

Fuel Consumption Evaluation of Some Commonly Used Farm Tractors for Ploughing Operations on the Sandy-loam soil of Oyo State, Nigeria

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Abstract: Farm 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 ploughing operations performances. Ploughing operations, using ASABE standard D 497.5 were carried out 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 ploughing speeds for ploughing depths of 20, 25 and 30 cm. Mean fuel consumption for Fiat, MF and Steyr models were 23.35, 23.58 and 24.55 l/ha while average of 16.78, 22.02 and 32.67 l/ha of diesel were used to plough 20, 25 and 30 cm depths, respectively. Fuel consumption increased by 31% when ploughing depth increased from 20 to 25 cm and 48% when increased from 25 to 30 cm. Mean fuel consumption at 5.5, 6.5 and 7.5 km/h ploughing speeds were 20.0, 24.25 and 27.23 l/ha, respectively. Fuel consumption varies significantly with ploughing depth and speed ($p < 0.05$, $0.87 \leq r^2 \leq 0.99$). Fuel consumption values increases with ploughing dept and speed significantly, the depth of crop roots should determine the appropriate ploughing depth in order to minimize expenses on fuel.

Keywords: Fuel consumption, ploughing depth, ploughing speed, soil types

INTRODUCTION

Agricultural mechanization is one of the greatest contributions of technological advancements to agricultural production in Oyo State-Nigeria 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 agricultural credits, it became very critical for existing farmers, farm managers and agricultural investors to make informed decisions based on figures, and improve the management of mechanization operations. Bamigboye and Ojolo (2002) opine 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 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 Lohar, 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 (2010) 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 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 (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 (Asoegwu 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 and, or explored.

MATERIALS AND METHODS

Nigeria is the largest country in Africa comprising of thirty six states and the Federal Capital Territory

(FCT). It is categorized into 8 agro-ecological 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-ethnic variations. This research work focused on Oyo State Nigeria where mechanized farming 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 1000-1300 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 as shown in Fig. 1.

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 five hectares farmland having 100 m by 500 m dimension on the 3 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 3 tractor types with 3 replications resulting in 243 runs. These data were



Fig. 1: Map of Nigeria showing Oyo State and the study area

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	8×2 4WD	8×2 4WD	8×2 4WD
Type of injector pump	In-line injector	In-line injector	In-line injector
Power output (hp)	101	100	100
Fuel tank capacity (L)	70	70	70
Rated engine speed (rpm)	2600	2600	2600
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	15.4-28	15.4-28
Rear inflation pressure (psi)	28	28	28

Field experiment 2011



Fig. 2: The ploughing operation in progress



Fig. 3: Measuring ploughing effective width of cut

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 Ferguson, Fiat and Steyr models of farm tractors purchased in 2009 were used to carry out the ploughing operations at the depth of 20, 25 and 30 cm for each of 5.5, 6.5 and 7.5 km/h tractor speeds. The detail specifications of each tractor are in Table 1.

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 (Fig. 2 and 3).

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 depth and speeds.

RESULTS AND DISCUSSION

The results of the soil analysis tests carried out on the research farmland is 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 1160 kg/m³ bulk density. Air temperature measured 23-25°C during the experiment. This bulk density is slightly higher than the 1102 kg/m³ 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

The average fuel consumption for Fiat, Massey Ferguson and Steyr models of tractor are 23.35, 23.58 and 24.55 l/ha, respectively. The fuel consumption of these three tractors were measured for ploughing depths of 20, 25 and 30 cm with 16.70% moisture content, 7.1 pH and 1,206 kg/m³ bulk density. The operation of the disc plough requires average of 16.79, 22.02 and 32.67 l/ha of diesel for ploughing depths of 20, 25 and 30 cm, 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.

The fuel consumption value increased by 5.23 L (31%) when ploughing depth increased from 20 to 30 cm 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. The linear relationship

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

Field experiments, 2010

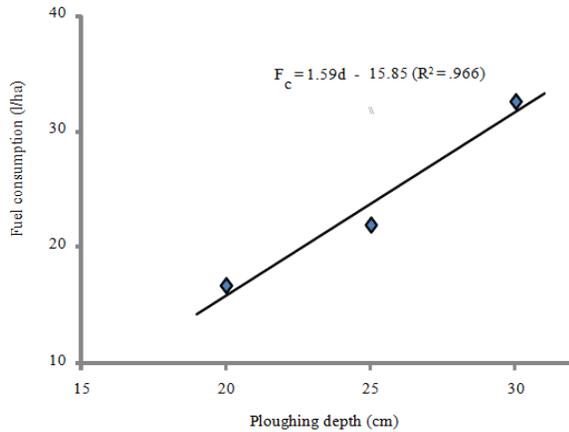


Fig. 4: Tractor fuel consumption as a function of ploughing depth of disc

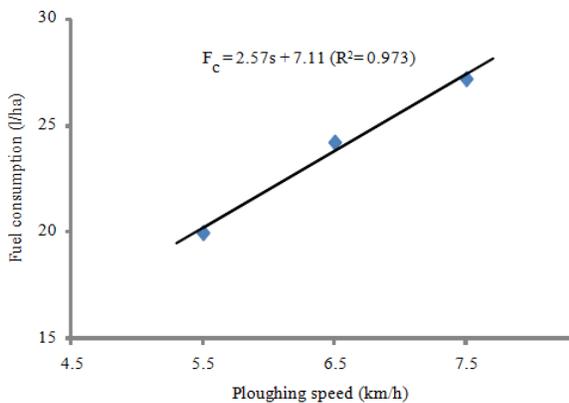


Fig. 5: Tractor fuel consumption as a function of ploughing speed

between tractor fuel consumption and ploughing depth is represented as Eq. (1) and shown in Fig. 4:

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

where,

F_c = Fuel consumption (l/ha)
 D = Ploughing depth (cm)

Farm tractors' average fuel consumption at ploughing speed of 5.5, 6.6 and 7.5 km/h were 20.00, 24.25 and 27.23 l/ha, 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 resulted in increase of fuel consumption by 4.25 L (21%) while increase in ploughing speed from 6.5 to 7.5 km/h increased tractor fuel consumption by 2.98 L (12%). Fuel consumption increased with ploughing speed of farm tractors, the linear relationship is shown in Fig. 5 as represented by Eq.(2):

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

where,

F_c = Fuel consumption (l/ha)
 S = Ploughing speed (km/h)

The three-dimensional surface relationship between tractor fuel consumption, ploughing depth and ploughing speed is represented as shown in Fig. 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.

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 Eq. (3).

$$F_c = 23.83 + 2.57s + 7.94 + 0.42sd \quad (R^2 = 0.965) \quad (3)$$

where,

F_c = Fuel consumption (l/ha)
 S = Ploughing speed (km/h)
 D = ploughing depth (cm)

The mean fuel consumption of Fiat, MF and Steyr being the commonly used farm tractor in Oyo State-Nigeria as a function of the ploughing depth and ploughing speed is shown in Fig. 7. Ploughing depth and speed 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.

Fathollahzadeh *et al.* (2009) examined the effect of ploughing depth on the instantaneous tractor fuel consumption with three-share disc plough using a 72.3kw 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 depth of 15, 23 and 30 cm, respectively on a loam-clay

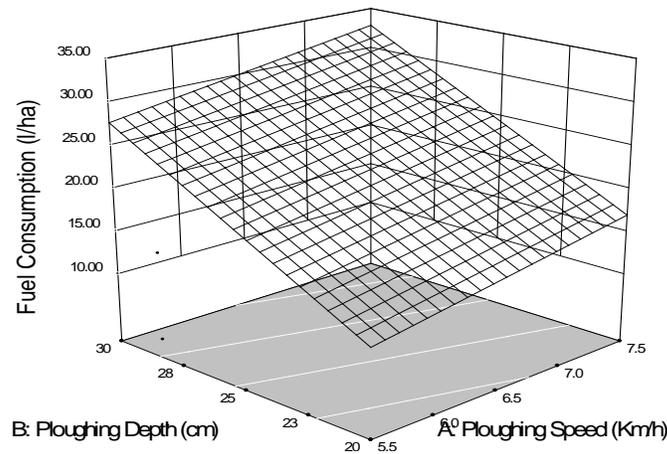


Fig. 6: The effect of ploughing speed and ploughing depth on tractor fuel consumption

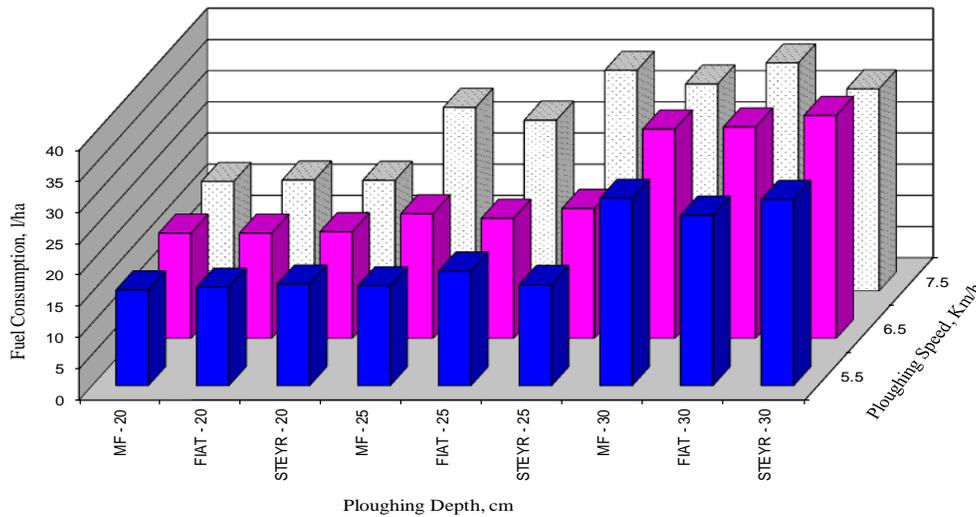


Fig. 7: Effect of ploughing depth and speed on the fuel consumption of some commonly used farm tractors on the sandy-loam soil of Oyo State-Nigeria

Table 3: Analysis of variance for tractor fuel consumption during ploughing operations at various depths and speeds

Source of variance	SS	df	Mean square	F-value	p-value	Prob>F
Model	11423.17	4	2855.790	174.78	<0.0001	
Ploughing speed	1071.600	1	1071.600	65.58	<0.0001	
Ploughing speed	10204.75	1	10204.75	624.53	<0.0001	
Tractor type	146.8200	2	73.41000	4.49	0.0122	
Residual	3888.860	238	16.34000	9.68	<0.6001	
Lack of fit	3140.530	72	43.62000			
Pure error	748.3300	166	4.510000			
Cor total	15312.03	242				

Field experiment, 2010

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 are 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 for Fiat, MF and Steyr, respectively are however not significantly different ($p \leq 0.05$), this is shown in Table 3. This agrees with the findings of Ahaneku *et al.* (2009) and Williams (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 at the same conditions.

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 affects fuel consumption during ploughing as reported by McLaughlin *et al.* (1993). These researchers observed that soil texture, soil moisture content, soil compression ratio, plant residue and bulk density affects 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.

CONCLUSION

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 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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