EVALUATION OF THE SPECIIC VOLUMETRIC FUEL CONSUMPTION OF A TRACTOR DURING HARROWING PROCESS ON DIFFERENT SOIL TYPE

BY

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PLAGIARISM

This work **EVALUATION OF TRACTOR SPECIFIC VOLUMETRIC FUEL CONSUMPTION DURING HARROW OPERATION ON DIFFERENT SOILS** by ILABOYA, Excel Olohitare with Mat Number ENG2001989 of the Department of Agricultural Engineering, Faculty of Engineering, University of Benin, Edo State, Nigeria, has PASSED the PLAIGIARISM TEST.

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DEDICATION

I dedicate this work to God Almighty for giving me the strength and courage to finish this project

ACKNOWLEDGMENT

First and foremost, I thank God Almighty for His guidance, strength, and protection throughout the completion of this project. Without His blessings, this work would not have been possible.

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ABSTRACT

Efficient fuel utilization is a major concern in mechanized agriculture, especially during soil tillage operations such as harrowing. Fuel costs account for a significant proportion of farm operation expenses, and optimizing tractor fuel consumption has direct implications on profitability and sustainability. This study investigated the variability of specific volumetric fuel consumption (SVFC) during harrowing in loamy sand and clay loam soils. Field experiments were conducted at varying depths (10 cm, 13 cm, and 16 cm) and speeds (4 km/h, 6 km/h, and 8 km/h). Parameters such as soil bulk density, cone index, draught force, power output, and moisture content were measured to establish their influence on SVFC. Results revealed that soil type, depth of operation, and tractor forward speed significantly affected SVFC, with loamy sand soils exhibiting lower draught resistance but higher fuel consumption variability compared to clay loam soils. Statistical analyses including ANOVA and paired t-tests confirmed that SVFC differences between soil types were significant ($p < 0.05$). The findings highlight the importance of specific soil management strategies for improving tractor fuel efficiency. This study provides useful insights for farmers, engineers, and policymakers seeking to optimize energy use in agricultural mechanization, reduce production costs, and enhance sustainable food production.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Agricultural modernization plays a critical role in increasing its productivity and efficiency in food production systems worldwide. Among the most important tillage operations is harrowing, which helps in seedbed preparation, weed control, and soil pulverization for improved crop growth (Kepner, Bainer, & Barger, 2013). However, mechanization is energy-intensive, with tractors and implements consuming a substantial portion of farm operational energy in the form of fossil fuels (Srivastava et al., 2006). Fuel represents one of the most significant recurrent costs in mechanized farming, making fuel efficiency a vital area of study for sustainable agriculture.

Specific volumetric fuel consumption (SVFC) is a performance indicator that measures the volume of fuel spent per unit of power output during field operations (Rijk, 2019). It is influenced by several factors, including soil type, moisture content, bulk density, cone index, depth of cut, and tractor operating speed (Grisso et al., 2014). Inappropriate combinations of these parameters may lead to excessive fuel consumption, reduced field efficiency, and increased production costs.

Soil texture and structure are particularly important, as they directly affect draught force requirements during tillage. Sandy soils often exhibit lower draught resistance but may increase slippage and operational variability, while clay soils are more resistant to penetration, leading to higher fuel consumption (Manuwa & Ademosun, 2007). Understanding the interaction between soil type and tractor operational parameters is therefore crucial for optimizing fuel use.

In Nigeria and other developing countries, where small- and medium-scale farmers face rising fuel prices and limited access to credit, improving tractor fuel efficiency can enhance profitability and food security (Asoegwu & Asoegwu, 2007). This study focuses on evaluating SVFC during harrowing operations in loamy sand and clay loam soils at different depths and speeds to provide insights into energy-efficient mechanization practices.

1.2 Statement of the Problem

The escalating cost of fuel and the environmental implications of excessive fossil fuel consumption pose significant challenges to sustainable agricultural mechanization. Farmers often operate tractors without adequate consideration of soil type, depth of cut, and tractor speed, leading to inefficient fuel utilization and higher production costs. Despite several studies on tillage energy requirements, there is limited empirical data on SVFC variations in different Nigerian soil types. The lack of such localized data hinders effective decision-making in selecting appropriate tillage practices. Thus, there is a need to investigate the relationship between soil texture and SVFC during harrowing operations to guide farmers and engineers in adopting fuel-efficient practices.

1.3 Aim of the Study

The aim of this study is to evaluate the specific volumetric fuel intake of a tractor during harrowing processes in loamy sand and clay loam soils at varying depths and speeds.

1.4 Objectives of the Study

The specific objectives are to:

1. Define the soil physical properties (texture, bulk density, cone index, and moisture content) of the experimental sites.
2. Measure draught force, power output, and fuel consumption during harrowing at different soil depths and tractor speeds.
3. Analyze the variability of SVFC in loamy sand and clay loam soils.
4. Compare SVFC between soil types to identify significant differences in fuel efficiency.
5. Recommend optimal operational practices for improving tractor fuel efficiency in different soil conditions.

1.5 Significance of the Study

This research is momentous for several reasons:

- Farmers will benefit from practical recommendations on how to reduce fuel costs during harrowing operations.
- Engineers and researchers will gain empirical data for developing energy-efficient tillage implements and practices.
- Policymakers will obtain insights useful in formulating guidelines and training programs on sustainable mechanization.
- Academia will have access to localized scientific data on tractor fuel efficiency in Nigerian soils, contributing to the body of knowledge in agricultural mechanization.

1.6 Scope of the Study

This study is restricted to evaluating SVFC during secondary tillage (harrowing) in two soil types: loamy sand and clay loam. The investigation was conducted under field conditions at varying depths (10 cm, 13 cm, and 16 cm) and tractor speeds (4 km/h, 6 km/h, and 8 km/h). Other tillage operations such as plowing and ridging were not considered. Additionally, the study did not account for variations in tractor brands or fuel types, focusing instead on the influence of soil properties and operational parameters on SVFC.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Fuel consumption during tillage is one of the utmost significant cost aspects in agricultural mechanization. Specific volumetric fuel consumption (SVFC) is a key parameter that measures the volume of fuel consumed per unit of power output per hour (Grisso, Roberson, & Pitman, 2010). This indicator helps in assessing tractor performance under different soil and operational conditions. It is affected by soil properties, depth of operation, tractor speed, and implement type (Manuwa & Ademosun, 2007; Nkakini et al., 2019).

2.2 Definition and Measurement of SVFC

SVFC is commonly expressed as liters per kilowatt-hour (L/kWh). According to Grisso et al. (2010), SVFC is expressed as the proportion of fuel consumption rate (L/h) to tractor power output (kW). This normalization allows comparison across tractors and operational conditions. While other fuel indicators such as fuel per hectare (L/ha) are widely used, SVFC is more precise for evaluating engine efficiency (Rijk, 2019).

2.3 Factors Affecting Fuel Consumption

2.3.1 Soil Properties

Soil cone index, bulk density, and moisture content significantly affect draught and fuel requirements. Grisso et al. (2014) found that high cone index soils lead to increased draught, thereby raising fuel use. Similarly, Manuwa and Ademosun (2007) observed that clayey soils consumed more fuel than sandy soils due to higher resistance to penetration.

2.3.2 Depth of Process

Deepness of cut is one of the most influential factors. Nkakini (2019) reported that increasing tillage depth significantly raised fuel consumption rates during ploughing. Serrano, Peça, and Mateus (2007) also confirmed that greater depth increased draught and fuel requirements in disc harrow operations.

2.3.3 Forward Speed

Forward speed has mixed effects. Igoni, Harry, and Tonye (2020) showed that higher speeds increased fuel consumption rates, although optimum speeds minimized SVFC. In contrast, Srivastava, Goering, and Rohrbach (2006) noted that beyond certain limits, increasing speed may lead to higher slippage and fuel wastage.

2.3.4 Implement Type and Geometry

Implement design and geometry influence draught. Serrano et al. (2007) demonstrated that disc harrows required more energy than tine harrows due to higher soil disturbance. Varani, Pagliai, and Pellegrini (2023) also showed that power harrows were particularly demanding on soils with strong structure.

2.4 Modelling Approaches

Nkakini et al. (2019) developed predictive regression models for fuel use during tillage in Nigerian soils, showing strong dependence on cone index, bulk density, and moisture. Serrano et al. (2007) used mechanistic models based on soil-tool interaction. More recently, Al-Sager, Almady, Marey, Al-Hamed, and Aboukarima (2024) applied artificial neural networks (ANN) to predict SVFC, showing that machine learning approaches can outperform traditional regression models.

2.5 Synthesis and Research Gap

Existing studies show that soil properties, speed, and depth significantly affect SVFC. However, few localized studies have compared SVFC specifically for harrowing in Nigerian loamy sand and clay loam soils. Most predictive models rely on generalized data from other regions (Nkakini, 2019; Al-Sager et al., 2024). This gap underscores the need for experimental research under Nigerian conditions to provide practical recommendations for fuel-efficient harrowing.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The experiments were carried out on the field between August, 2025 at the Bayelsa State School-to-Land, Rice Rice Farm, Otuasegha, Ogbia, Bayelsa State, situated at 4° 53′ 23.8′′ N Latitude, 6° 21′ 26.9′′ E Longitude. The texture of the soils is of the class ranged from sandy clay loam, loamy sand and clay loam. Bayelsa State typically receives about 241.52 millimeters (9.51 inches) of rainfall and has 296.16 rainy days (81.14% of the time) yearly. Positioned at an elevation of 3 meters (9.84 feet) above sea level. Bayelsa has a Humid monsoon climate (Classification: Am). The city's yearly temperature is 28.64ºC (83.55ºF) and it is -0.82% lower than Nigeria's averages.

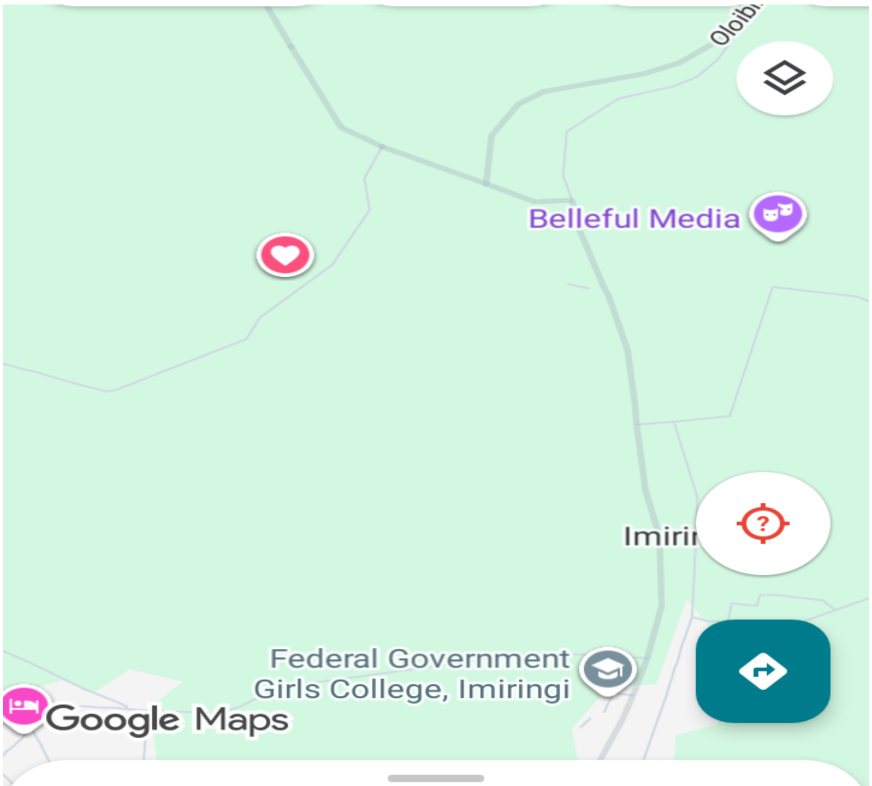

Figure 3.1: Map of Bayelsa State School-to-Land, Rice Rice Farm, Otuasegha, Ogbia, Bayelsa State (Source: Google Map)

3.2 Materials and Equipment

The subsequent resources and equipment were used in the study:

i. Agricultural tractor
ii. Disc plough
iii. Disc harrow
iv. Disc ridger
v. Measuring tape, plastic metre rule, steel tape
vi. Fuel flow meter
vii. Tractor (Swaraj 978 FE)
viii. Stop watch
ix. Hydrometer
x. Soil core drill
xi. Auger
xii. Sample bags

3.2.1 Tractor and Implement Specifications

The tractor qualifications are shown in Table 3.1, equipment specification (disc harrow) in Table 3.2 and technical specification of a fuel flow meter in Table 3.3. Also, their images are displayed in Plates 3.1, 3.2, and 3.3 respectively.

Table 3.1 Tractor Specifications

Property	Description
Model	Swaraj 978 FE
Drive	2-Wheel drive
Engine power capacity(hp)	72 hp
Lifting power	2200 kg
Hitch	3-point CAT III
Front tyres	7.5 - 16 ,8 – ply
Rear tyres	16.9 - 28,12 – ply
Width	2030 mm
Net Weight	3050 kg
Producing company	Swaraj
Country	India

Plate 3.1: Tractor (Swaraj 978 FE)

Table 3.2: Implement Specifications

Property	Harrow
Number of Disc	9
Operating Depth (mm)	150
Frame Span (mm)	1800
Width of Cut (mm)	1500
Disc Diameter (mm)	508
Disc Spacing (mm)	-
Estimated weight (Kg)	207
Tractor Required Power (Hp)	25 – 35
Model	HI
Manufacturer	Baldan Implementos Agricolas
Nation of Production	Brazil

Plate 3.2: Disc Harrow (Baldan Implementos Agricolas, Brazil)

Table 3.3: Fuel Flow Meter Specifications

Property	Description
Model	DFM 100CD
Nominal fuel pressure (MPa)	0.2
Maximum fuel pressure (MPa)	2.5
Minimum kinematic viscosity (mm^2/s)	1.5
Maximum kinetic viscosity (mm^2/s)	6.0
Permeation size in liquid (mm) no more than	0.08
Minimum supply voltage (V)	10
Maximum supply voltage (V)	45
Maximum current consumption (mA) for Unom 12/24 V	50/25
Operating temperature range (ºC)	-40……+85 / -20…….+60
Ingress protection rating (IP Code	54
Manufacturer	Technoton Engineering
Country	Belarus

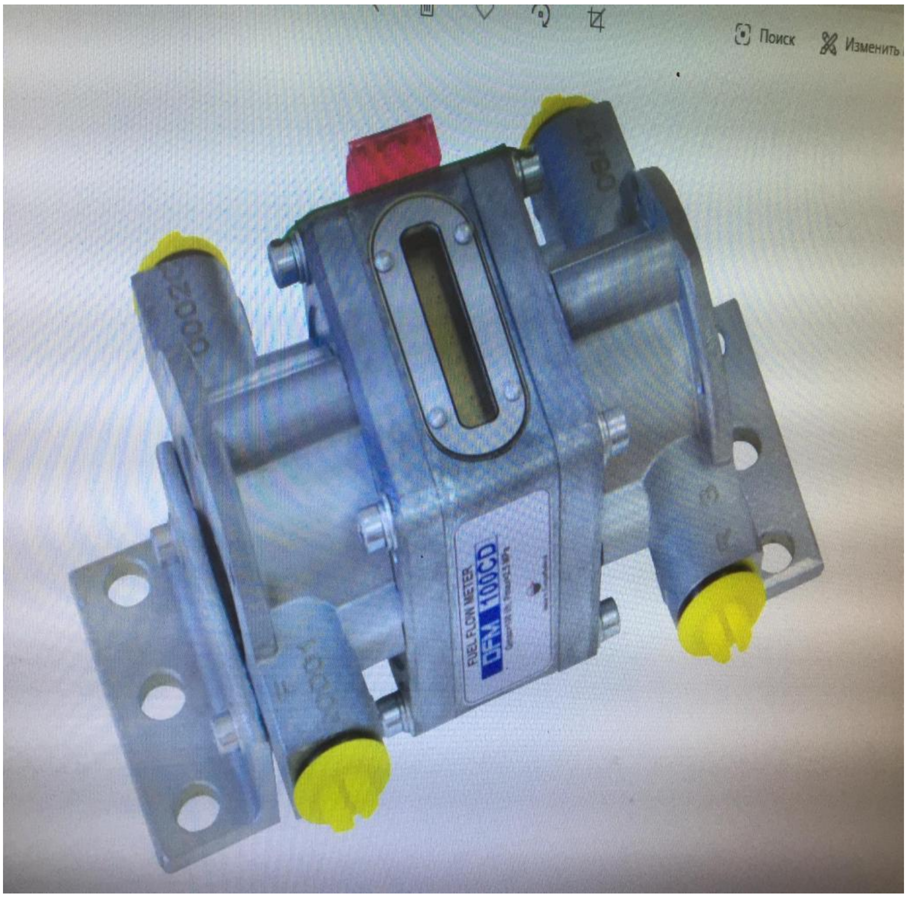

Plate 3.3: DFM 100CD Fuel Flow Meter (Technoton Engineering, Belarus)

3.4 Experimental Design

The experiment was carried out during the peak of raining term in beginning of August, 2025. The tentative design adopted was factorial in randomized complete block design (RCBD) to estimate the effects of tractor forward speed and tillage depth on fuel consumption during tillage procedures (harrowing). The design consisted of 9 experimental treatments with three replicates as shown in figure 3.2. Randomization was carried out using draw lots method. The experimental land area was 160 m by 32.5 m (5200 m^2) which was shared into three blocks of 9 plots each. Each plot, was marked out 50 m by 2.5 m along with 1m wide paths between, was allocated for the different treatment options and a spacing of 4 m was provided between each block, with 1 m at the sides of the of the outer blocks.

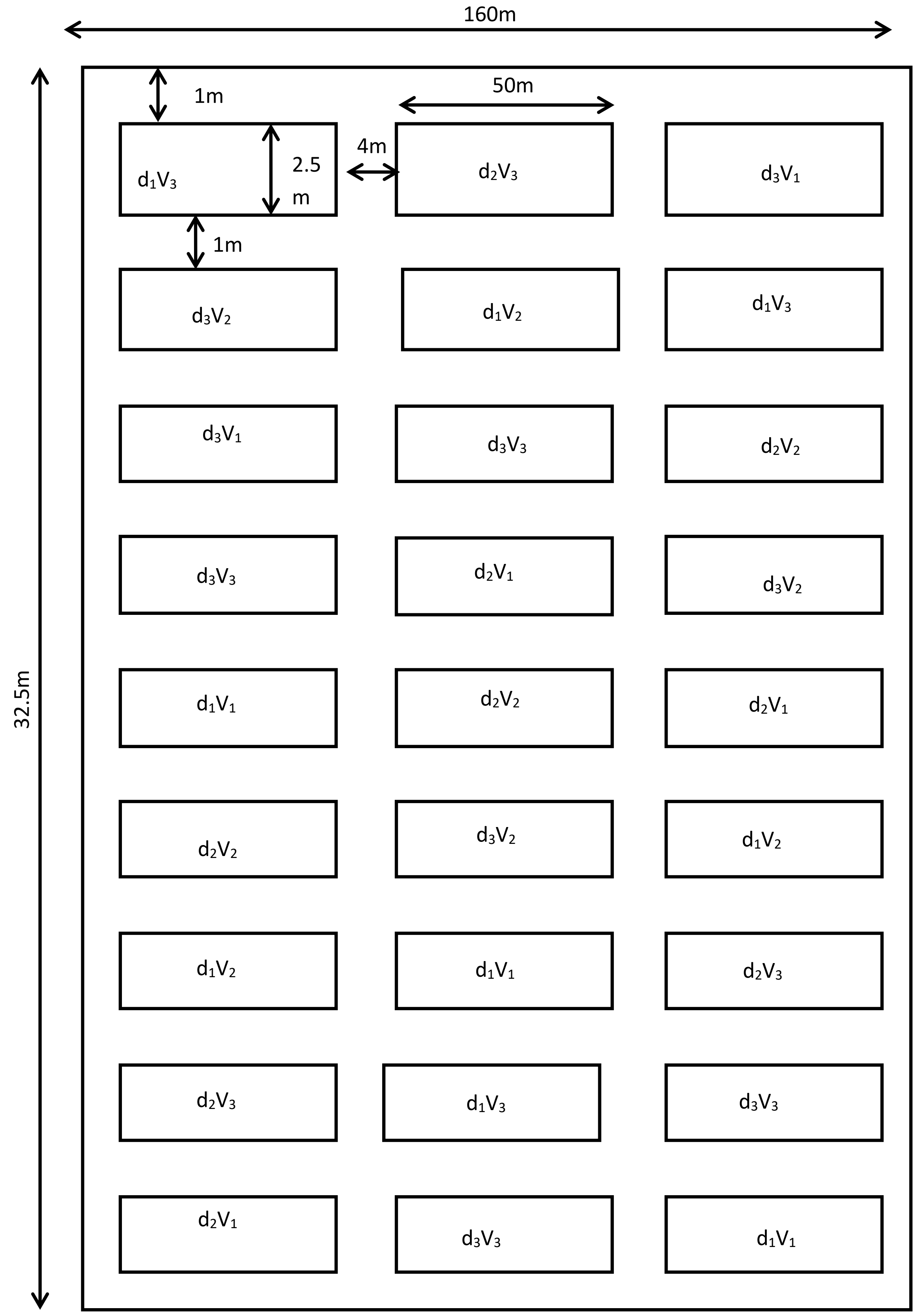

Figure 3.2: Layout of Factorial Randomized Complete Block Design with Nine Treatments and Three Replications (Not Drawn to Scale)

d_1V_1: harrowing with depth of 10 cm at speed of 4km/h^{-1}

d_1V_2: harrowing with depth of 10 cm at speed of 6km/h^{-1}

d_1V_3: harrowing with depth of 10 cm at speed of 8km/h^{-1}

d_2V_1: harrowing with depth of 13 cm at speed of 4km/h^{-1}

d_2V_2: harrowing with depth of 13 cm at speed of 6km/h^{-1}

d_2V_3: harrowing with depth of 13 cm at speed of 8km/h^{-1}

d_3V_1: harrowing with depth of 16 cm at speed of 4km/h^{-1}

d_3V_2: harrowing with depth of 16 cm at speed of 6km/h^{-1}

d_3V_3: harrowing with depth of 16 cm at speed of 8km/h^{-1}

3.4 Experimental Procedure

3.4.1 Soil Sampling

Soil samples were extracted from the study area before any field operations with implements. Soil auger was used to obtain sample at the depth of 0 - 0.30m, randomly across the field, for the determination of soil moisture content and textural classification. The composite soil samples were placed in properly labelled polyethylene bags and transported immediately to the laboratory immediately.

3.4.2 Particle Size Distribution (PSD)

The particle size distribution (PSD) of the soil was determined using the hydrometer method. 102 g of ambient-dried soil was weighed and placed in a 500 ml beaker filled in within 5 cm of the top with distilled water. The baffle was inserted into the suspension and the contents were stirred for 10 minutes. The suspension in the cylinder was made up to 1250 ml mark with the hydrometer. The hydrometer was removed and the top of the cylinder was covered and inverted several times. After about 30 seconds the hydrometer was slowly and carefully placed in and out of the suspension and the temperature of the suspension was recorded. After 2 hours the hydrometer was replaced and a reading was taken and the temperature of the suspension was noted. Hence, the temperature readings were recorded, and percentage of sand, silt and clay were calculated. Finally, the soil textural class was determined using the textural triangle.

3.4.3 Soil Moisture Content

The oven dry method was used to determine the moisture level of the soil prior to tillage process. Soil specimen were collected preceding tillage operation to determine the soil moisture content. The collected soil were collected randomly at depths of 0 – 30 cm soil using auger. 100g of wet soil was weighed and put into an aluminium pan and placed into an oven at 105°c. The soil was reweighed and the solid mass was recorded. The water content was then calculated as expressed below:

$$Moiture\ Content\ = \frac{Mass\ of\ water}{Mass\ of\ dry\ soil} \times 100 \qquad (3.1)$$

$$\frac{MW}{MS} \times 100$$

Where the result is shown as

Weight of container, w_1

Weight of container + wet soil, w_2

Weight of container + dry soil, w_3

Hence, Moisture Content (Mc) $= \frac{W2 - W3}{W3 - W1} \times 100.$ (3.2)

3.4.4 Cone Index

The Cone index (CI), also referred to as soil resistance ,was determined to quantify the soil strength profile. Measurements were taken using a simple device called a cone penetrometer, which has a tip with an included angle of 30°and a base area of 3.23cm^2 (323mm^2) mounted on a shaft of 45.72cm long (457.20mm) (figure 3.2). The Cone index (soil resistance to implement penetration) was recorded at three different depths, 0.10, 0.20, 0.30m respectively before any of the tillage operations were carried out. During the operation, the cone penetrometer was positioned between the operator's two legs.With both hands on the handle it was pushed into the soil until the marked point on the shaft was reached, and the reading was then recorded.

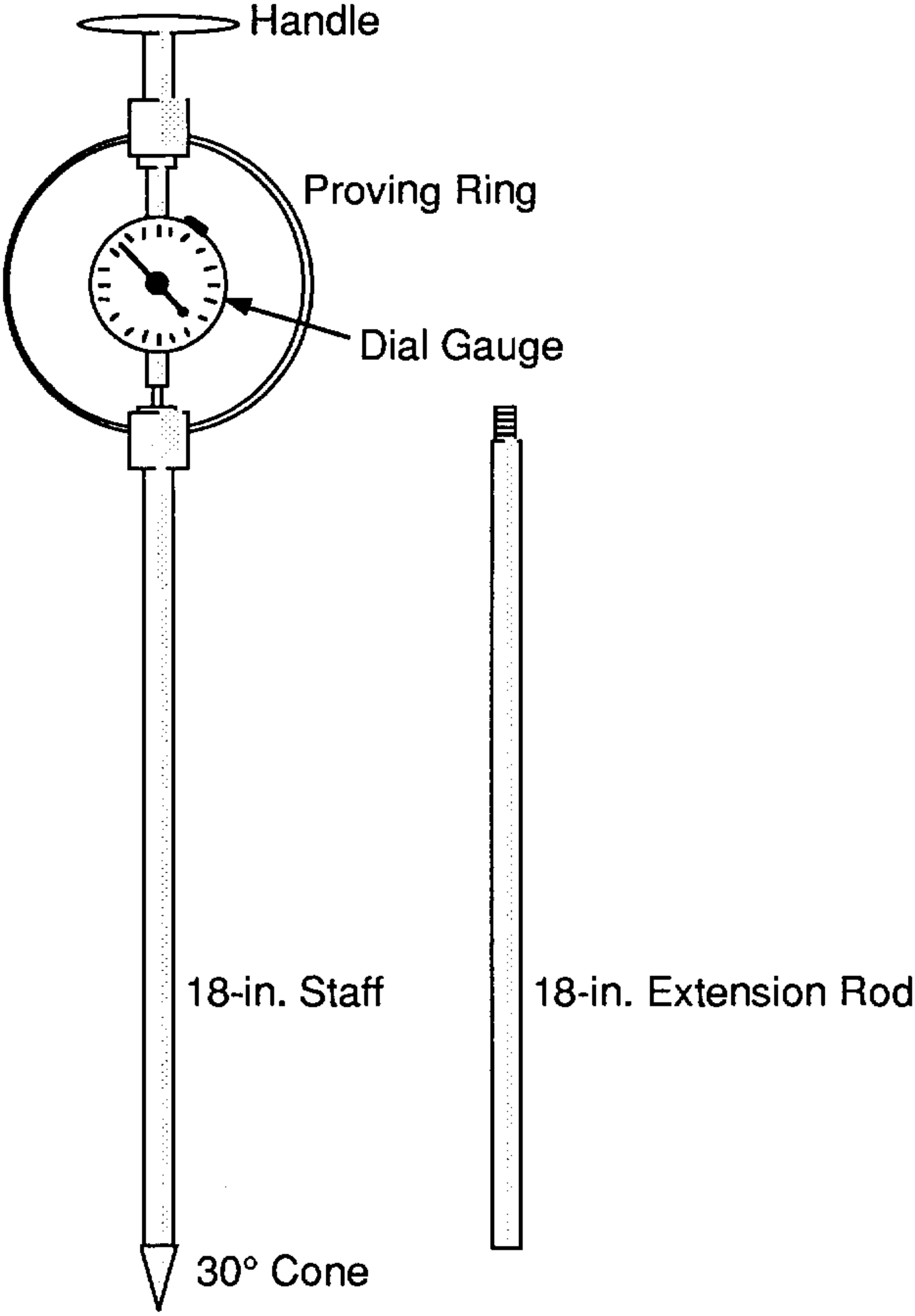

Figure 3.2: Hand-held cone penetrometer (after ASAE 1985)

3.4.5 Width of Cut and Tillage Depth

During ploughing, harrowing and ridging operations, the operating tillage depths were determined by setting the controlling level of the lifting mechanism (three-point linkage height) at specific level to lower the implement's disc corresponding to the desired tillage depth. Operating tillage depths were selected and fixed using the tractor depth controller. The width of cut and tillage depth was measured randomly and the data were collected for analysis. The tillage depth was measured by placing the meter rule from furrow bottom to the surface of the unploughed land, while the width of cut was measured by placing a steel tape from one side of the furrow wall to the other end.

3.4.6 Tillage Speed

Tillage speeds were determined by selecting a particular gear that would give the desired speed. This was done either at full or reduced throttle setting. The tractor was operated at the respective throttle and gear settings to gain the required tractor forward speed at a particular operating tillage depth corresponding to the required parameters at a gear best suited for targeted operational speed of 1.39, 1.94 and 2.50 ms^{-1} respectively.

3.4.7 Time

This was determined with stop watch setting at zero before each operation. The reading was taken at the end of each operation test.

3.4.8 Draught Force

Draught force was determined using the formula represented below (ASAE, 2000a):

$$D = F_i \, [A + B(S) + C(S)^2]WT \tag{3.3}$$

Where;

D = 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)

3.4.9 Determination of Useful Power Output (Drawbar Power)

This will be determined using equation:

$$P = \frac{F \times V}{\eta} \qquad (3.4)$$

Where:

P = Useful power output (kW)

F = Draft force (kN)

V = Tractor speed (m/s)

η = Transmission efficiency (typically 0.75–0.90 for tractors)

3.5 Measurement of Fuel Consumption

3.4.6 Determination of Fuel Consumption

Fuel consumption was determined by digital method (use of fuel DFM flow meter) (Plate 3.5). The metre was mounted on the fuel line between the tractor's fuel tank and the pump (Plate 3.10). At the end of each test operation the data was taken from the fuel flow meter as displayed information switching is performed by light touch to the top cover of fuel flow meter by iButton key (Plate 3.11). Similar method has been adopted by Sumer et al. (2010); Spagnolo et al (2012); Lopez-Vazquez et al. (2019); Ivanov (2019).

Plate 3.10: Mounting of Fuel Flow Meter

3.4.6.1 Determination of Hourly Fuel Consumption

The fuel consumption per working hour was determined mathematically by adopting (3.5) (Shafaei *et al*., 2018):

$$Q = \frac{T_{fc}}{h} \qquad (3.5)$$

Where:

Q = Fuel consumption rate, L/h;

T_{fc} = Tractor fuel consumption, L;

h = Working hour, h.

3.4.6.2 Determination of Specific Volumetric Fuel Consumption

Fuel consumption data will be converted into Specific Volumetric Fuel Consumption (SVFC) using the equation:

$$SVFC = \frac{Q}{P} \qquad (3.6)$$

Where:

SVFC = Specific Volumetric Fuel Consumption (L/kWh)

P = Useful power output (kW)

3.6 Data Collection

The following data will be collected during field operations:

- Volume of fuel consumed per treatment.
- Time taken to complete each operation (to compute work rate).
- Forward speed of the tractor.
- Soil moisture and bulk density at the time of operation.

3.7 Data Analysis

The collected data were subjected to Analysis of Variance (ANOVA) using Microsoft excel. The statistical model test the effects of soil type, implement type, and their interaction on SVFC. Means were compared at a 5% significance level.

Graphical representations such as bar charts were used to illustrate differences in fuel consumption across treatments.

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3.8 Comparison of the SVFC Soil

The paired t Test was used to compare the SVFC data of sandy loam and clay loam soils to determined significant difference at 5% level of significance (95% confidence) levels as given in equation (3.7).

$$t = \frac{\sum D/N}{\sqrt{\frac{\sum D^2 - \left(\frac{(\sum D)^2}{N}\right)}{(N-1)(N)}}} \tag{3.7}$$

Where:

$\sum D$ = summation of the differences.

$\sum D^2$ = summation of the squared differences,

$(\sum D)^2$ = summation of the differences squared.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Soil Textural Class of the Studied Location

The particle size analysis of the two study sites revealed that soils from the loamy sand field contained 80–84% sand, 7–10% silt, and 8–13% clay, classifying them as loamy sand (Table 4.1). In contrast, the clay loam field had about 43% sand, 28% silt, and 29% clay, classifying them as clay loam according to USDA classification.

These results confirm that the experimental sites captured two distinct soil textural classes. The sandy soils exhibited lower cohesion and penetration resistance, whereas the clay loam soils were more compact, exhibiting higher cone index and bulk density values. This difference was expected to significantly affect draught and fuel consumption during harrowing, consistent with earlier findings by Manuwa and Ademosun (2007), who reported that sandy soils typically require less draught but may result in higher slippage, while clayey soils resist penetration more strongly and demand more fuel.

Table 4.1: Soil Textural Class (Particle Size Distribution)

Sample	Depth, d (cm)	Percentage, % by Mass			Textural Class
		Clay	Silt	Sand	
A	0 - 10	9.60	6.80	83.60	Loamy sand
B	11 - 13	8.60	9.80	81.60	Loamy sand
C	14 - 16	12.60	6.80	80.60	Loamy sand
D	0 - 10	29.00	28.00	43.00	Clay loam
E	11 - 13	29.00	28.00	43.00	Clay loam
F	14 - 16	29.00	28.00	43.00	Clay loam

4.2 Variability of Specific Volume Fuel (SVFC) Consumption during Harrowing Operation in Loamy Sand Soil

The results of SVFC obtained in loamy sand soil are presented in Table 4.2. At a 10 cm depth, fuel consumption increased with speed from 2.92 L/h at 4 km/h to 4.19 L/h at 8 km/h, while SVFC decreased from 0.72 L/kWh to 0.44 L/kWh. Similar trends were observed at 13 cm and 16 cm depths, where higher speeds resulted in higher fuel use but lower SVFC values.

This pattern indicates that while fuel consumption rate (L/h) increases with speed due to higher workload, the tractor engine operates more efficiently at higher loads, thereby lowering SVFC. Grisso et al. (2010) explained that optimum tractor performance occurs when the engine operates near its rated load, reducing fuel consumed per unit of power.

The ANOVA results (Table 4.3) showed that both speed and depth had significant effects on SVFC ($p < 0.05$). This implies that operational parameters must be carefully managed to optimize tractor fuel efficiency in sandy soils.

Table 4.2: SVFC Mean Results of Field Test Performed during Harrowing Operation in Loamy Sand Soil

d, cm	V, Km/h	W, m	ρb, g/cm3	CI, N/cm2	D, N	MC, %	D_P, kW	FC, L/h	SVFC, L/kWh
10	4	1.5	1.4	154.04	3661.63	14.36	4.07	2.92	0.72
10	6	1.5	1.4	154.04	3976.13	14.36	6.63	4.09	0.62
10	8	1.5	1.4	154.04	4290.62	14.36	9.53	4.19	0.44
13	4	1.5	1.46	204.82	4760.12	15.19	5.29	4.26	0.81
13	6	1.5	1.46	204.82	5168.97	15.19	8.61	5.96	0.69
13	8	1.5	1.46	204.82	5577.81	15.19	12.40	6.1	0.49
16	4	1.5	1.47	243.89	5858.61	16.91	6.51	6.42	0.99
16	6	1.5	1.47	243.89	6361.81	16.91	10.60	8.97	0.85
16	8	1.5	1.47	243.89	6865.00	16.91	15.26	9.18	0.60

d = depth of cut, V = speed, W = width of cut, ρ_b = bulk density, CI = cone index, D = draught, Dp = Power output, FC = fuel consumption rate, SVFC = specific volume fuel consumption

Table 4.3: Analysis of Variance for SVFC during Harrowing in Loamy Sand Soil

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0758	2	0.0379	47.375	0.001641	6.944272
Columns	0.1674	2	0.0837	104.625	0.000352	6.944272
Error	0.0032	4	0.0008			
Total	0.2464	8				

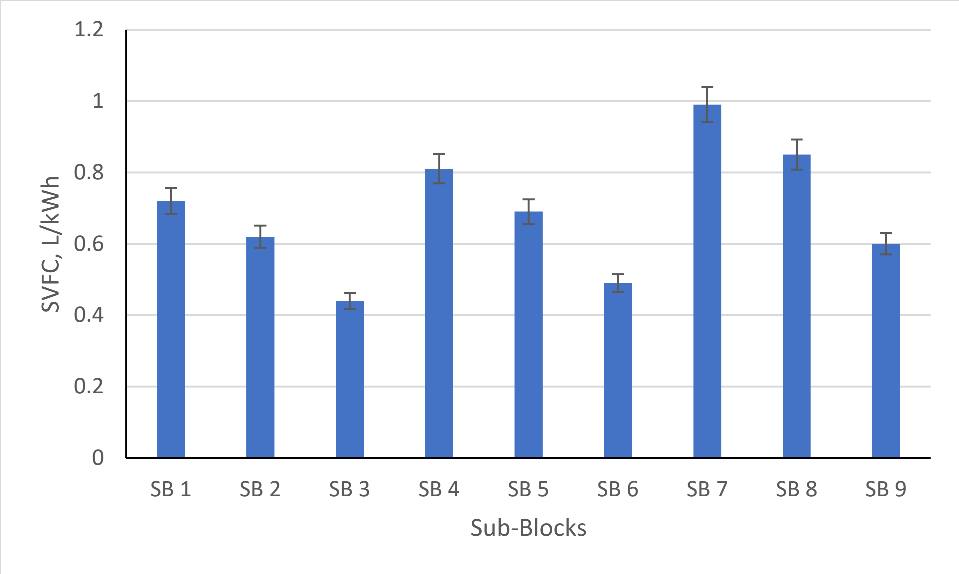

Figure 4.1: Variability of Specific Volume Fuel Consumption during Harrowing in Loamy Sand Soil

4.3 Variability of Specific Volume Fuel (SVFC) Consumption during Harrowing Operation in Clay Loam Soil

Table 4.4 presents the SVFC results for clay loam soil. At a 10 cm depth, fuel consumption increased from 3.08 L/h at 4 km/h to 4.31 L/h at 8 km/h, while SVFC decreased from 0.59 L/kWh to 0.35 L/kWh. Similarly, at 16 cm depth, fuel consumption rose to 9.34 L/h at 8 km/h, while SVFC declined to 0.48 L/kWh.

These results mirror the trend observed in loamy sand soils but with higher absolute draught and fuel values due to the higher resistance of clay loam. Serrano, Peça, and Mateus (2007) also reported that heavier soils demand higher draught forces and consequently more power and fuel. The ANOVA analysis (Table 4.5) confirmed that both depth and speed significantly influenced SVFC in clay loam soil ($p < 0.05$).

Table 4.4: SVFC Mean Results of Field Test Performed during Harrowing Operation in Clay Loam Soil

d, cm	V, Km/h	W, m	ρb, g/cm3	CI, N/cm2	D, N	MC, %	D_P, kW	FC, L/h	SVFC, L/kWh
10	4	1.5	1.3	174.35	4694.4	15.89	5.22	3.08	0.59
10	6	1.5	1.3	174.35	5097.6	15.89	8.50	4.24	0.499
10	8	1.5	1.3	174.35	5500.8	15.89	12.22	4.31	0.35
13	4	1.5	1.33	224.43	6102.72	17.97	6.78	4.41	0.65
13	6	1.5	1.33	224.43	6626.88	17.97	11.04	6.12	0.55
13	8	1.5	1.33	224.43	7151.04	17.97	15.89	6.24	0.39
16	4	1.5	1.38	257.65	7511.04	18.21	8.35	6.58	0.788
16	6	1.5	1.38	257.65	8156.16	18.21	13.59	9.13	0.67
16	8	1.5	1.38	257.65	8801.28	18.21	19.56	9.34	0.48

d = depth of cut, V = speed, W = width of cut, ρ_b = bulk density, CI = cone index, D = draught, Dp = Power output, FC = fuel consumption rate, SVFC = specific volume fuel consumption

Table 4.5: Analysis of Variance for SVFC during Harrowing in Clay Loam Soil

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.043656	2	0.021828	70.38803	0.000763	6.944272
Columns	0.110816	2	0.055408	178.6718	0.000123	6.944272
Error	0.00124	4	0.00031			
Total	0.155713	8				

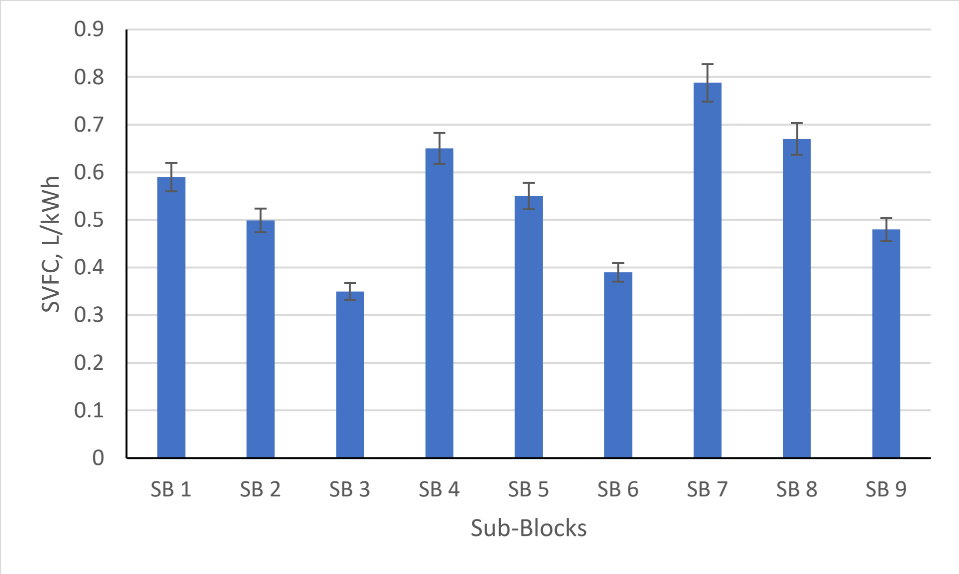

Figure 4.2: Variability of Specific Volume Fuel Consumption during Harrowing in Clay Loam Soil

4.6 Comparison of Variability of Specific Volume Fuel (SVFC) Consumption during Harrowing Operation in Loamy Sand and Clay Loam Soils

A paired t-test was conducted to compare mean SVFC values between the two soil types (Table 4.6). The results showed a significant difference ($t = 11.29$, $p < 0.05$), indicating that soil texture significantly affects fuel efficiency.

Loamy sand soils recorded higher variability in SVFC, ranging between 0.44–0.99 L/kWh, while clay loam soils exhibited lower SVFC variability (0.35–0.79 L/kWh). Although sandy soils had lower draught forces, their higher variability in traction losses led to less consistent fuel efficiency compared to clay loam soils. This agrees with findings by Igoni, Harry, and Tonye (2020), who noted that sandy soils, despite offering low resistance, often increase wheel slip and fuel wastage.

Figure 4.3 further illustrates that SVFC values were consistently lower in clay loam soils across the tested operational parameters. This demonstrates that tractor energy utilization is more stable in heavier soils despite higher draught requirements.

Table 6: Paired t Test for Comparing for SVFC during Harrowing in Loamy Sand and Clay Loam Soils

	Variable 1	*Variable 2*
Mean	0.69	0.551889
Variance	0.0308	0.019464
Observations	9	9
Pearson Correlation	0.998945	
Hypothesized Mean Difference	0	
df	8	
t Stat	11.29091	
P(T<=t) one-tail	1.7E-06	
t Critical one-tail	1.859548	
P(T<=t) two-tail	3.41E-06	
t Critical two-tail	2.306004	

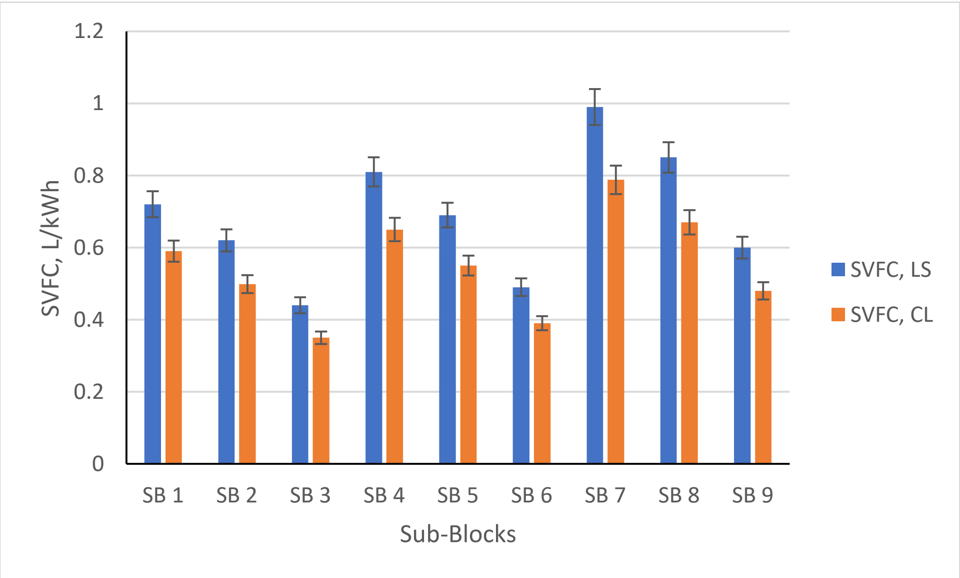

Figure 4.3: Plot of Comparison of Variability of Specific Volume Fuel Consumption during Harrowing in Loamy Sand and Clay Loamy Soils

4.7 Implications for Tractor Fuel Management

The results demonstrate that:

1. **Speed optimization is critical.** Although fuel consumption per hour rises with speed, SVFC decreases, implying improved energy efficiency at higher operating speeds (6–8 km/h). This aligns with the work of Grisso et al. (2014), who highlighted that medium-to-high load operations optimize fuel use per unit power.
2. **Depth of cut strongly influences fuel demand.** Increasing depth significantly raised fuel consumption, confirming the results of Nkakini (2019) that depth is the dominant factor in tillage fuel requirements.
3. **Soil type determines operational variability.** Loamy sand soils, though lighter to till, showed higher SVFC variability, while clay loam soils demonstrated more stable but generally higher fuel demands.

These findings provide practical insights for farmers and extension agents. Specifically, operating at moderate depths (10–13 cm) and higher speeds (6–8 km/h) can minimize SVFC, especially in clay loam soils where traction is more stable.

4.8 Discussion in Relation to Previous Studies

The findings of this study are consistent with earlier research. Manuwa and Ademosun (2007) reported higher draught and fuel use in clay soils, which supports the higher FC observed in clay loam. Similarly, Serrano et al. (2007) confirmed the role of depth and implement geometry in fuel requirements. Al-Sager et al. (2024) further showed that SVFC can be reliably predicted using soil and operational parameters, which this study also confirmed experimentally.

The novelty of this study lies in its localized assessment of SVFC under Nigerian soil conditions. Whereas most predictive models are based on data from Europe and North America (Grisso et al., 2010; Varani, Pagliai, & Pellegrini, 2023), this research provides empirical evidence for loamy sand and clay loam soils typical of West Africa.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study investigated the variability of specific volumetric fuel consumption (SVFC) of a tractor during harrowing operations in loamy sand and clay loam soils under varying depths and speeds. The results clearly demonstrated that soil type, depth of operation, and tractor forward speed significantly influenced SVFC.

In loamy sand soils, lower draught requirements were observed, but SVFC values were highly variable due to increased wheel slippage and traction losses. In clay loam soils, higher draught forces were recorded, leading to higher absolute fuel consumption rates; however, SVFC values were more stable and generally lower than those obtained in loamy sand soils. Statistical analyses confirmed that both operational parameters (speed and depth) and soil texture significantly influenced SVFC ($p < 0.05$).

Overall, the findings show that tractor energy utilization improves at higher operating speeds (6–8 km/h) and moderate depths (10–13 cm), conditions that optimize SVFC. These results underscore the importance of soil-specific and operation-specific management strategies to reduce fuel costs and enhance energy efficiency in mechanized agriculture.

5.2 Recommendations

Based on the findings of this study, the following recommendations are made:

1. **For Farmers:**

- Operate tractors at moderate depths (10–13 cm) for harrowing, as deeper operations significantly increase fuel costs without proportional agronomic benefits.

- Maintain tractor speeds between 6–8 km/h during harrowing to optimize SVFC and reduce fuel consumption per unit of power.
- Avoid unnecessary repeated passes in loamy sand soils to minimize variability in fuel efficiency caused by slippage.

2. **For Extension Agents and Policymakers:**

- Provide training and awareness programs to farmers on fuel-efficient tillage practices tailored to specific soil types.
- Promote mechanization strategies that emphasize fuel conservation as part of sustainable agriculture initiatives.

3. **For Engineers and Researchers:**

- Develop localized predictive models for SVFC using soil and operational parameters, which can be incorporated into decision-support tools for mechanized farming.
- Investigate the use of alternative energy sources (biofuels, hybrid tractors) to further reduce the carbon footprint of mechanized tillage.

5.3 Contributions to Knowledge

This study contributes to the body of knowledge in the following ways:

1. **Localized empirical data**: It provides experimental evidence of SVFC variability in loamy sand and clay loam soils in Nigeria, which has been scarcely reported in literature.
2. **Comparative insights**: The study highlights that although clay loam soils require more draught, they offer more stable and lower SVFC values compared to loamy sand soils.
3. **Operational optimization**: The research identifies optimal depth and speed ranges for minimizing fuel use during harrowing, offering practical guidelines for farmers.

4. **Foundation for predictive models**: The findings can serve as calibration data for advanced models such as artificial neural networks (ANNs) and regression-based fuel prediction systems.

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