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Evaluation of Tractor Specific Volumetric Fuel Consumption During Harrowing in Loamy- Sand and Clay-Loam Soils

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Abstract

Efficient fuel utilisation is very important in mechanised agriculture, particularly during soil tillage operations such as harrowing, where fuel makes up a large part of farm operational cost. This study measured the specific volumetric fuel consumption (SVFC) of a tractor during harrowing in loamy sand (LS) and clay loam (CL) soils under varying depths (10, 13 and 16 cm) and forward speeds (4, 6 and 8 km/h). Field measurements included soil bulk density, cone index, draught force, power output, and moisture content to observe how they affect the SVFC. Results show that loamy sand soil had higher draught resistance, which resulted to the use of less power and higher fuel consumption (2.92–4.19 L/h (liter/hour) at 10 cm depth). However, SVFC decreased from 0.72 to 0.44 L/kWh with increasing speed, indicating improved fuel efficiency despite fluctuations in fuel usage. In contrast, clay loam soil showed higher draught resistance because it is denser and more cohesive in nature, leading to higher fuel consumption (3.08–4.31 L /h at 10 cm and up to 9.34 L /h at 16 cm depth). Specific volumetric fuel consumption similarly decreased with speed (from 0.59 to 0.35 L/kWh at 10 cm and 0.48 L/kWh at 16 cm), showing the engine performed more efficiently under increased load. Analysis of variance (ANOVA) and paired t-tests, confirmed clear differences in SVFC between the two soil types ($P < 0.05$). These findings tell us that soil type and tractor settings is important when trying to save fuel in mechanised tillage. The study provides empirical data to inform tractor operation strategies, contribute to the optimisation of fuel and support small scale agricultural production. In addition, field conditions are not continuous and several factors affecting fuel consumption during tillage operations change continuously. Therefore, it is necessary to evaluate tractor performance during ploughing and harrowing operations. Improving the accuracy and efficiency of fuel use in these operations can help reduce costs, save time and enhance overall productivity.

Keywords: Draught, harrowing, soil type, specific volumetric fuel consumption, tractor

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Introduction

Agricultural modernization has become essential for improving productivity and efficiency in food production systems around the world. One of the key tillage operations is harrowing, which prepares the seedbed, controls weeds and breaks down soil clods to create a favorable environment for crop growth (Kepner et al., 2013). As global energy resources continue to decline, the cost of energy keeps rising. Fuel is one of the major recurring expenses in mechanized farming, making efficient fuel use an essential factor in promoting sustainable agricultural practices. This increase in fuel prices has encouraged people to choose vehicles that consume less fuel. As a result, fuel economy has become one of the most important factors people consider when deciding which vehicle to buy (Nurullah and Murat, 2023). 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). In Nigeria and many other developing countries, rising fuel prices and limited access to credit continue to challenge small- and medium-scale farmers. Improving tractor fuel efficiency can help reduce production costs, increase farm profitability and contribute to improved food security (Asoegwu and Asoegwu, 2007). Several factors influence this process, including soil type, moisture content, bulk density, cone index, depth of cut and tractor operating speed (Grisso et al., 2014). Fuel consumption during tractor harrowing also depends on soil properties, especially texture. Clay loam and loamy sand differ in resistance and energy demand, affecting fuel use (Eni-Ikeh, 2024). This study evaluates the specific volumetric fuel consumption (SVFC) of a tractor during harrowing operations in loamy sand and clay loam soils at different operating depths and speeds. The findings are intended to provide useful insights for improving fuel efficiency and promoting energy-efficient mechanized farming practices.

Material and Methods

The experiment was conducted in August 2025 at the School-to-Land Rice Farm, Otuasegha, Ogbia, Bayelsa State, Nigeria (4°53′23.8″ N, 6°21′26.9″ E). The experimental site comprised loamy sand, sandy clay loam and clay loam soils and has a humid monsoon climate. A Swaraj 978 FE tractor (72 hp, 2-wheel drive) coupled with a Baldan HI disc harrow (nine discs; 1.5 m working width) was used. Fuel consumption (FC) was measured using a DFM 100CD digital fuel flow meter installed between the tractor fuel tank and fuel pump. Other equipment included a stopwatch, measuring tape, soil auger, hydrometer, soil core sampler and cone penetrometer. The experiment was a 3 × 3 factorial arranged in a randomized complete block design (RCBD) with three replications. Treatments comprised three tractor forward speeds (4, 6 and 8 km h^{-1}) and three harrowing depths (10, 13 and 16 cm), giving nine treatment combinations and 27 experimental units. The 5,200 m^2 experimental area was divided into three blocks, with treatment combinations randomly assigned within each block. Individual plots measured 50 m × 2.5 m. The required forward speeds were achieved using appropriate gear and throttle settings, while harrowing depths were controlled using the tractor's depth-control mechanism.

Before tillage, soil samples were collected from 0–30 cm depth for determination of soil moisture content and particle-size distribution. Soil moisture was determined using the oven-dry method, while particle-size distribution was determined using the hydrometer method. Soil resistance (cone index) was measured at 10, 20 and 30 cm depths using a cone penetrometer. During each harrowing operation, forward speed, harrowing depth, width of cut, operating time and fuel consumed were recorded. Fuel consumption rate was calculated as the volume of fuel consumed per unit operating time (Lh^{-1}). Draft force was determined using the ASAE empirical relationship, and useful power output was calculated from draft force and tractor forward speed. The SVFC was calculated as the ratio of fuel consumption rate to useful power output and expressed in $LkWh^{-1}$.

The collected data were subjected to analysis of variance (ANOVA) for the 3 × 3 factorial RCBD to determine the effects of forward speed, harrowing depth and their interaction on fuel consumption and SVFC. Treatment means were compared at the 5% significance level.

Results and Discussion

The results of SVFC obtained in loamy sand soil are presented in Table 1. At a 10 cm depth for LS, FC 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 also applies to the CL soils. 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) similarly reported that optimal fuel efficiency is achieved under higher engine loading conditions.

Table 1. Effect of Harrowing Operation in Loamy Sand Soil and Clay Loam Soil

Depth cm	Velocity Km/h	FC, L/h (LS)	SVFC,L/kWh (LS)	FC, L/h (CL)	SVFC,L/kWh (CL)
10	4	2.92	O.72	3.08	O.59
10	6	4.09	O.62	4.24	0.49
10	8	4.19	0.44	4.31	0.35
13	4	4.26	0.81	4.41	0.65
13	6	5.96	0.69	6.12	0.55
13	8	6.1	0.49	6.24	0.39
16	4	6.42	0.99	6.58	0.79
16	6	8.97	0.85	9.13	0.67
16	8	9.18	0.60	9.34	0.48

LS= Loamy sand, L/h=Litre/hr, CL=Clay loam, FC= Fuel Consumption, SVFC= Specific Volumetric Fuel Consumption
Significant difference was observed between the LS and CL ($P<0.05$)

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

A paired t-test was performed to compare the mean SVFC between the two soil types (Table 1). The results revealed a statistically significant difference ($t = 11.29$, $P < 0.05$), indicating that soil texture has a significant influence on tractor fuel efficiency. The SVFC values in loamy sand soils showed greater variability, ranging from 0.44 to 0.99 L/kWh, whereas clay loam soils recorded a narrower range of 0.35 to 0.79 L/kWh. Although loamy sand soils required lower draft forces, the increased wheel slippage and traction losses resulted in less consistent fuel efficiency. In contrast, the more stable traction conditions in clay loam soils contributed to more consistent SVFC values. These findings are consistent with those of Igoni et al. (2020), who reported that sandy soils, despite offering lower resistance to tillage, often lead to greater wheel slip and increased fuel losses. Manuwa and Ademosun (2007) reported that clay soils require higher draft force and consume more fuel than lighter soils, supporting the higher SVFC observed in clay loam during this study. Similarly, Serrano et al. (2007) found that tillage depth and implement geometry significantly influence fuel requirements. In addition, Al-Sager et al. (2024) demonstrated that SVFC can be accurately predicted using soil properties and operating parameters, a finding that was also confirmed by the results of this study.

The novelty of this research lies in its localized evaluation of SVFC under Nigerian soil conditions, providing information that can support more efficient tractor operation and sustainable mechanized farming in the region.

Conclusions and Outlook

This study demonstrated that soil type, tillage depth, and tractor forward speed significantly influenced specific volumetric fuel consumption (SVFC) during harrowing operations. Loamy sand soils exhibited lower draft requirements but greater variability in SVFC, potentially due to increased wheel slippage and traction losses. In contrast, clay loam soils required higher draft forces but exhibited more stable and generally lower SVFC values. These findings highlight the importance of considering soil conditions and operating parameters when selecting tillage strategies to improve tractor fuel efficiency. Future research should investigate the effects of soil moisture content, tractor ballast, and tire inflation pressure on SVFC and traction performance across different soil types. Further experiments under diverse field conditions are also needed to identify optimal combinations of forward speed and tillage depth for reducing fuel consumption and improving the energy efficiency of tillage operations.

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