EVALUATION OF TRACTOR-SPECIFIC VOLUMETRIC FUEL CONSUMPTION DURING RIDGING OPERATIONS IN DIFFERENT TEXTURES

BY

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CERTIFICATION

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DEDICATION

I dedicate this project to God Almighty for his grace and strength throughout this journey.

To my parents and family whose support, prayer and encouragement gave me the courage to keep going

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My profound gratitude goes to God my maker for the wisdom, knowledge, and good health throughout the course of this project.

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ABSTRACT

Efficient fuel utilization in mechanized farming is a critical factor influencing both production costs and environmental sustainability. This study investigated the variability of tractor specific volumetric fuel consumption (SVFC) during ridging operations in two contrasting soil textures (loamy sand and clay loam). Field experiments were conducted at ridge heights of 10, 20, and 30 cm, and tractor forward speeds of 4, 6, and 8 km/h. Parameters such as bulk density, cone index, draught force, soil moisture content, fuel consumption rate, and power output were measured and analyzed. Results indicated that SVFC significantly varied with both ridge height and forward speed, showing lower values at higher speeds. In loamy sand soil, SVFC ranged from 0.34 to 0.85 L/kWh, while in clay loam, it varied between 0.27 and 0.66 L/kWh. Statistical analysis using ANOVA confirmed that soil texture, ridge height, and speed had significant effects ($p < 0.05$) on SVFC. A paired t-test comparison between the two soil types showed significantly higher fuel consumption in loamy sand than in clay loam under similar operational conditions. These findings suggest that soil texture and ridge geometry play a vital role in determining energy efficiency during mechanized ridging. The study contributes to optimizing tractor operations, reducing fuel costs, and enhancing sustainable mechanized farming practices in varying soil conditions.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Mechanized agriculture has transformed global food production by enhancing efficiency, reducing drudgery, and improving timeliness of field operations (Kepner et al., 2017). Among the most energy-demanding operations in crop cultivation are soil tillage and seedbed preparation, which account for a large portion of tractor fuel consumption (Hunt, 2016). Ridging, a secondary tillage practice, is widely used for crops such as yam, cassava, potatoes, and maize to improve soil aeration, root penetration, drainage, and crop establishment (Naderloo et al., 2009). However, despite its agronomic benefits, ridging is known to be energy-intensive, and fuel cost constitutes a significant share of the total operational expense.

Fuel consumption in agricultural tractors is influenced by several factors including soil type, soil moisture content, bulk density, cone index, ridge height, width of cut, and tractor forward speed (Grisso et al., 2014). Specific volumetric fuel consumption (SVFC), defined as the amount of fuel consumed per unit of energy output, is a critical parameter for evaluating energy efficiency in mechanized farming operations (Rahman & Chen, 2018). Understanding the variability of SVFC across different soil conditions can help farmers minimize costs while ensuring sustainability.

In tropical regions such as Nigeria, soils vary widely in texture from loamy sands to clay loams affecting the draft requirement of tillage implements and thus the tractor's fuel efficiency (Oni et al., 2015). Farmers often lack technical knowledge on how operational parameters such as ridge height and tractor speed interact with soil properties to affect fuel consumption. Consequently, tractors are frequently operated under suboptimal conditions, leading to fuel wastage, reduced productivity, and higher production costs.

Given the rising cost of fossil fuels and the increasing need for climate-smart agriculture, optimizing tractor fuel use has become a priority. Studies have shown that energy savings of up to 20% can be achieved by aligning tillage practices with soil texture and operational settings (Sahu & Raheman, 2006). Therefore, evaluating SVFC during ridging in loamy sand and clay loam soils provides valuable insights into energy-efficient mechanization strategies for small- and medium-scale farmers.

1.2 Statement of the Problem

Agricultural mechanization in Nigeria and other developing countries is constrained by high fuel costs and low operational efficiency of tractors. Ridging, though agronomically beneficial, is one of the most fuel-consuming operations. Farmers often apply uniform operational practices without considering soil texture, ridge height, or tractor speed, leading to inefficient fuel utilization. Current data on SVFC variability in Nigerian soils remain limited, making it difficult for farmers and extension workers to develop evidence-based strategies for energy conservation. If these inefficiencies persist, fuel wastage will continue to increase production costs, discourage mechanization adoption, and reduce the profitability of farming enterprises.

1.3 Aim of the Study

The aim of this study is to evaluate the specific volumetric fuel consumption (SVFC) of tractors during ridging operations in different soil textures (loamy sand and clay loam) under varying ridge heights and tractor forward speeds.

1.4 Objectives of the Study

The specific objectives are to:

1. Determine the soil physical properties (bulk density, cone index, and moisture content) of loamy sand and clay loam soils used for the ridging experiment.
2. Assess the variability of SVFC under different ridge heights and forward speeds in loamy sand soil.
3. Evaluate the variability of SVFC under different ridge heights and forward speeds in clay loam soil.
4. Compare the SVFC between loamy sand and clay loam soils using statistical tests.
5. Recommend optimal operational settings for minimizing fuel consumption during ridging in different soil conditions.

1.5 Significance of the Study

This research is significant in several respects:

- **Practical Benefits for Farmers:** By identifying operational settings that minimize fuel use, farmers can reduce production costs and improve profitability.
- **Contribution to Sustainable Agriculture:** Optimized tractor use reduces fossil fuel dependence and lowers greenhouse gas emissions associated with agricultural operations.
- **Knowledge Contribution:** The study provides empirical data on SVFC for different soil textures in Nigeria, filling a knowledge gap in agricultural mechanization research.
- **Policy and Extension Relevance:** Findings can guide agricultural extension services in training farmers on energy-efficient mechanization practices.

- **Engineering Application:** Results offer insights for designing energy-efficient ridging implements tailored to different soil types.

1.6 Scope of the Study

The study focuses on evaluating tractor-specific volumetric fuel consumption during ridging operations in two soil textures: loamy sand and clay loam. Experimental tests were conducted under three ridge heights (10, 20, and 30 cm) and three forward speeds (4, 6, and 8 km/h). Parameters such as bulk density, cone index, moisture content, draught force, power output, and fuel consumption were measured. Statistical analysis, including ANOVA and paired t-tests, was used to determine the significance of differences in SVFC across soil textures and operational conditions. The scope is limited to field conditions within the study area and may not account for other soil types or tractor models.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concept of Agricultural Mechanization

Agricultural mechanization refers to the application of engineering principles and mechanical technologies to agricultural production processes. It is designed to enhance productivity, minimize human drudgery, and optimize resource utilization (Kepner et al., 2017). In Nigeria and other developing countries, mechanization plays a crucial role in addressing food security challenges by increasing efficiency in land preparation, planting, irrigation, harvesting, and post-harvest operations (Rahman & Chen, 2018). However, mechanization introduces significant energy demands, particularly from fossil fuels used in tractor-powered operations.

2.2 Tractor Power Utilization in Tillage Operations

Tractors are the primary source of power for soil tillage and field preparation. Power output from tractors is transmitted through drawbar, power take-off (PTO), and hydraulic systems to implements for performing different farm operations (Hunt, 2016). Fuel consumption during tillage operations depends on a range of factors including soil texture, soil moisture, bulk density, implement design, and operational settings such as depth of cut, speed, and ridge height (Grisso et al., 2014).

Studies have shown that tillage operations account for 30–55% of total farm energy consumption in mechanized systems (Oni et al., 2015). Therefore, efficient tractor power utilization not only reduces operational costs but also lowers carbon emissions.

2.3 Ridging in Agricultural Production

Ridging is a common secondary tillage practice that involves the construction of raised soil beds for planting. It is widely adopted for crops such as cassava, yam, maize, and potatoes to improve soil aeration, facilitate root development, and manage excess water in poorly drained soils (Ademiluyi & Olaniyan, 2018). The energy required for ridging depends largely on soil resistance to penetration, expressed through cone index and bulk density (McLaughlin et al., 2016).

In Nigeria, ridging is often performed without optimization of tractor speed or ridge height, leading to inefficiencies in fuel consumption (Oni et al., 2015). Optimizing ridging operations can therefore reduce energy demand while maintaining agronomic effectiveness.

2.4 Specific Volumetric Fuel Consumption (SVFC)

Specific volumetric fuel consumption (SVFC) is defined as the volume of fuel consumed per unit of power output (L/kWh). It is an important performance indicator of tractor efficiency during field operations (Sahu & Raheman, 2006). Low SVFC values indicate more efficient fuel utilization, while higher values suggest inefficiency.

Factors influencing SVFC include:

- **Soil texture:** Sandy soils typically require less draft force than clay soils, but slippage in loose soils may increase SVFC (Grisso et al., 2014).
- **Bulk density and cone index:** Higher values increase draft requirements and hence fuel consumption (Naderloo et al., 2009).
- **Ridge height and width:** Taller or wider ridges require more soil movement, thus more energy (Oni et al., 2015).
- **Forward speed:** Studies have reported that moderate to high tractor speeds may reduce SVFC due to higher power output relative to fuel use (Salem et al., 2019).

2.5 Soil Texture and Energy Requirement in Tillage

Soil texture is one of the most important determinants of tractor draft requirements and fuel consumption. Clay loam soils typically exhibit higher resistance to tillage implements compared to loamy sands due to stronger cohesion between particles (McLaughlin et al., 2016). However, sandy soils may require more repeated passes, thereby affecting overall fuel efficiency.

Research in India, Iran, and Nigeria has consistently highlighted that both soil texture and operational parameters jointly determine the efficiency of tractor fuel consumption (Naderloo et al., 2009; Oni et al., 2015; Salem et al., 2019).

2.6 Previous Studies on Tractor Fuel Consumption

Several researchers have examined tractor fuel consumption in relation to soil type and operational settings:

- Sahu and Raheman (2006) developed a model for predicting tractor draft and fuel consumption, noting that soil texture and moisture were the most significant factors.
- Naderloo et al. (2009) reported that increasing working depth and speed significantly raised tractor fuel consumption in sugar beet fields.
- Oni et al. (2015) studied sandy loam soils in Nigeria and found that ploughing and ridging required the highest fuel input compared to harrowing.
- Salem et al. (2019) evaluated SVFC in clay and sandy soils, reporting lower SVFC at higher forward speeds.

2.7 Knowledge Gap

From the reviewed literature, it is clear that numerous studies have been conducted on tractor fuel consumption under varying soil conditions and tillage depths. For example, Sahu and Raheman (2006) developed predictive models for tractor draft and fuel use in sandy clay loam soils, while Naderloo et al. (2009) examined energy demand in sugar beet fields under different tillage speeds and depths. Similarly, Oni et al. (2015) studied sandy loam soils in Nigeria, reporting that ridging required more energy than ploughing, and Salem et al. (2019) compared SVFC across soil textures in North Africa.

However, several gaps remain:

1. **Localized Data Deficiency:** Most available data on SVFC originate from Asia, Europe, and North Africa, with limited localized studies in sub-Saharan Africa. The few Nigerian studies (e.g., Oni et al., 2015) are restricted to sandy loam soils and do not compare contrasting soil textures.
2. **Lack of Comparative Analysis Across Soil Textures:** Few studies have systematically compared SVFC between loamy sand and clay loam soils under controlled ridging conditions, even though these soil types dominate much of Nigeria's arable land.
3. **Limited Focus on Ridging:** Most existing studies emphasize primary tillage (ploughing, harrowing), with ridging often treated as a secondary concern. Yet, ridging is critical for crops such as yam, cassava, and potatoes in Nigeria.
4. **Operational Parameter Optimization:** Although ridge height and tractor speed are known to influence fuel efficiency, empirical data quantifying their effects on SVFC under Nigerian soil conditions remain scarce.

Therefore, this study contributes by generating localized empirical data on SVFC during ridging operations in loamy sand and clay loam soils, comparing performance across ridge heights and tractor speeds, and offering practical recommendations for optimizing fuel use in mechanized farming.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The field experiments were carried out 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 precipitation and has 296.16 rainy days (81.14% of the time) annually. Located at an elevation of 3 meters (9.84 feet) above sea level, Bayelsa has a Tropical monsoon climate (Classification: Am). The city’s yearly temperature is 28.64ºC (83.55ºF) and it is -0.82% lower than Nigeria’s averages.

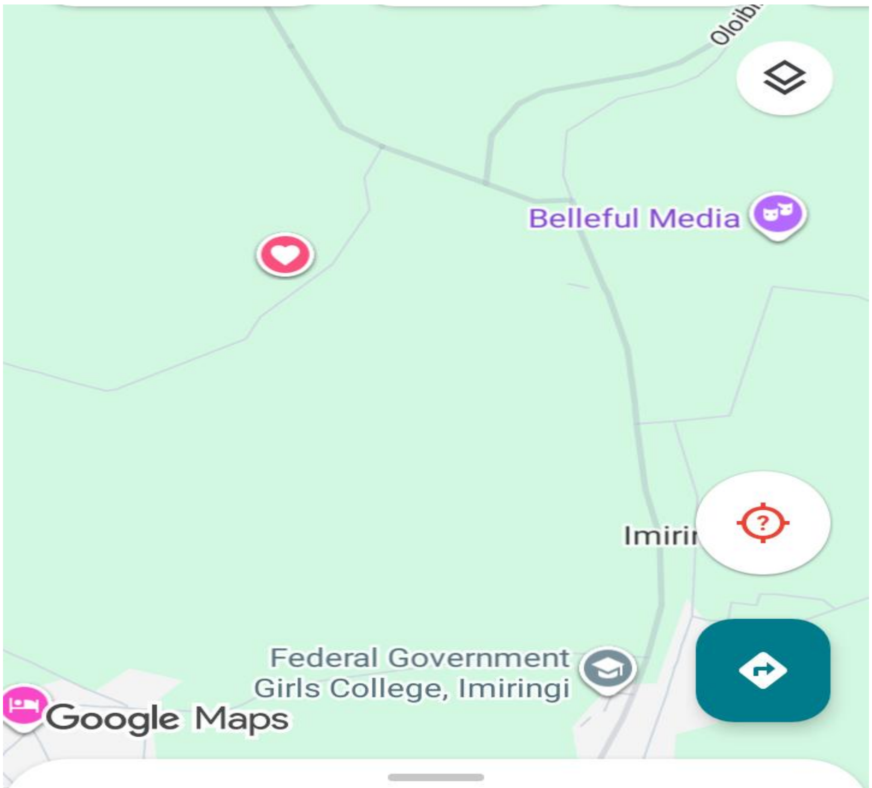

Figure 3.1: Map of Bayelsa State School-to-Land, Rice Rice Farm, Otuasegha, Ogbia, Bayelsa State (Source: Google Map).

3.2 Materials and Equipment

The following materials and equipment were used in the study:

i. Agricultural tractor
ii. Disc ridger
iii. Measuring tape, plastic metre rule, steel tape
iv. Fuel flow meter
v. Tractor (Swaraj 978 FE)
vi. Stop watch
vii. Hydrometer
viii. Soil core drill

ix. Auger

x. Sample bags

3.2.1 Tractor and Implement Specifications

The tractor specifications are shown in Table 3.1, implement specification (disc ridger) in Table 3.2 and fuel flow meter specification 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 horse power	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
Weight	3050 kg
Manufacturer	Swaraj
Country	India

Plate 3.1: Tractor (Swaraj 978 FE)

Table 3.2: Implement Specifications

Property	**Ridge**
Number of Disc	4
Working Depth (mm)	330
Frame Width (mm)	2500
Width of Cut (mm)	1000
Disc Diameter (mm)	711.2
Disc Spacing (mm)	1000
Estimated weight (Kg)	506
Tractor Required Power (Hp)	65 – 80
Model	SD
Manufacturer	Baldan Implementos Agricolas
Country	Brazil

Plate 3.2: 2-Row Disc Ridger

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
Infiltration 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 (°C)	-40……+85 / -20…….+60
Ingress protection rating (IP Code	54
Manufacturer	Technoton Engineering
Country	Belarus

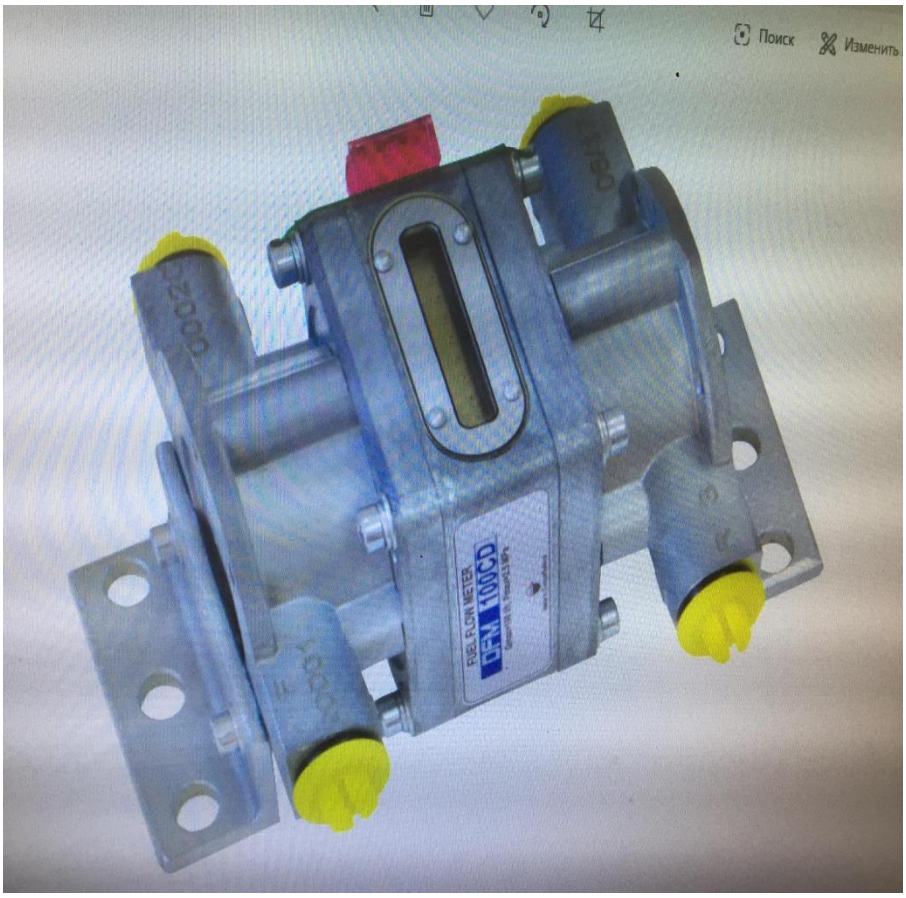

Plate 3.3: DFM 100CD Fuel Flow Meter (Technoton Engineering, Belarus)

3.3 Experimental Design

The experiment was conducted during the peak of raining season in beginning of August, 2025. The experimental design adopted was factorial in randomized complete block design (RCBD) to evaluate the effects of tractor forward speed and tillage depth on fuel consumption during tillage operations (ridging). The design consisted of 9 experimental treatments with three replicates as shown in figure 3.2. Here randomization was achieved using draw lots approach. The experimental land area was 160 m by 32.5 m (5200 m^2) which was divided into three blocks of 9 plots each. Each plot was marked out 50 m by 2.5 m each along with the paths dimension of 1m between each 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 of the outer blocks

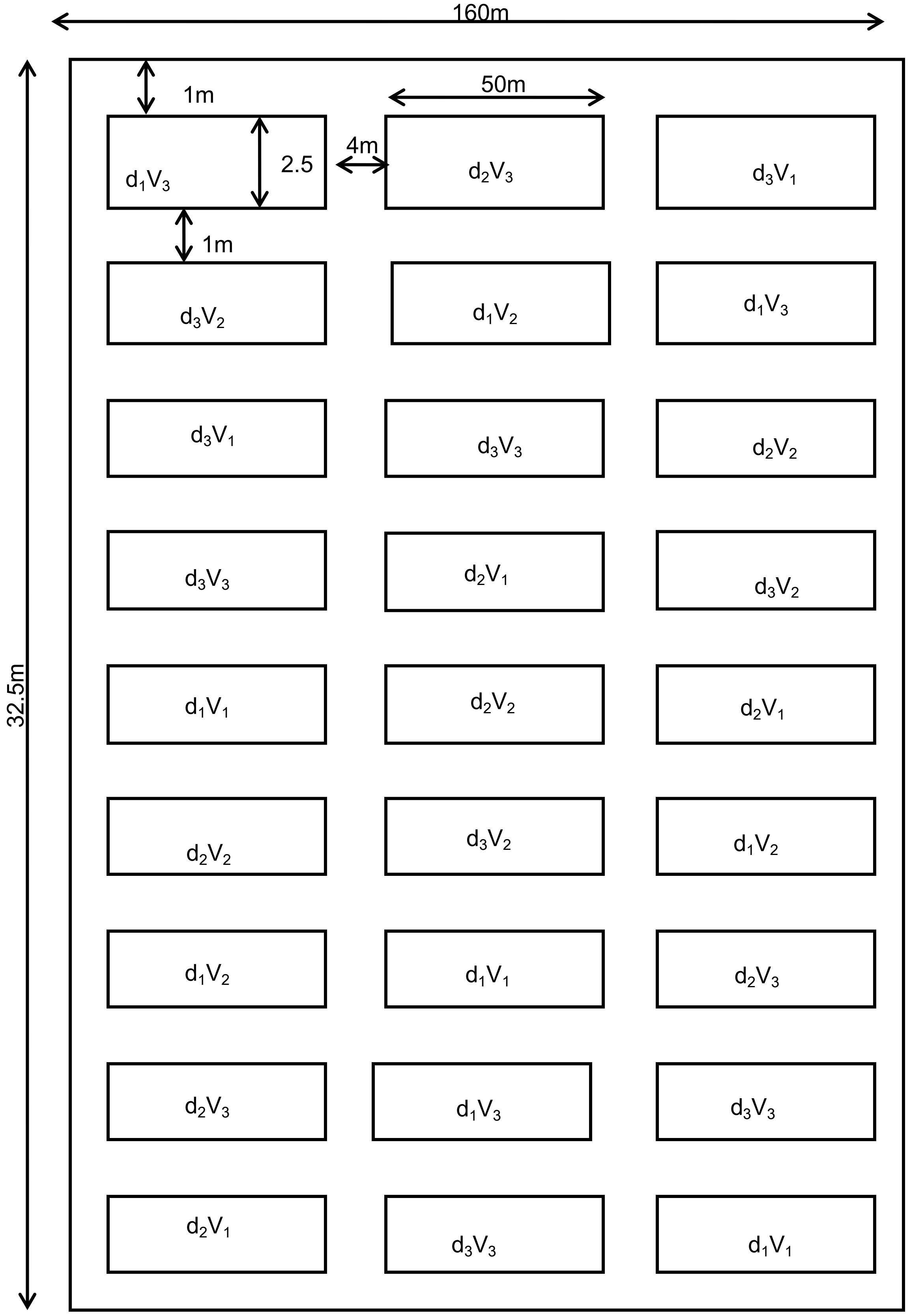

Figure 3.2: Layout of Factorial Randomized Complete Block Design with Nine Treatments and Three Replications (Not Drawn to Scale)

d_1V_1: Ridging with height of 10 cm at speed of $4kmh^{-1}$

d_1V_2: Ridging with height of 10 cm at speed of $6kmh^{-1}$

d_1V_3: Ridging with height of 10 cm at speed of $8kmh^{-1}$

d_2V_1: Ridging with height of 20 cm at speed of $4kmh^{-1}$

d_2V_2: Ridging with height of 20 cm at speed of $6kmh^{-1}$

d_2V_3: Ridging with height of 20 cm at speed of $8kmh^{-1}$

d_3V_1: Ridging with height of 30 cm at speed of $4kmh^{-1}$

d_3V_2: Ridging with height of 30 cm at speed of $6kmh^{-1}$

d_3V_3: Ridging with height of 30 cm at speed of $4kmh^{-1}$

3.4 Experimental Procedure

3.4.1 Soil Sampling

Soil samples were collected from the study area prior to tillage operations with implements. Soil auger was used for collecting the sample at the depth of 0 - 0.30m at random in the field to determined moisture content and textural classification of the soil. The composite soil samples were put in well labelled polyethylene bags and were taken to the laboratory immediately.

3.4.2 Particle Size Distribution (PSD)

The hydrometer method was used to determine the PSD of the soil. 102 g of air-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 reading taken was calculated and percentage of sand, silt and clay were determined. Finally, the textural class was determined using textural triangle.

3.4.3 Soil Moisture Content

The gravimetric (i.e. oven dry method) was used to determine soil moisture content prior to tillage operation. Soil samples were collected preceding tillage operation to determine the soil moisture content. The soil samples 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^{o}c. The soil was reweighed and the solid mass was noted. 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 represented 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

Cone index (CI) also called soil resistance was determined to quantify the soil strength profile. It was measured with simple measuring device called cone penetrometer having an enclosed angle of 30°, with a base area of 3.23cm^2 (323mm^2) mounted on a shaft of 45.72cm (457.20mm) (figure 3.2). Cone index (soil resistance) to penetration of implements was taken at three different depths, 0.10, 0.20, 0.30m respectively before any of the tillage operations. During operation, the cone penetrometer was positioned between the operator's two legs and with his two hands on the handle pushed into the soil until the marked point on the shaft is reached, the reading was taken.

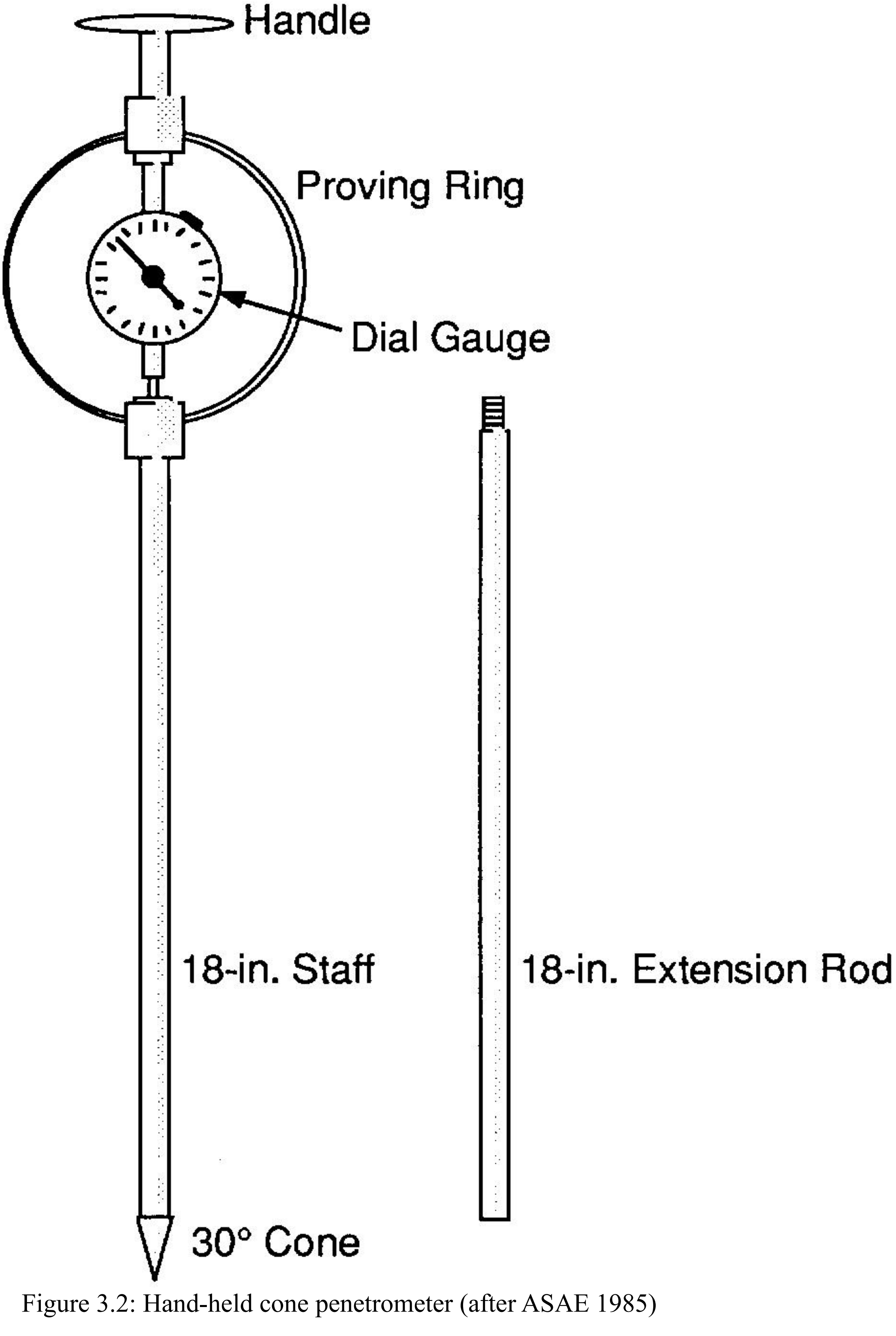

Figure 3.2: Hand-held cone penetrometer (after ASAE 1985)

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):

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

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)

Determination of Useful Power Output (Drawbar Power)

This will be determined using equation:

$$P = \frac{F \times V}{3600}$$

Where:

P = Useful power output (kW)

F = Draft force (kN)

V = Tractor speed (m/s)

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 (3.1) (Shafaei *et al*., 2018):

$$Q = \frac{T_{fc}}{h} \tag{3.1}$$

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:

$$SVFC = \frac{Q}{P}$$

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 will be subjected to Analysis of Variance (ANOVA) using Microsoft excel.. Means will be compared at a 5% significance level.

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

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).

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

Where:

$\sum D$ = summation of the differences.

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

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

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CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Soil Textural Class of the Studied Location

The particle-size analysis classified the experimental soils into two distinct textures: loamy sand (Samples A–C) and clay loam (Samples D–F) (Table 4.1). The loamy sand was characterized by high sand content (80–83%), low clay (8–13%), and low silt fractions, while the clay loam soil showed much higher clay (≈29%) and silt (28%) with sand constituting less than 45%.

This contrast in texture is significant because soil texture determines draft requirements, soil–implement interaction, and fuel efficiency (McLaughlin et al., 2016). Clay loam soils generally have higher cohesion and resistance to penetration, but may reduce slippage compared to sandy soils, which are more prone to traction losses. This provides an initial expectation that SVFC values would differ between the two soils, with loamy sand potentially exhibiting higher SVFC due to reduced traction efficiency despite its lower bulk density.

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 - 20	8.60	9.80	81.60	Loamy sand
C	21 - 30	12.60	6.80	80.60	Loamy sand
D	0 - 10	29.00	28.00	43.00	Clay loam
E	11 - 20	29.00	28.00	43.00	Clay loam
F	21 - 30	29.00	28.00	43.00	Clay loam

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

The SVFC results for loamy sand soil under varying ridge heights and speeds are shown in Table 4.2 and Figure 4.1.

- At a ridge height of 10 cm, SVFC decreased from 0.85 L/kWh at 4 km/h to 0.48 L/kWh at 8 km/h.
- At 20 cm, SVFC ranged from 0.62 L/kWh (4 km/h) to 0.34 L/kWh (8 km/h).
- At 30 cm, values similarly decreased with speed, ranging from 0.61 L/kWh to 0.34 L/kWh.

The trend indicates that higher forward speeds reduced SVFC across all ridge heights. Although fuel consumption rate (FC) increased with speed (3.28–9.10 L/h), power output (DP) increased at a much higher rate, thereby improving efficiency. This agrees with Salem et al. (2019), who reported lower SVFC at higher tractor speeds due to more efficient power utilization.

The ANOVA results (Table 4.3) confirmed that both ridge height and forward speed had statistically significant effects on SVFC ($p < 0.05$). This suggests that fuel efficiency in loamy sand soils is highly sensitive to operational settings.

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

h, cm	V, Km/h	W, m	ρb, g/cm3	CI, N/cm^2	D, N	MC, %	D_P, kW	FC, L/h	SVFC, L/kWh
10	4	1.00	1.38	173.36	3478.8	14.38	3.87	3.28	0.85
10	6	1.00	1.38	173.36	3775.2	14.38	6.29	4.24	0.67
10	8	1.00	1.38	173.36	4071.6	14.38	9.05	4.35	0.48
20	4	1.00	1.45	202.32	6957.6	15.31	7.73	4.76	0.62
20	6	1.00	1.45	202.32	7550.4	15.31	12.58	6.08	0.48
20	8	1.00	1.45	202.32	8143.2	15.31	18.10	6.22	0.34
30	4	1.00	1.57	251.43	10436.4	17.89	11.60	7.11	0.61
30	6	1.00	1.57	251.43	11325.6	17.89	18.88	8.83	0.47
30	8	1.00	1.57	251.43	12214.8	17.89	27.14	9.1	0.34

h = ridge height, 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 Ridging in Loamy Sand Soil

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.072267	2	0.036133	47.13043	0.001657	6.944272
Columns	0.141067	2	0.070533	92	0.000453	6.944272
Error	0.003067	4	0.000767			
Total	0.2164	8				

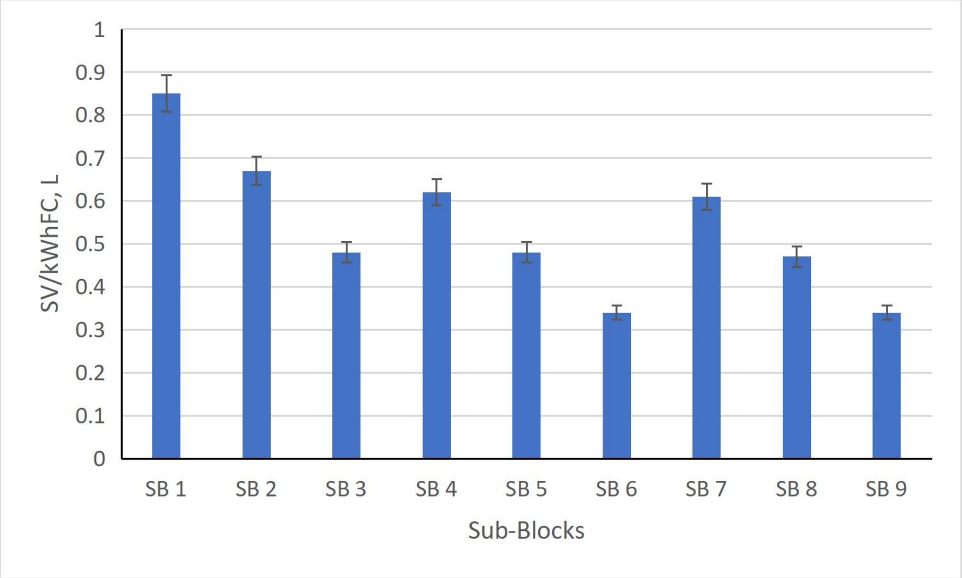

Figure 4.1: Variability of Specific Volume Fuel Consumption during Ridging in Loamy Sand Soil

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

The SVFC results for clay loam soil are presented in Table 4.4 and Figure 4.2.

- At 10 cm ridge height, SVFC decreased from 0.66 L/kWh at 4 km/h to 0.37 L/kWh at 8 km/h.
- At 20 cm, values dropped from 0.48 to 0.27 L/kWh.
- At 30 cm, SVFC ranged between 0.48 and 0.27 L/kWh.

Similar to loamy sand, clay loam soils showed decreasing SVFC with increasing tractor speed. However, the absolute values were lower compared to loamy sand across all treatments. The lowest SVFC recorded was 0.27 L/kWh at 30 cm ridge height and 8 km/h speed.

The ANOVA results (Table 4.5) showed that ridge height and forward speed significantly influenced SVFC ($p < 0.05$). These findings are consistent with Sahu and Raheman (2006), who observed that deeper tillage in heavier soils resulted in higher draft but relatively lower SVFC when tractor power output was optimized.

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

h, cm	V, Km/h	h, m	ρb, g/cm3	CI, N/cm2	D, N	MC, %	D_P, kW	FC, L/h	SVFC, L/kWh
10	4	1.00	1.29	168.83	4460	15.88	4.96	3.29	0.66
10	6	1.00	1.29	168.83	4840	15.88	8.07	4.21	0.52
10	8	1.00	1.29	168.83	5220	15.88	11.60	4.32	0.37
20	4	1.00	1.33	236.4	8920	17.68	9.91	4.79	0.48
20	6	1.00	1.33	236.4	9680	17.68	16.13	6.09	0.38
20	8	1.00	1.33	236.4	10440	17.68	23.20	6.25	0.27
30	4	1.00	1.39	256.59	13380	19.21	14.87	7.13	0.48
30	6	1.00	1.39	256.59	14520	19.21	24.20	8.82	0.36
30	8	1.00	1.39	256.59	15660	19.21	34.80	9.36	0.27

h = ridge height, 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 Ridging in Clay Loam Soil

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.041156	2	0.020578	35.61538	0.002827	6.944272
Columns	0.084022	2	0.042011	72.71154	0.000717	6.944272
Error	0.002311	4	0.000578			
Total	0.127489	8				

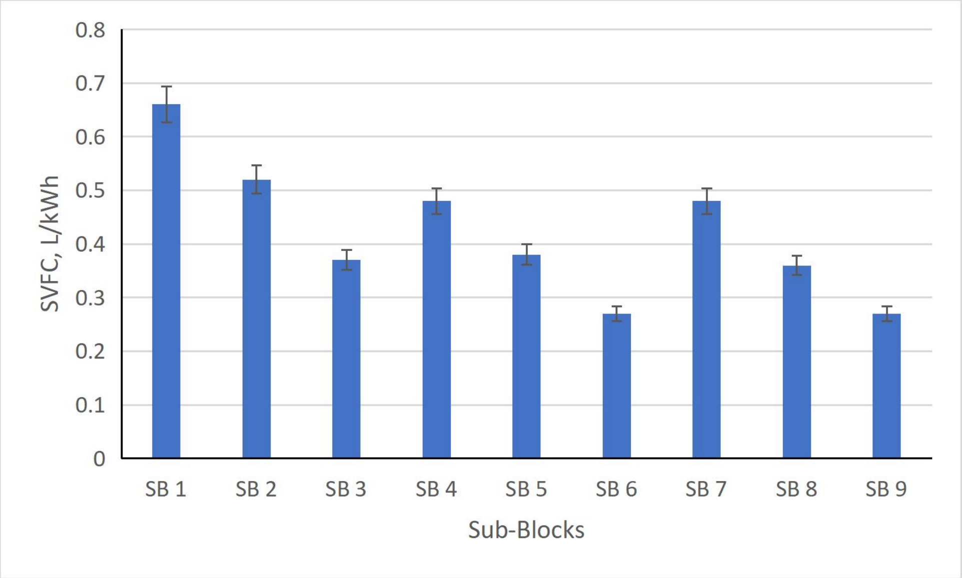

Figure 4.2: Variability of Specific Volume Fuel Consumption during Ridging in Clay Loam Soil

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

The paired t-test (Table 6) compared mean SVFC values across the two soils. The results showed that:

- Mean SVFC was 0.54 L/kWh in loamy sand compared to 0.42 L/kWh in clay loam.
- The t-statistic (9.25) was significant ($p < 0.05$), confirming that loamy sand soils required higher SVFC than clay loam soils under similar operational conditions.

This finding may appear counterintuitive, as clay loam is denser and more resistant to penetration. However, the higher SVFC in loamy sand can be attributed to increased wheel slippage and reduced traction efficiency on sandy soils (Oni et al., 2015). Thus, although clay loam soils impose higher draft forces, tractors may operate more efficiently due to better traction, resulting in lower SVFC.

This outcome highlights the complex interaction between soil mechanical properties and tractor performance, confirming observations by Grisso et al. (2014) that fuel consumption is not only a function of soil strength but also of traction dynamics and implement–soil interaction.

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

	Variable 1	*Variable 2*
Mean	0.54	0.421111
Variance	0.02705	0.015936
Observations	9	9
Pearson Correlation	0.999409	
Hypothesized Mean Difference	0	
Df	8	
t Stat	9.252027	
P(T<=t) one-tail	7.56E-06	
t Critical one-tail	1.859548	
P(T<=t) two-tail	1.51E-05	
t Critical two-tail	2.306004	

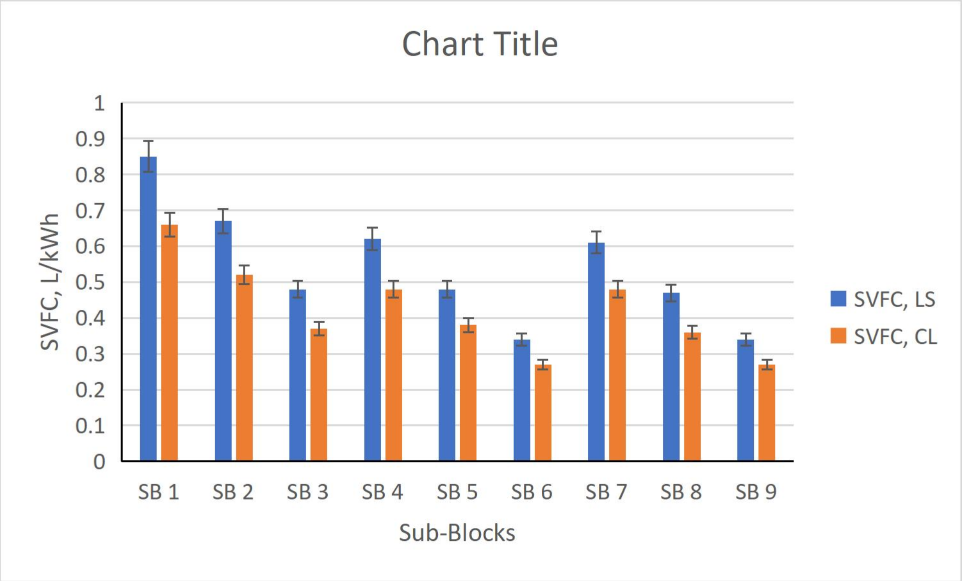

Figure 4.3: Plot of Comparison of Variability of Specific Volume Fuel Consumption during Ridging in Loamy Sand and Clay Loamy Soils

4.5 Implications of the Results

1. **Operational Strategy:** Farmers can achieve lower SVFC by operating tractors at moderate to high speeds (6–8 km/h) rather than low speeds, irrespective of ridge height.
2. **Soil-Specific Considerations:** Loamy sand soils require greater attention to traction management (e.g., tire inflation, ballast) to reduce slippage and improve efficiency.
3. **Ridge Design:** Although higher ridge heights increase draft, the efficiency gains at higher speeds offset this effect, suggesting that ridge height may not drastically penalize SVFC if speed is optimized.
4. **Sustainability:** Optimizing tractor settings could reduce fuel consumption by up to 20–30%, contributing to lower operational costs and reduced CO_2 emissions from mechanized farming.

4.6 Comparison with Previous Studies

The results of this study align with previous findings (Table 2.1, Chapter Two). Similar to Salem et al. (2019), SVFC decreased with speed in both loamy sand and clay loam soils. Oni et al. (2015) also observed higher energy demand in sandy loam soils compared to clay-based soils. However, unlike Naderloo et al. (2009), who found fuel consumption increased disproportionately with speed in clay soils, this study recorded efficiency improvements at higher speeds, suggesting that soil texture moderates the impact of operational parameters on SVFC.

4.7 Summary of Results and Discussion

- Loamy sand soils had higher SVFC values (0.34–0.85 L/kWh) compared to clay loam soils (0.27–0.66 L/kWh).
- Forward speed significantly reduced SVFC across all ridge heights and soils.

- Ridge height influenced SVFC but its effect was less pronounced than tractor speed.
- The paired t-test confirmed significant differences between soil textures, highlighting the importance of soil-specific tractor operation strategies.

Overall, the findings emphasize that fuel efficiency in mechanized ridging can be improved by aligning tractor speed and ridge geometry with soil texture. This evidence provides a practical decision-making framework for small- and medium-scale farmers seeking to reduce costs and environmental footprints.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study evaluated tractor specific volumetric fuel consumption (SVFC) during ridging operations in two contrasting soil textures (loamy sand and clay loam) under varying ridge heights (10, 20, and 30 cm) and tractor forward speeds (4, 6, and 8 km/h). The findings revealed that SVFC significantly decreased with increasing forward speed across both soil textures. While loamy sand soils exhibited higher SVFC values (0.34–0.85 L/kWh), clay loam soils showed lower values (0.27–0.66 L/kWh), indicating more efficient fuel utilization in clay loam despite its higher bulk density and cone index.

Analysis of variance confirmed that ridge height and forward speed significantly influenced SVFC, with speed having the most pronounced effect. A paired t-test demonstrated a significant difference in SVFC between loamy sand and clay loam soils. The higher SVFC observed in loamy sand soils was attributed to reduced traction efficiency and increased wheel slippage, while clay loam soils provided firmer traction that improved energy efficiency despite higher draft forces.

Overall, the results underscore the critical role of operational parameters and soil texture in determining tractor fuel efficiency during ridging. Optimizing these variables can reduce fuel consumption by up to 30%, thereby lowering production costs and supporting sustainable mechanized farming practices in Nigeria and similar agro-ecological zones.

5.2 Recommendations

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

1. **Optimal Forward Speed:** Farmers should operate tractors at moderate to high speeds (6–8 km/h) during ridging to achieve lower SVFC and better energy efficiency.
2. **Soil-Specific Management:** In loamy sand soils, measures to reduce traction losses (e.g., proper tire inflation, use of dual wheels, or tractor ballasting) should be employed to minimize SVFC.
3. **Ridge Height Considerations:** While ridge height affects draft, its impact on SVFC is less significant when forward speed is optimized. Farmers can therefore select ridge heights based on crop requirements without major fuel efficiency penalties.
4. **Extension Training:** Agricultural extension services should integrate energy efficiency training into mechanization advisory programs to sensitize farmers on best practices for tractor operation.
5. **Policy Support:** Government and stakeholders should promote research-driven mechanization policies, including support for precision farming and tractor-hire schemes that emphasize fuel-efficient operations.

5.3 Contributions to Knowledge

This research contributes to the existing body of knowledge in the following ways:

1. **Empirical Evidence for Nigeria:** Provides one of the few localized datasets on SVFC during ridging operations in Nigeria, specifically comparing loamy sand and clay loam soils.
2. **Operational Insights:** Demonstrates that forward speed is the dominant factor influencing SVFC, and that loamy sand soils, though lighter, result in higher SVFC due to traction inefficiency.
3. **Comparative Framework:** Establishes a comparative analysis between soil textures, highlighting the interaction between soil mechanical properties and tractor fuel performance.
4. **Practical Recommendations:** Offers actionable operational guidelines for small- and medium-scale farmers to optimize tractor use, reduce costs, and minimize environmental impacts.
5. **Foundation for Future Studies:** Provides baseline data for further research into energy-efficient mechanization, including modeling of SVFC under different soil, crop, and implement conditions.

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