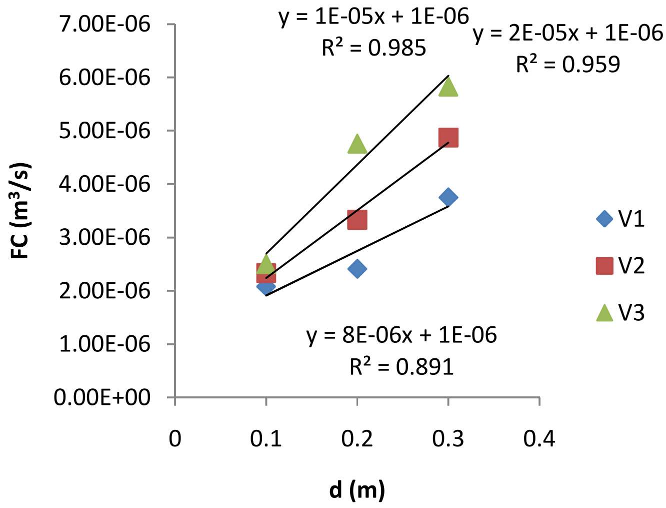

Figure 4: Effect of Tillage Depth (cm) on Fuel Consumption (m^3/s) during Ploughing at Stated Forward Speeds

3.4 Combined effects of Tractor Forward Speed and Depth on FC during Ploughing

The tractor forward speed and tillage depth interaction effects on fuel consumption are shown in Figure 5. It can be observed that tractor forward speed increased from 1.39 to 2.50m/s alongside with variations in tillage depth from the 10 cm to 30cm. The variation in the combination of forward speed and tillage steered 64% change in fuel consumption during ploughing. The result of the ANOVA (Table 2) for the combined effects of tractor forward speed and tillage depth on the fuel consumption in the course of ploughing operation showed that there were highly significant different at 0.01 and 0.05 significance (99 and 95% confidence) levels as the tillage depths increased from 10cm to 30cm and a CV of 0.37 % indicated the negligibility and reliability of the experimental error. This agrees with the outcomes of Adewoyin and Ajav (2013), and Shafaei *et al.* (2018).

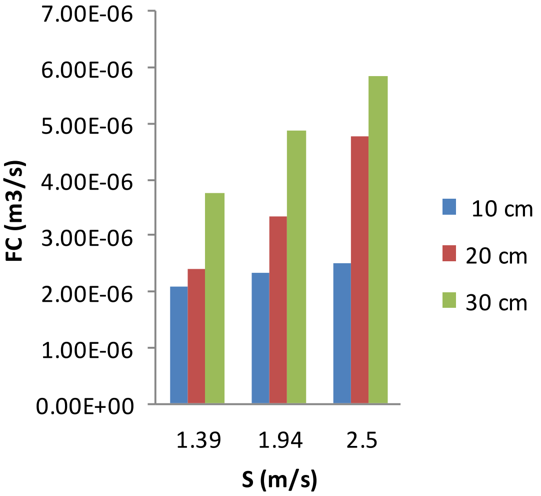

Figure 5: Combined Effects of Forward Speed (m/s) and Tillage Depth (m) on Fuel Consumption (m^3/s)

4. CONCLUSION:

Evaluation of the effects of tractor forward speed and depth of tillage on tractor fuel consumption in the course of ploughing operation have been studied. The findings led to the following conclusions:

(i) The incresae in tractor forward speed during ploughing operation increased fuel consumption;
(ii) Similarly, increase in tillage depth in the course of ploughing operation increases fuel consumption more than the forward speed;
(iii) Moreover, the combined effects of forward speed and tillage depth increase fuel consumption.

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