

*Full Length Research Paper*

# Tractor fuel consumption dependence on speed and height of ridging on a sandy loam soil

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Received 8 November, 2019; Accepted 18, October, 2020

The effect of tractor forward travel speed and ridge height on the amount of fuel consumed by a tractor during ridging operation on a sandy loam soil in a humid tropical environment was investigated. The investigation was the Agricultural Development Programme farm at Rumuodumanya, Rivers State, Nigeria. The experimental plot of 160 by 32.5 m, totaling 5,200 m<sup>2</sup>, was divided into three major blocks; and further sub-divided into nine sub-plots, measuring 50 × 2 m each. An inter-subplot spacing of 2 m was provided along the longitudinal axis of the plots, to serve as channels for effective and efficient administration of field treatments. Field operations of making ridges of different heights were carried out with a two-row disc ridger mounted on a Swaraj 978 FE tractor. *In situ* values of soil moisture content and bulk density were determined and assumed constant for the duration of the study. In the process of the operation, the tractor forward travel speed, ridge width and height, ridging time and amount of fuel used during ridging operation were measured. The experimental data obtained was analyzed statistically using Analysis of Variance (ANOVA), Coefficient of Variation (CV) and Duncan Multiple Range Test (DMRT). The analysis showed coefficients of determination R<sup>2</sup> of 0.9499, 0.9112 and 0.9993 for speeds of 1.39, 1.94 and 2.50 m/s, respectively and R<sup>2</sup> of 0.978, 0.9578 and 0.9997 for heights of 10, 20 and 30 cm, respectively. From the results of ANOVA and DMRT, there were significant differences at 95 and 99% confidence levels on the effect of speed, ridge height and their combination on the amount of fuel consumed by the tractor during ridging operation. Furthermore, a CV of 0.24% showed that experimental error was low and the investigation reliable. Therefore, tractor fuel consumption during ridging operation can be controlled and optimized by appropriate combinations of ridge height and speed of tractor.

**Key words:** Tractor, fuel consumption, ridging speed, ridging height, sandy loam soil, tropical environment.

## INTRODUCTION

In agricultural soil tillage operation, ridging is a veritable aspect that forms the soil into raised beds or ridges between two furrows with specific configuration; the

length depending on the size and layout of the field, while the width and height of the ridge depend on the implement adjustment and size of the disc used

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(Imonigie, 2007). Ridges are usually for undulating, flat and low lying fields, and/or any other topography that are prone to being wet. The permanently raised ridges are flat and usually 30 to 61 cm (12 to 24 inches) wide and 10 to 16 cm (4 to 6 inches) high; and the ridging operation is accomplished with a tillage implement called ridger. It is conventional to perform mechanical ridging operation after ploughing and harrowing, as the latter only pulverize the soil, but do not form the desired mounds of soil.

There are fundamental interdependencies between ridging and ridge variables and tractor operational performance parameters, like the amount of fuel consumed. Fuel is the energy source for almost all mechanized farm operations and the tractor depends largely on it as its sole energy source. It has been found that the rate of tractor fuel consumption depends not only on the tractor engine characteristics, but also on such other variables as soil texture, moisture content, etc., directly related to the particular operation. According to Ikpo and Ifem (2005), tractor fuel consumption rates increase linearly with time and area covered for each tillage operation. Sarkar et al. (2016) established that fuel consumption and tilling time could be reduced by the application of appropriate tillage pattern. They concluded that the traditional tillage pattern requires less fuel and time for tillage operation compared to the circuitous and straight alternation pattern that would reduce the production cost.

It has been shown that differences in soil textures influence tractor fuel consumption during tillage operations, the highest fuel consumption of 81.83 L ha<sup>-1</sup> recorded for conventional tillage, being for silty clay loam soil, followed by silty loam at 68.38 L ha<sup>-1</sup> (Stajanko et al., 2009). Olatunji and Davis (2009) reported that soil texture, moisture content, bulk density and shear strength contribute to tillage energy requirement. Several other investigations have shown a variety of tillage operation parameters that affect tractor fuel consumption during field operations, including type and structure of soil, climate, tractor type, tractor size and tractor-implement relationship (Fathollahzadeh et al., 2010; Ajav and Adewoyin, 2012; Adewoyin, 2013; Adewoyin and Ajav, 2013).

Furthermore, Cortez et al. (2008), Kichler et al. (2011), Silveira et al. (2013), Moitzi et al. (2014), Leghari et al. (2016), and Nasr et al. (2016) have identified that an increased working speed, actual width of cut, soil strength, moisture content and working depth will result in increased power requirement in tillage equipment use, leading ultimately to increased amount of fuel consumed. However, the implement depth of cut in the soil and the tractor's forward travel speed have been identified as more critical in their effect on the amount of fuel used by the tractor during field operations (Fathollahzadeh et al., 2009, 2010; Gulsoylu et al., 2012; Adewoyin and Ajav, 2013; Moitzi et al., 2014; Shafaei et al., 2018).

Because of the high cost of energy fuel, there is need to ensure that tractor fuel consumption during field operations is controlled, to reduce overall cost of agricultural production. Moitzi et al. (2014) suggested that the proficient way of saving fuel is to choose an appropriate driving strategy, indicative of an operation close to the optimal engine operating point. Taiwo (2015) said that in order to reduce fuel consumption during primary and secondary tillage operations, the width of cut should be maximized, while Serrano et al. (2005, 2008) explained that fuel consumption in tillage operations can be minimized by selecting an engine speed of approximately 70 to 80% of the nominal speed and using a higher gear ("shift-up throttle-down" concept). Correia et al. (2015) reported that the choice of 220 rad s<sup>-1</sup> (2100 rpm) rotation and 3.65 km h<sup>-1</sup> for a tractor field operation, resulted in desirable fuel economy and higher worked area amount per unit time.

Ridges are of different heights and configurations, mainly determined by the type of crop to be planted, type of soil, depth of ridger cut in the soil and tractor forward travel speed. The effect of the last three parameters on the amount of fuel consumed during ridging operation on a sandy loam soil in a humid tropical environment has, hitherto, not been evaluated; and this would be relevant in the optimization of ridging operation. Therefore, the objective of this study was to enhance tractor fuel utilization efficiency during ridging operation, by determining appropriate combinations of the respective ridging heights and speeds that would be required.

## MATERIALS AND METHODS

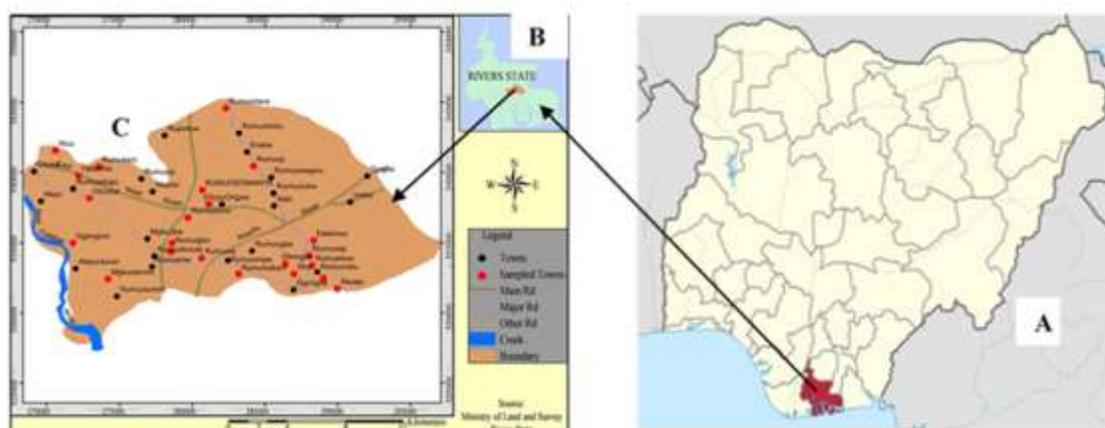
### Experimental site

This research work was carried out on the 8th of August, 2018, between 08.00 and 17.00 h, at the farm of Rivers State Agricultural Development Programme, in Obio/Akpor Local Government Area (LGA) of Rivers State, Nigeria. The farm is located at latitude 4° 49' 27" N and longitude 7° 2' 1" E. Figure 1 is a map showing the study area.

The experimental set-up was a randomized complete block design (RCBD). A field size of 160 m by 32.5 m (5,200 m<sup>2</sup>) was used. It was divided into three equally-sized field blocks of 50 m by 32.5 m (1,625 m<sup>2</sup>), with an inter-block spacing of 4 m and 1 m spacing at the extremes along the 160 m dimension. The 50 m by 32.5 m field blocks were further sub-divided into nine plots each, measuring 50 m by 2 m, with an inter-plot spacing of 1 m, including at the external extremes of the plots along the 32.5 m dimension. The various divisions and sub-divisions gave rise to a total of twenty-seven plots, to allow for the administration of different treatment regimes.

### Tractor and implement specifications

A four-wheel Swaraj 978 FE tractor, shown in Figure 2, which is commonly used in Rivers State, was used for this study. It is a 72 hp tractor, with a torque of 189 lb-ft and PTO rating of 46.3 kW. The total weight of the tractor was 3,015 kg, with the features of the front tyre as 7.5 to 16 radial tyre with 8 ply rating and rear tyre as



**Figure 1.** A - Map of Nigeria with Rivers State inset; B - Map of Rivers State with Obio/Akpor LGA inset; C - Map of Obio/Akpor showing the site of field investigation. Source: Wikipedia (2018).



**Figure 2.** Swaraj 978 FE tractor.



**Figure 3.** Two-Row disc ridger.

16.9 to 28 bias tyre with 12 ply rating. A mounted-type two-row disc ridger, as shown in Figure 3, was used. The ridger, which is 2,525 mm wide, is a Baldan Implement made from Agrícolas, Brazil; and designed to be used with a 65 to 80 hp tractor. It was mounted on the tractor using the tractor's three-point linkage system, where its top link was used for levelling the ridger on the field in order to minimize parasitic forces.

#### Experimental procedure

The investigation began with the characterization of the soil. Soil samples were randomly collected in the field at depths between 0

and 30 cm; and analyzed for soil textural classification, moisture content and bulk density. The textural classification was determined by hydrometer method; the moisture content by gravimetric (oven-drying method); and the bulk density by excavation method. The preliminary soil investigation was accompanied by the ridging operation. The ridge heights were controlled through the tractor lifting mechanism (that is, the three-point linkage system) and measured with a meter rule from the furrow bottom to the top of the ridge, while the speeds were fixed by appropriate gear selection and throttling combination, and then read on the tractor speedometer. Ridging speeds were determined by selecting a particular gear that will give the desired speed. The width of soil cut to form the ridge was measured with a steel tape, measuring from

**Table 1.** Tractor field test/soil property measurements.

Parameter	h <sub>1</sub>			h <sub>2</sub>			h <sub>3</sub>		
	S <sub>1</sub> (m/s)	S <sub>2</sub> (m/s)	S <sub>3</sub> (m/s)	S <sub>1</sub> (m/s)	S <sub>2</sub> (m/s)	S <sub>3</sub> (m/s)	S <sub>1</sub> (m/s)	S <sub>2</sub> (m/s)	S <sub>3</sub> (m/s)
F <sub>C</sub> (×10 <sup>-6</sup> m <sup>3</sup> /s)	2.07	2.32	2.45	2.36	3.33	4.66	3.66	3.78	5.73
W (m)	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32
MC (%)	18.52	18.52	18.52	18.52	18.52	18.52	18.52	18.52	18.52
ρ <sub>b</sub> (g/cm <sup>3</sup> )	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83	1.83

Ridging speeds, S<sub>1</sub> = 1.39 m/s; S<sub>2</sub> = 1.94 m/s; and S<sub>3</sub> = 2.50 m/s; Ridging heights, h<sub>1</sub>, = 10 cm; h<sub>2</sub> = 20 cm; h<sub>3</sub> = 30 cm. W - width of ridge (m); MC - Moisture content (%); and ρ<sub>b</sub> - Bulk density (g/cm<sup>3</sup>).

one side of the furrow wall of the ridge to the other end of the ridge wall of the adjacent furrow. The operation time was determined with a stop watch.

The amount of fuel consumed by the tractor during the ridging operation was determined using the method of refilling the fuel tank before and after every operation. This process involved filling of the tractor fuel tank to the brim before and after each operation test performed, using a 1,000 ml graduated cylinder, from where the quantity of fuel used is measured per time of the operation. This direct method of measuring tractor fuel consumption, as an improvisation for fuel consumption measuring meter, has proved quite effective and relatively accurate, as observed in the works of Abbouda et al. (2001), Udo and Akubuo (2004), Ahaneku et al. (2011), Ajav and Adewoyin (2013), and Shah et al. (2016).

From the measurements, the specific fuel consumption was then determined mathematically using Equation 1 as:

$$FC_s = \frac{V_{fc}}{t} \quad (1)$$

where FC<sub>s</sub>= specific fuel consumption, m<sup>3</sup>/s; V<sub>fc</sub> = volume of fuel consumed, m<sup>3</sup>; and T = time, s.

### Statistical analysis

The data obtained from the field test in this study was analyzed using Analysis of Variance (ANOVA) based on F-test. This was used to obtain an appropriate error term with single probability risk, determined if the mean values measured are totally different and if the difference is so much deviated from what could be ascribed to chance or experimental error. It was considered significant at F<sub>computed</sub> > F<sub>table</sub>.

The Coefficient of Variation (CV) was computed using Equation 2:

$$CV = \frac{\sqrt{\text{Error MS}}}{\text{Grand mean}} \times 100 \quad (2)$$

Furthermore, the mean values of the various treatments were compared using Duncan's Multiple Range Test (DMRT) and were considered as having significant difference if less than the computed difference at 0.05 and 0.01 levels of significance (that is, treatment mean < computed difference).

The computations of the standard deviation (S<sub>d</sub>) and the (t - 1) values of the shortest significant range (R<sub>p</sub>) were done using Equations 3 and 4:

$$S_d = \sqrt{\frac{2S^2}{r}} \quad (3)$$

where S<sub>d</sub>= standard deviation, S<sup>2</sup> = Error Mean Square (EMS), and r = number of replications.

$$R_p = \frac{(r_p)(S_d)}{\sqrt{2}} \text{ for } p = 2, 3, \dots, t \quad (4)$$

where R<sub>p</sub>= shortest significant range.

## RESULTS AND DISCUSSION

The field investigation results are presented in Table 1 and analyzed using the charts in Figures 4 to 6. Table 1 shows the respective amounts of fuel consumed by the tractor while ridging at particular heights, with varying speeds. Values of the ridge width and some soil properties are also presented.

### Effect of ridging speed on fuel consumption during ridging

The effect of ridging speed on the amount of fuel consumed by the tractor is as shown in Figure 4. The figure shows there is a direct proportional relationship between the ridging speed and amount of fuel consumed by the tractor during the operation, at any given height, characterized by a linear regression equation. This relationship is applicable to ridging operations at different heights. The gradients of the curves,  $\frac{d(FC)}{ds}$ , of 34.2% (at h<sub>1</sub>), 207.2% (at h<sub>2</sub>) and 186.5% (at h<sub>3</sub>) indicate that, although the tractor fuel consumption during ridging is generally directly proportional to the tractor speed, there is a ridging height at which the fuel consumption would be optimized for the same speed range. The descriptive regression equations relating the fuel consumption to ridging speed at the different heights of ridging are presented in Equations 5, 6 and 7 as follows:

$$FC = 5.00 \times 10^{-7}S + 2.00 \times 10^{-6} \text{ (10 cm height)} \quad (5)$$

$$FC = 2.00 \times 10^{-6}S + 1.00 \times 10^{-6} \text{ (20 cm height)} \quad (6)$$

$$FC = 2.00 \times 10^{-6}S + 1.00 \times 10^{-6} \text{ (30 cm height)} \quad (7)$$

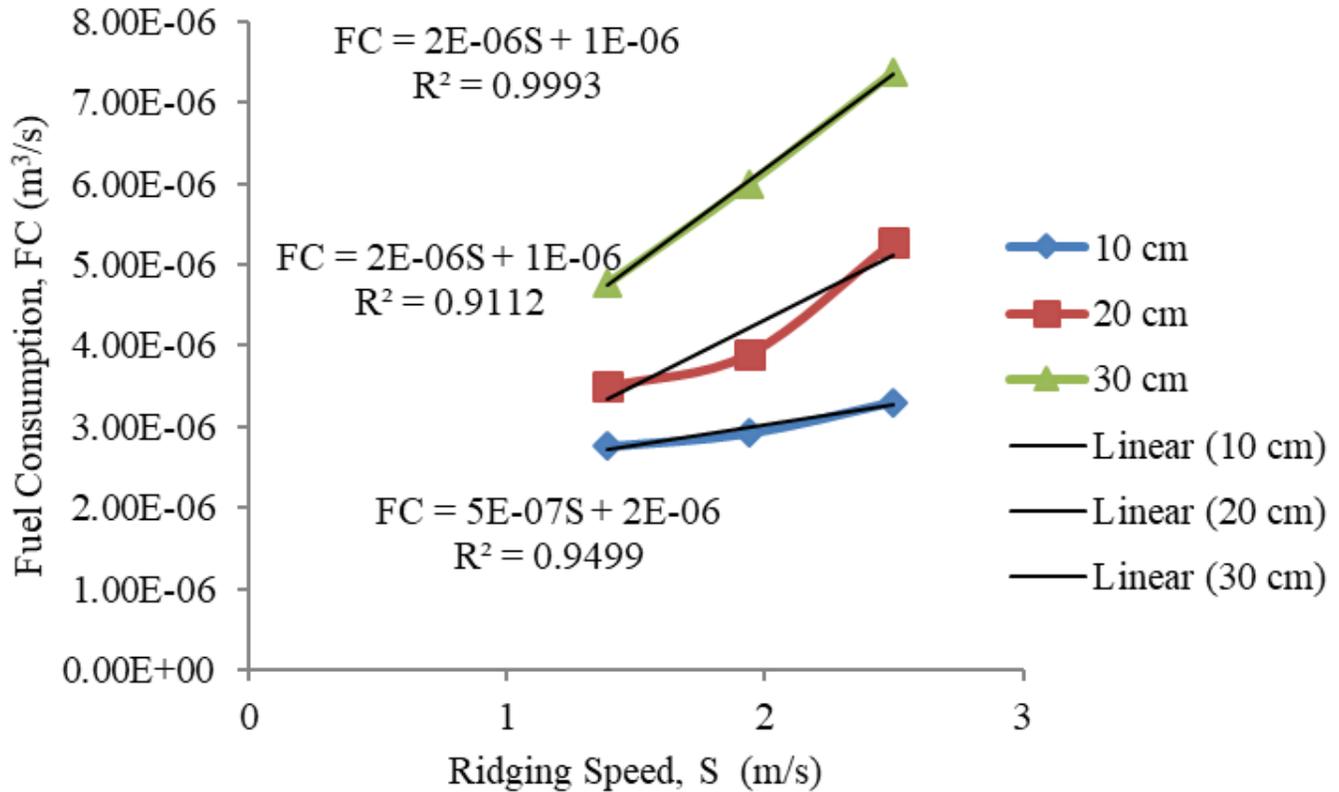


Figure 4. Effect of ridging speed on fuel consumption.

where FC = Fuel Consumption,  $m^3/s$  and S = tractor forward speed,  $m/s$ .

Furthermore, from the curves in Figure 4, the coefficients of determination,  $R^2$  are 0.9499, 0.9112 and 0.9993 for ridge heights of 10, 20 and 30 cm, respectively. The Analysis of Variance (ANOVA) results for the effect of forward speed on fuel consumption during the ridging operation indicated that there were highly significant differences at 95 and 99% confidence levels, as the forward speed increment (86%) from 1.39 to 1.94 and to 2.50  $m/s$  accounted for fuel consumption rise of 18.00, 33.71 and 35.50%, respectively at the three ridge heights used in the study. Also, the Duncan Multiple Range Test (DMRT) results showed that there were highly significant differences between their means at 0.05 and 0.01 levels of significance. This agrees with the findings of Ahaneku et al. (2011), Adewoyi and Ajav (2013), Balami et al. (2015), Almaliki et al. (2016) and Shafaei et al. (2018).

#### Effect of ridge height on fuel consumption during ridging

The effect of ridge height on fuel consumption at varying speeds is presented graphically in Figure 5.

In Figure 5, it can be deduced that the relationship between ridge height and fuel consumption during ridging operation is characterized by a linear regression equation at the different forward speeds of 1.39, 1.94 and 2.50  $m/s$ , respectively as presented in Equations 8, 9 and 10 as follows:

$$FC = 1.00 \times 10^{-5}h + 2.00 \times 10^{-6} \quad (1.39 \text{ m/s}) \quad (8)$$

$$FC = 2.00 \times 10^{-5}h + 1.00 \times 10^{-6} \quad (1.94 \text{ m/s}) \quad (9)$$

$$FC = 2.00 \times 10^{-5}h + 1.00 \times 10^{-6} \quad (2.50 \text{ m/s}) \quad (10)$$

where FC = fuel consumption ( $m^3/s$ ) and h = ridge height (cm).

From the curves of Figure 5, the coefficients of determination,  $R^2$  are respectively 0.978, 0.9578 and 0.9997 at varying speeds; and the ANOVA result for the effect of ridge height on the FC during ridging operation showed highly significant differences at 95 and 99% confidence levels, with a 200% increase of ridge height from 10 to 30 cm, that resulted in a corresponding FC of 42.02, 51.33 and 55.28% respectively, at the three ridge heights. Also, the DMRT results showed that there were strongly significant differences between their means at 0.5 and 0.1 levels of significance. This result corroborates

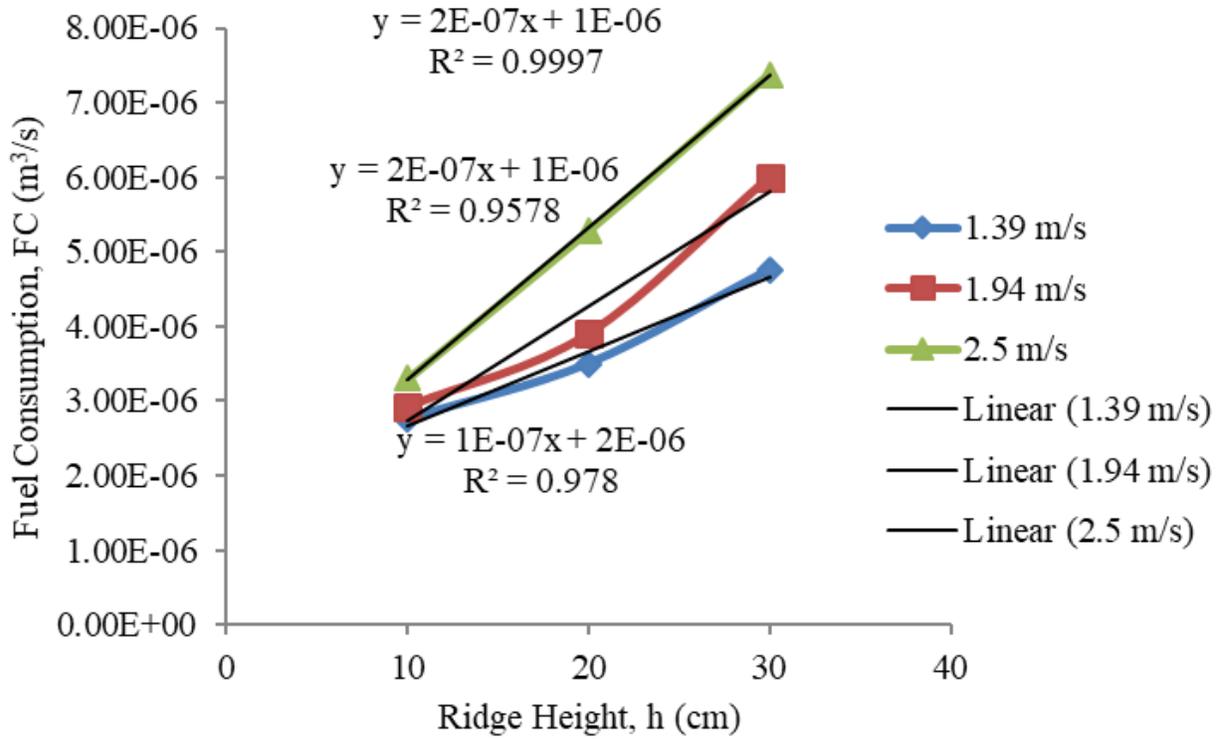


Figure 5. Effect of ridge height on fuel consumption.

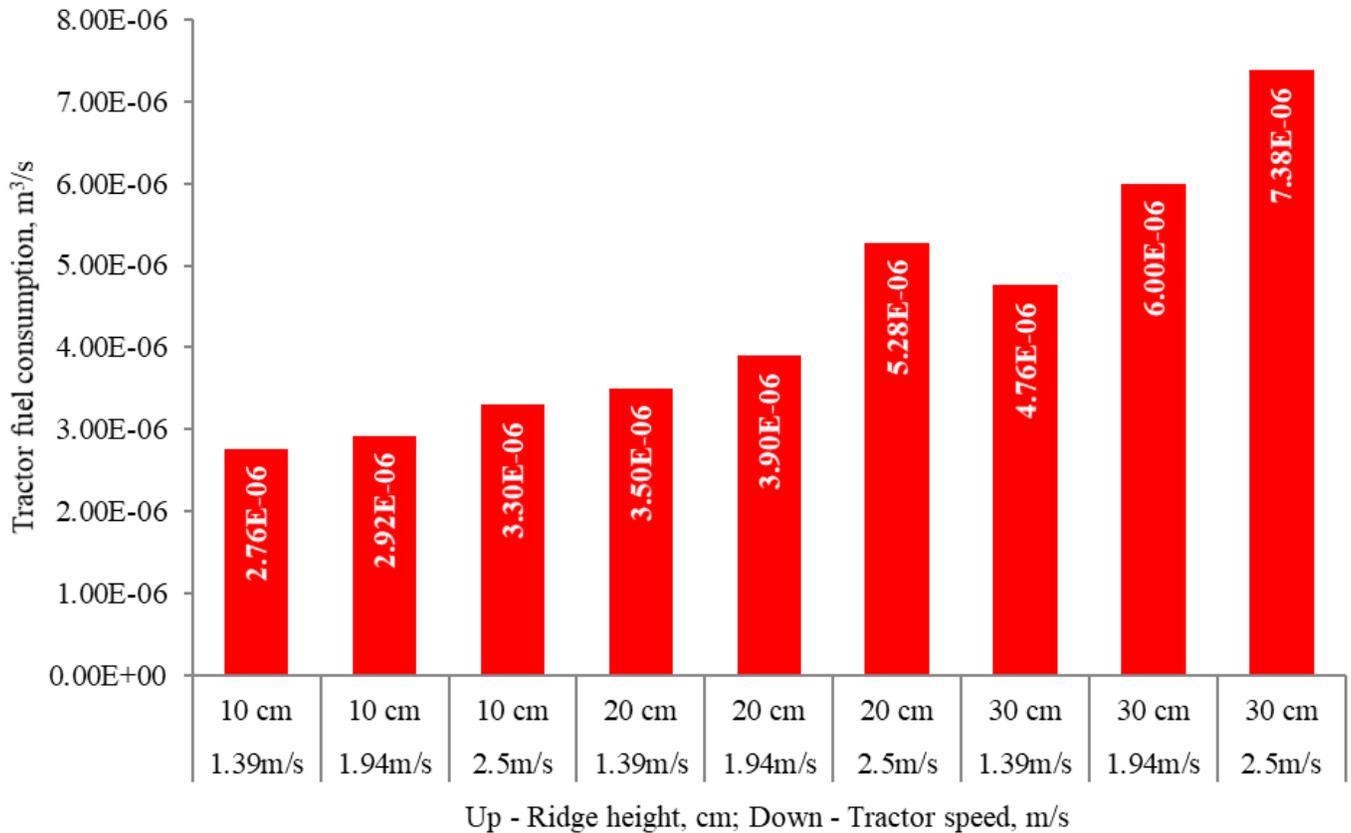


Figure 6. Combined effects of ridging speed and height on fuel consumption.

the findings of Fathollahzadeh et al. (2009, 2010), Gulsoylu et al. (2012), Adewoyin and Ajav (2013), Moitzi et al. (2014) and Shafaei et al. (2018).

### Combined effects of ridging speed and height on fuel consumption during ridging operation

Figure 6 shows the combined effects of speed and height of ridging on tractor fuel consumption during ridging operation. The figure shows the effects of varying combinations of speeds and heights of ridging on the amount of fuel consumed by the tractor during ridging operation, especially the effects of varying speeds of ridging (1.39, 1.94, and 2.50 m/s) at constant ridge heights of 10, 20 and 30 cm, respectively on tractor fuel consumption. From the range of the treatments from a combination of 1.39 m/s and 10 cm to 2.5 m/s and 30 cm, fuel consumption increased by almost 63.16%. At ridge height of 10 cm, there was no significant difference in percentage of fuel consumption (7%) for ridging speeds of 1.39 and 1.94 m/s, and that of 8% fuel consumption at ridging speed of 2.50 m/s, as it is negligibly at 1%. Hence, fuel consumption increased by 12.50%. At ridge height of 20 cm, fuel consumption was 9, 10 and 13% for the varying speeds of 1.39, 1.94 and 2.50 m/s), which give differences of 1% between 1.39 and 1.94 m/s; and 3% between 1.94 and 2.50 m/s, with an overall percentage increase of FC of 46.15%. Similarly, for the ridge height of 30 cm, FC of the three ridging speeds (1.39, 1.94 and 2.50) was 12, 15 and 19%, respectively. Therefore, the FC differences at the 30 cm height were 3 and 4%, with an overall percentage increase of FC of 63.16% relative to the values at 10 cm ridge height.

The ANOVA result for the combined effects of ridging speed and ridge height on fuel consumption during ridging operation indicates that there were highly significant differences at 95 and 99% confidence levels; and a Coefficient of Variation (CV) of 0.24% indicates that the experimental error is low and reliable. Furthermore, the DMRT results show that there were strongly significant differences between their means at 0.05 and 0.01 significant levels. This result agrees with the findings of Adewoyin and Ajav (2013) and Shafaei et al. (2018).

### Conclusion

In the evaluation of the comparative dependencies of tractor fuel consumption on ridging speed and height during ridging operation on a sandy loam soil in a humid tropical region, it has been found that, although tractor fuel consumption increases in direct proportion to increasing ridging speed and height, an increase in fuel consumption during ridging operation is facilitated more by increasing ridge height than increasing tractor speed. Furthermore, there is a range of combination of ridging

height and speed values at which the tractor fuel consumption is optimal; such that, with increasing ridge height and decreasing ridging speed, the fuel consumption decreases, relative to a combination of a lower ridge height and higher tractor speed. It is, therefore, recommended that the selection of ridge height should not be done arbitrarily, as is commonly observed in many farms, but should depend on the effective root depth of the crop to be cultivated. The ridge height should be accompanied by an appropriate tractor travel speed. This will minimize tractor fuel consumption during ridging operation and result in a subsequent reduction of agricultural production cost.

### CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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