Fuel consumption of some tractor models for ploughing operations in the sandy-loam soil of Nigeria at various speeds and ploughing depths

Adewoyin, A. O.*, E. A. Ajav

(*Department of Agricultural and Environmental Engineering, Faculty of Technology, University of Ibadan, Ibadan, Nigeria*)

Abstract: Tractors acquired in Oyo State-Nigeria are primarily utilized for ploughing operations which represents the most costly single item in the budget of an arable farmer. Tractor fuel consumption constitutes a significant parameter that affects tractors performances for ploughing operations. The effect of ploughing speed and depth on tractors fuel consumption was therefore examined in a bid to establish their optimum operating conditions. The soil characteristics of the study site were determined using laboratory tests. Ploughing operations, using ASABE standard D497.5, were carried out on 100×500 m research farmland using Massey Ferguson (MF 435, 100 hp), Fiat (F130D, 100 hp) and Steyr (CVT170, 100 hp) tractors that were purchased in 2009. Field experiments were conducted at 5.5, 6.5 and 7.5 km h^{-1} ploughing speeds for ploughing depths of 20, 25 and 30 cm. The soil type in the study site is predominantly sandy-loam. Mean fuel consumption for Fiat, MF and Steyr models were 23.35, 23.58 and 24.55 L ha^{-1} while average of 16.78, 22.02 and 32.67 L ha^{-1} of diesel were used to plough 20, 25 and 30 cm depths respectively. Fuel consumption values increases with ploughing dept significantly, there is 31% increase from 20 to 25 cm and 48% increase from 25 to 30 cm depths. Mean fuel consumption at 5.5, 6.5 and 7.5 km h^{-1} ploughing speeds were 20.0, 24.25 and 27.23 L ha^{-1} respectively. Fuel consumption increased by 4.25 L (21%) when speed is increased from 5.5 to 6.5 km h^{-1} and 2.98 L (12%) when speed increases from 6.5 to 7.5 km h^{-1}. Mean fuel consumption (23.35, 23.58, 24.55) L ha^{-1} for MF, Fiat and Steyr tractors respectively were significantly different at the various speeds and ploughing depths (p<0.05, $0.87 \le r^2 \le 0.99$). The most appropriate combination of ploughing operating parameters in terms of tractor fuel economy is achieved using Fiat tractors at 6.5 km h^{-1} ploughing speed and 25 cm ploughing depth. Tractors' performance for ploughing operation depends significantly on ploughing speed, ploughing depth and tractor type. However, the depth of crop roots should determine the appropriate ploughing depth in order to minimize expenses on fuel.

Keywords: tractor performance, soil types, ploughing depth, ploughing speed, fuel consumption

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1 Introduction

In Nigeria, agricultural mechanization is one of the greatest contributions of technological advancements to agricultural production. The appropriate choice and subsequent proper use of mechanized inputs into agriculture has a direct and significant effect on the achievable levels of land productivity, labour productivity, the profitability of farming, the environment and the quality of life of people engaged in agriculture. Government at all levels considered acquisition and subsequent distribution of farming equipment especially tractors as a significant action that improves agricultural production, yet, no commensurable attention has been devoted to performance management of these equipments with respect to adequacy, appropriateness, economic efficiency and sustainability (Cecil et al., 2002).

Due to the global demand for food items, the increased costs of mechanization on the farm and the current disposition of financial institutions towards

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*** Corresponding author: Adewoyin, A.O.,** Postal Address: P. O. Box 20749, UI Post Office, Ibadan. Phone: 2348066504066. Email: adewoyin_adewale@yahoo.com.

agricultural credits, it became very critical for existing farmers, farm managers, and agricultural investors to make informed decisions based on figures, and to improve the management of mechanization operations. Bamigboye and Ojolo (2002) opined that the cost of operating farm tractors can be reduced if the right tractor is used for the right operation as well as operating at manufacturers' recommended annual use.

The formulation of appropriate agricultural mechanization strategy that provides the basic conditions for largely self sustaining developments might not be effective without critical assessment of the economic implication of the requisite investment. Profit making is critical to the success and sustainability of any business venture, and it is pertinent that agricultural mechanization follow the same trend for a meaningful economic and environmental impact.

The tractor is the main unit of farm machinery and ensures better quality of farm operations, timely completion of farm activities, better management supervision and dignity of labour (Sandeep and Kumar, 2006). Tillage activities in Oyo State-Nigeria especially for large scale farmers are achieved through the use of farm tractors and relevant equipment. The majority of the farm tractors acquired in Oyo State Nigeria are directed towards tillage operation among other uses. AL-Suhaibani and Ghaly (2006) defines tillage as the process of creating a desirable soil condition for seed germination and growth. Tillage provides good weed control with low herbicide cost; allows the control of disease and insects by destroying them through burying of crop residues. Three things are involved in soil tillage which includes the power source, the soil and the implement (Olatunji, 2007).

The tillage of soil is considered to be one of the biggest farm operations as it requires the most energy on the farm. Disc plough is widely used in Oyo State Nigeria by farmer as primary tillage tool. Ploughing operation is the mechanical manipulation of the soil aimed at improving soil conditions for crop production. It represents the most costly single item in the budget of an arable farmer. High levels of energy is required to cut and invert the soil, and the draft force required to plough also needs relatively high weight to give traction (Adewuyi et al., 2006). The depth of ploughing depends on the crop to be cultivated, soil characteristics and also on the source of power available (Pandey, 2004).

Disc plough as the major tillage implement used in fields to substitute hoe and cutlass in Oyo State Nigeria is powered essentially by Massey Fergusson, Fiat and Steyr models of farm tractor being the commonly used farm tractors for ploughing operations having long service life and high efficiency among others (Adewoyin and Ajav, 2011). There are many parameters in tillage operation affecting fuel consumption of tractors, such as type and structure of soil, climate, relative humidity, tractor type, tractor size and tractor-implement relationship.

However, management planning and financial performance review of agricultural mechanization has suffered severe neglect especially by our local farmers and farm managers; hence, it is perceived as a worthless and profitless business ventures (Edward, 2009). However, apt investment and operational decision making are key management practices that are used to command profitability and sustainability of businesses by managers, therefore, efficient use of farm tractors and implement, and their contribution to a producer's relative cost of production is increasingly important (Aaron et al., 2003)

The steep rises in the price of tractors and other farm machines have lowered the purchasing power for farm machines by rural farmers and this trend is calling for management planning tool (Asoegwuand and Asoegwu, 2007). This study places a particular attention on farm tractors for ploughing operation being the most explored primary tillage operation mode by farmers in the Oyo State Nigeria among several alternatives and, also it is considered as the most significant element of the total crop production systems with the largest fixed and operational costs.

Research has been conducted for measuring the effect of ploughing depth on average and instantaneous fuel consumption with three-share disc plough using fuel flow meter and electronic board (Fathollahzadeh et al., 2009), they reported that some of the factors that affects the fuel consumption of tractors during ploughing operation vary continuously in the farm. Al-Suhaibani and Ghaly (2010) investigated the effect of ploughing depth and forward speed on the performance of a medium size chisel plow operating in a sandy soil but the effect of ploughing depth and ploughing speed on the average fuel consumption for varieties of farm tractors operating in the same zone such as Oyo State Nigeria where there is high concentration of tractors and equipment as well as a large number of arable farmers has not been fully investigated or explored.

In addition, there are no detailed studies in Nigeria related to the consideration of tractor fuel consumption in tillage operations using disc plough at various depths and ploughing speeds despite the fact that cost of fuel constitutes over 70% of tractor's operational costs. Disc plough is widely used by Nigerian farmer and the performance data for the ploughing operation is essential to reduce cost of ploughing operation and make economic decisions. In this research, tractor fuel consumption was measured at different ploughing depths and ploughing speeds.

2 Materials and methods

Nigeria is the largest country in Africa comprising of 36 states and the Federal Capital Territory (FCT). It is categorized into eight agro-acological zones namely, semi-arid, dry sub-humid, sub-humid, humid, very-humid, ultra-humid, mountainous and plateau having various degree of climatic characteristics (FAO, 1991). Each of these zones is characterized by different land and climatic conditions aside the numerous socio-ethnical variations. This research work focused on Oyo State Nigeria where mechanized faming activities are relatively prevalent. The major occupation of the inhabitants is farming.

Oyo State is a typical southern guinea savannah with well drained sandy-loam soil, relatively light vegetation and sub-humid zone with annual rainfall ranging from 1,000-1,300 mm. The climate of the area follows the tropical pattern with bi-modal rainfall peaks in July and September and the season runs from November till March every year with average annual temperature of about 32°C (FAO, 2001). The vegetation and the soil support the cultivation of maize, yam, cassava, legumes and tobacco.

The research farmland of the Oyo State Agricultural Development Programme (OYSADEP), located in the northern area of Saki was selected. The farm is fully mechanized with a decent numbers of newly acquired farm equipment. The location of the study site is shown in Figure 1.

Figure 1 Map of Nigeria showing Oyo State and the study area

Primary research data were collected using actual field experiments conducted on research farms via well designed completely randomized block designs using computer and statistical tools.

The field experiments were conducted on a carefully measured and mapped 5 ha farmland having 100 m by 500 m dimension on the three research farms. Ploughing time, Ploughing speed, Ploughing depth and fuel consumption were recorded in three replications for each run of the experiment. There were 27 runs for each of the three tractor types with three replications resulting in 243 runs. These data were coded in a randomized complete block with both discrete and numeric input variables.

The field experiments were carried out on the research farmland of the Oyo State Agricultural Development Programme at Saki, Oyo State. Pre-experiment training was conducted for the research assistants with the aim of understanding the research purpose, procedures and ensures adequate understanding of the function of each assistant on the field. The research field was measured, marked and mapped out with pegs to create a 100 m length by 500 m field. A medium size (100 hp), fully instrumented Massey Fergusson, Fiat and Steyr models of farm tractors purchased in 2010 were used to carry out the ploughing operations at the depths of 10, 20 and 30 cm for each of 5.5, 6.5 and 7.5 km h^{-1} tractor speeds. The detail specifications of each tractor are in Table 1.

Table 1 Farm Tractors Specification

Specifications	Massey fergusson	Fiat	Steyr
Model	MF 435	F130 D	CVT 170
Type of engine	4-Cylinder	4-Cylinder	4-Cylinder
Type of fuel	Diesel	Diesel	Diesel
Type of steering system	Power-assisted	Power-assisted	Power-assisted
Transmission	8X2 4WD	8X2 4WD	8X2 4WD
Type of injector pump	In-line Injector	In-line Injector	In-line Injector
Power output/hp	110	100	100
Fuel tank capacity/L	70	70	70
Rated engine speed/r min^{-1}	2600	2600	2500
Type of cooling system	Water-cooled	Water-cooled	Water-cooled
Front tyre size	6.0- 16	6.0- 16	6.0- 16
Front inflation pressure/psi	32	32	32
Rear tyre size	15.4-28	14-28	16.5-28
Rear inflation pressure/psi	28	28	28

Note: source: Field Experiment 2011.

Each run of the ploughing operation experiment was carried out of a 400 m length (4 - to and fro along the 100 m field) with three replications each. The same disc plough set with given working width, tilt angle and disc angles was used for the ploughing. Ploughing depth and acquiring tractor speed were adjusted uniformly and stabilized in an area with length of approximately 10 m before the target field length. The speeds of ploughing were determined using the tractor hand throttle and constant gear ratio (monitored on the tractor's dash board) and the ploughing depths were selected and fixed using the tractor depth controller. The ploughing depth was measured using a steel measuring tape with the undisturbed soil surface as a reference (Figures 2 and 3).

Figure 2 The ploughing operation in progress

Figure 3 Measuring ploughing effective width of cut

The fuel tank of tractors was filled to capacity at the commencement of each run of the ploughing operation experiments. Quantity of diesel consumed by each tractor for the ploughing operations were estimated at the end of each run by measuring the amount of fuel required to refill the fuel tank to capacity using measuring cylinders. Three replications of each runs were recorded for each tractor at the varying plough depths and speeds.

3 Results and discussion

The results of the soil analysis tests carried out on the research farmland are shown in Table 2. The soil is found to be predominantly sandy-loam, almost neutral and has high water retention ability with average moisture content of 16.70% dry basis and 1,160 kg m^{-3} bulk density. Air temperature measured 23-25°C during the experiment. This bulk density is slightly higher than 1,102 kg m^{-3} reported by Fathollahzadeh et al (2009) on the sandy soils of Tehran, Iran. This is accounted for by the variation in the soil texture and moisture content. Vegetation is sparsely populated in the research location and the soil is nearly neutral with pH level of 7.1.

Table 2 Soil analysis tests on research farm

Variables	Soil characteristics
pH Level	7.1
Sand/%	57
Silt/%	19
Clay/%	24
Soil type	Sandy-Loam
Soil moisture content (db)	16.70%
Soil bulk density	1,206 kg m^{-3}

Note: source: Field experiments, 2010.

The average fuel consumption for Fiat, Mercy

Ferguson and Steyr models of tractor are 23.35, 23.58 and 24.55 L ha^{-1} respectively. The fuel consumption of these three tractors were measured for ploughing depths of 15, 25 and 30 cm with 16.70% moisture content, 7.1 pH and 1,206 kg m^{-3} bulk density. The summary of the fuel consumption of the three commonly used farm tractors in Oyo State-Nigeria at the various ploughing depths and ploughing speeds is presented in Table 3. The operation of the disc plough requires average of 16.79, 22.02 and 32.67 L ha^{-1} of diesel for ploughing depths of 15, 25 and 30cm respectively. Analysis of variance and Duncan multiple range tests reveals that tractor fuel consumption increases significantly with increase in ploughing depth at 5% significance level.

Table 3 Average fuel consumption of tractors at various ploughing speed and depths

	Ploughing Speed /km h^{-1}			Ploughing Depth /cm			Tractor Type		
	5.5	6.5	7.5	20	25	30	Fiat	MF	Steyr
F_c	20.00	24.25	27.23	16.79	22.02	32.67	23.35	23.58	24.55
S_d	6.23	7.97	7.93	1.10	6.44	4.02	7.62	7.98	8.29

Note: F_c = Fuel Consumption (l/ha), S_d = Standard Deviation, MF = Massey Ferguson.

The fuel consumption value increased by 5.23 L (31%) when ploughing depth increased from 20 to 30cm while it increased by 10.65 L (48%) when ploughing depth increases from 25 to 30 cm. The increase in fuel consumption when ploughing depth was increased from 20 to 25 cm was higher than the increase in fuel consumption when ploughing depth is increased from 25 to 30 cm. Fuel consumption of farm tractor for ploughing operations was statistically significant with increase in ploughing depth ($p\leq0.05$). The linear relationship between tractor fuel consumption and ploughing depth is represented as Equation (1) and is shown in Figure 4.

$$F_c = 1.59d - 15.85\ (R^2 = 0.966) \qquad (1)$$

where, F_c - fuel consumption (L ha^{-1}) and d - ploughing depth (cm).

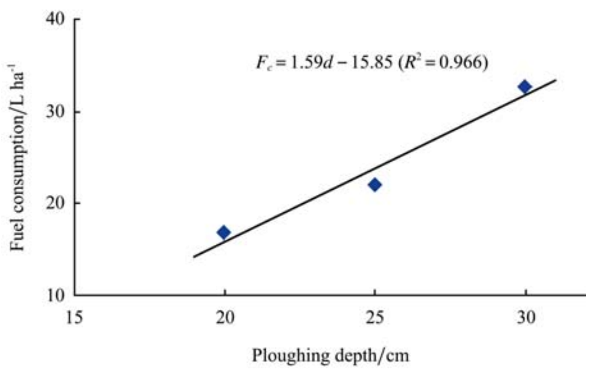

Figure 4 Tractor fuel consumption as a function of ploughing depth of disc

The volume of soil disturbed in m^3 ha^{-1} during ploughing operations has a direct relationship with the depth of cut; this was obtained by multiplying the average effective field capacity and the depth of cut. Average volume of soil disturbed for 20, 25 and 30 cm ploughing depth were found to be 12.78, 14.10 m^3 ha^{-1} respectively, and it increases with increase in ploughing depth and also statistically significant at 5% significance level.

Farm tractors' average fuel consumption at ploughing speed of 5.5, 6.6 and 7.5 km h^{-1} were 20.00, 24.25 and 27.23 L ha^{-1} respectively. The average fuel consumption of farm tractors increased with increase in ploughing speed. An increase of tractor ploughing speed from 5.5 to 6.5 km h^{-1} resulted in increase of fuel consumption by 4.25 L (21%) while increase in ploughing speed from 6.5 to 7.5 km h^{-1} increased tractor fuel consumption by 2.98 L (12%). Fuel consumption increased significantly with increase in ploughing speed of farm tractors ($p\leq0.05$), the linear relationship is shown in Figure 5 as is represented by Equation (2).

$$F_c = 2.57s + 7.11\ (R^2 = 0.973) \qquad (2)$$

where, F_c = fuel consumption (L ha^{-1}) and s = ploughing speed (km h^{-1})

The three-dimensional surface relationship between tractor fuel consumption, ploughing depth and ploughing speed is represented in Figure 6. The fuel consumption of farm tractors increases with ploughing depth and ploughing speed; however, the effect of increasing the ploughing depth within the 30 cm top soil depth on tractor fuel consumption is greater than the effect of increasing the tractor ploughing speed from 5.5 to 7.5 km h^{-1}.

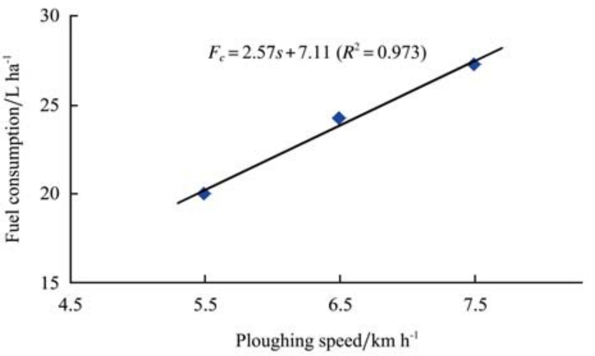

Figure 5 Tractor fuel consumption as a function of ploughing speed

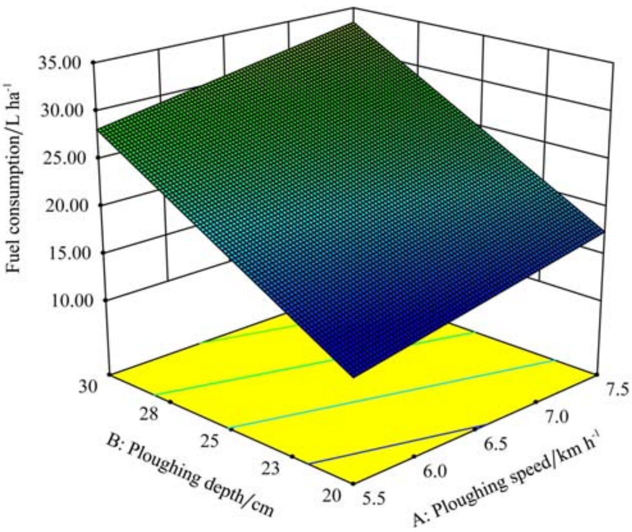

Figure 6 Effect of ploughing speed and ploughing depth on tractor fuel consumption

The effect of ploughing depth and speed on the fuel consumption of farm tractor during ploughing operation on the sandy-loam soil of Oyo State Nigeria was examined in this study. The results reveal that the fuel consumption of farm tractor varies with changes in ploughing speed and depth, and the model that gives the best fit is a linear relationship represented in Equation (3).

$$F_C = 23.83 + 0.0257s + 0.0794d + 0.0042sd \ (R^2 = 0.965) \quad (3)$$

where, F_C –fuel consumption (L ha^{-1}); s-ploughing speed (km h^{-1}); d-ploughing depth (cm).

The mean fuel consumption of Fiat, MF, and Steyr commonly used farm tractor in Oyo State- Nigeria as a function of the ploughing depth and ploughing speed is shown in Figure 7. Ploughing depths and speeds were varied in this experiment as effective factors that impact the fuel consumption of farm tractors. There are other parameters that affect tractors' fuel consumption during ploughing operation such as compression ratio, plant residue, tractor's size and variation in tractor engine configurations.

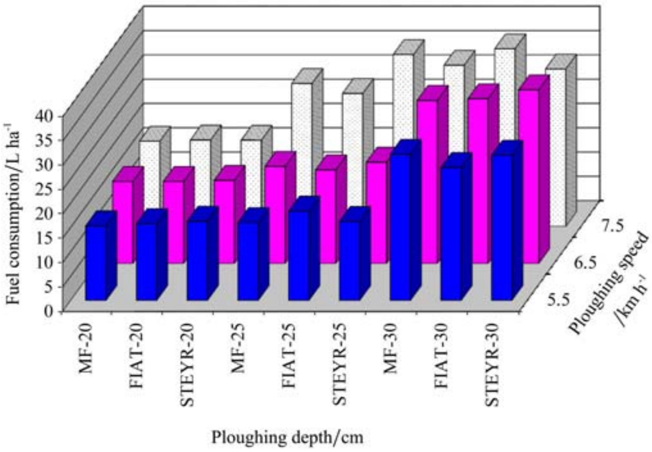

Figure 7 Effect of ploughing depth and speed on the fuel consumption of some commonly used farm tractors on the sandy-loam soil of oyo state-nigeria

Fathollahzadeh et al. (2009) examined the effect of ploughing depth on the instantaneous tractor fuel consumption with three-share disc plough using a 72.3 kW John Deere 3140 tractor in Iran and they reported that the tractor consumed average of 19.66, 24.71 and 28.64 L of fuel per hectare for ploughing depths of 15, 23 and 30 cm respectively on a loam-clay soil. The variation in the fuel consumption with ploughing depth agrees with the findings of this work though the value of the fuel consumption in this study is higher than that reported by Fathollahzadeh et al. (2009), because bigger tractors were used in this study and it is expected that bigger tractor will consume more fuel than smaller ones.

Analysis of variance shows that ploughing speed and ploughing depth varies significantly with tractor fuel consumption. The average fuel consumption of 23.35, 23.58 and 24.55 L ha^{-1} for Fiat, MF and Steyr respectively are however not significantly different ($p \le 0.05$), and this is shown in Table 4. This agrees with the findings of Ahaneku et al. (2009) on the comparative evaluation of three models of Mahindra tractor. They reported that the fuel consumption parameter did not show any significant difference when operated in the same conditions.

Table 4 Analysis of variance for tractor fuel consumption during ploughing operations at various depths and speeds

Source of variance	Sum of squares	Mean df	F square	p-value value	Prob > F
Model	11423.17	4	2855.79	174.78	<0.0001
Ploughing Speed	1071.60	1	1071.60	65.58	<0.0001
Ploughing Depth	10204.75	1	10204.75	624.53	<0.0001
Tractor type	146.82	2	73.41	4.49	0.0122
Tractor type*Ploughing depth	53.45	4	13.36	2.32	0.058
Tractor type*Ploughing speed	16.64	4	4.16	0.73	0.577
Ploughing depth*Speed	1408.52	4	352.13	61.22	0.00001
Tractor type*Speed*Depth	355.51	8	44.4	7.7	0.0001
Residual	3888.86	238	16.34		
Lack of Fit	3140.53	72	43.62	9.68	<0.6001
Pure Error	748.33	166	4.51		
Cor Total	15312.03	242			

Note: source: Field experiment, 2010.

Kheiralla et al. (2007) measured fuel consumption for a disc plough with three shares attached to a 64 kW MF3060 tractor in various conditions. They reported fuel consumption values of 20.6 and 22.7 for 17.4 and 23.4 cm depths respectively. Although the conditions were different, average fuel consumption values obtained in this study are close to those reported by Kheiralla et al. (2007). The observed trend signifies that fuel consumption varies with ploughing speed and depth among other factors that affect fuel consumption during ploughing as reported by Srisvastava (1993) and McLaughlin (1993). These researchers observed that soil texture, soil moisture content, soil compression ratio, plant residue and bulk density affect tractor fuel consumption during ploughing operation.

Shallow seed placement (less than 25 mm) is recommended for most crops that are directly seeded (Collins and Fowler, 1996). However, the depth of the crop roots should determine plowing depths, while the availability of time and implement width will determine the speed required to finish the work on time (Mustafa and Turgut, 2007). The results obtained from this study indicated that the ploughing depth has more effect on the tractor fuel consumption than the ploughing speed. Therefore, the depth of plowing should be determined based on the root length of crop. Increasing the ploughing speed will improve the quality of the seedbed and will not increase the fuels consumption proportionally.

4 Conclusions

The effect of ploughing depth and ploughing speed on the fuel consumption of commonly used farm tractors in Oyo State- Nigeria was investigated. The results indicated that increase in ploughing depth and ploughing speed significantly increases tractor fuel consumption. However, ploughing depth is the most impactful factor in the determination of tractor fuel consumption during ploughing operations.

The depth of ploughing operation should be determined based on the root type, length and size of crop to be cultivate, while the availability of time, soil texture and implement width will determine the speed required to finish the ploughing operation. The results obtained from this study indicate that the ploughing depth has more effect on the fuel consumption of farm tractors than the ploughing speed. Therefore, the depth of plowing should be determined based on the root length of crop in other to optimize cost of fuel.

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