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Optimization of Some Operational Parameters to Improve Tractor Fuel Usage Efficiency

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ABSTRACT

General Full Factorial Design (GFFD) methodology was used to optimize tractor fuel usage during ridging operations. The study assesses how fuel consumption per ridged area is affected by two important operational parameters: tractor forward speed and ridge height. A 72-hp tractor and a 6-disc ridger were used in the field tests, and a DFM 100CD fuel flow meter was used to gather data in order to guarantee accurate fuel measurement. Three forward speeds (5 km/h, 7 km/h, and 9 km/h) and three ridge heights (0.10 m, 0.20 m, and 0.30 m) as determined in line with depth of cut were systematically evaluated; each combination was reproduced to guarantee statistical reliability. MINITAB 19 software was used for the statistical analysis and experimental design. The analysis employed in this were ANOVA, main and interaction effects, residual diagnostics, multiple linear regression modelling, and model adequacy checks. The results showed that fuel consumption is greatly influenced by both forward speed and ridge height, with the lowest value (6.27 L/ha) recorded at a forward speed of 5 km/h and ridge height of 0.10 m. With R^2, adjusted R^2, and predicted R^2 all hitting 100%, the created regression model demonstrated exceptional prediction performance, demonstrating the model's dependability. These conclusions were supported by optimization analysis employing composite desirability functions, which also offered a statistically sound framework for making decisions. According to the study's findings, choosing operational parameters to improve fuel efficiency in agricultural field operations can be successfully guided by GFFD

Keywords: Agriculture Field, Disc Ridger, Forward Speed, Fuel, Optimization.

1. INTRODUCTION

A key component of contemporary crop yield and total agricultural output is effective soil preparation. The foundation of land preparation is still tillage operations, including primary and secondary tillage, which have a direct effect on crop establishment, yield, and fuel efficiency. Particularly in regions with high moisture content, one such procedure, ridging, is crucial for creating raised soil beds that promote water drainage, crop row definition, and enhanced root aeration (Nkakini & Fubara-Manuel, 2012).

Optimizing fuel utilization during ridging operations has become a major concern for farmers and agricultural engineers due to the escalating expense of fossil fuels. Deeper tillage can result in increased fuel usage and longer operation durations (Asoegwu 1999; Michalski et al., 2014). Fuel consumption is a major concern in mechanized farming system. Fuel economy is influenced by a number of factors, including ridge height, tractor forward speed, soil type, and implement type (Fathollahzadeh et al., 2010; Adewoyin & Ajav, 2013).

Increased tractor speed or ridge height causes higher fuel usage (Igoni et al., 2019; Igoni et al., 2020). Furthermore, it is hypothesized that fuel consumption tends to grow more dramatically with ridge height than with speed increases, highlighting the significance of simultaneously optimizing both parameters (Igoni et al.,

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2020). A dependable way to assess and optimize these operational variables is to use Design of Experiments (DOE) in General Full Factorial Design (GFFD) (Aboukarima, 2016; Ekemube et al., 2023a, 2023b, Ekemube et al., 2024).

This study identifies the best combination of tractor forward speed and ridge height in tractor fuel consumption reduction during ridging using statistical analysis. The present information will help develop field management techniques that are both economical and energy-efficient, which is particularly important in areas where mechanized agriculture is prevalent.

2. MATERIALS AND METHODS

2.1 Location of Experiments

The experiment was conducted in the Rivers Institute of Agricultural Research and Teaching (RIART) farm located at Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria, (latitude of 4° 49′ 27″ N and a longitude of 7° 2′ 1″ E). It is situated 274 mm above mean sea level and receives an average annual precipitation of 2310.9 mm.

2.2 Design of Experiments

Two factors at three levels is 2^3 full factorial design (two factors at three levels) with repetitions was employed to investigate the impact of forward speed and ridge height in line with depth of cut on tractor fuel consumption per ridged area during the ridging process. The two variables were the height of the ridges (0.10, 0.20, and 0.30 m) and the forward velocity of the tractor (5, 7, and 9 kph). The response under investigation was the quantity of tractor fuel consumed per ridged area. Based on the amount of tractor fuel used per tilled area, Block 1 ridging operations was at depths of 0.10 m, Block 2 for 0.20 m depths, and Block 3 for 0.30 m heights. Three duplicates of each of the nine experimental treatments made up the design as explained in Table 1. In this study, randomization was achieved using the MINITAB 19 software program (Minitab Inc, State College, PA, USA). The experimental field area measured 160 m by 28 m (4,480 m²), divided into three blocks of nine plots each, resulting in a total of 27 treatments. Each plot measured 50 m by 2 m, with a 4 m gap between each block and a 1 m margin at the periphery of the outer blocks. An alley of 1 meter was also included for varying treatment options between each plot.

Table 1: Design of experiments by MINITAB Software Version 19

Std Order	Run Order	Blocks	Depth, d (m)	Speed, V (Km)
22	1	1	1	1
23	2	1	1	2
26	3	1	1	3
20	4	1	3	2
21	5	1	3	3
19	6	1	2	1
25	7	1	2	2
27	8	1	2	3
24	9	1	3	1
13	10	3	1	3
15	11	3	3	3
18	12	3	2	1
17	13	3	3	2
11	14	3	2	2
12	15	3	1	2
16	16	3	3	1
14	17	3	2	3
10	18	3	1	1
9	19	2	3	1
4	20	2	1	1
3	21	2	1	3
5	22	2	2	1
6	23	2	3	2
1	24	2	2	3
2	25	2	3	3
7	26	2	2	2
8	27	2	1	2

2.3 *Tractor and Implement Specifications*

The tractor with 72 hp of engine power and 2200 kg of lifting capacity, and total weight of 3015 kg was utilized in this study's ridging operation. The tyres on the front and back were, respectively, radials of 16.9, 28 and 12 and ply of 7.5, 16 and 8 (Figure 1). The trials used a disc ridger (Baldan Implementos Agricolas, Brazil) with a 4-disc bottom mounted on a gauge wheel, measuring 2500 mm in frame width, disc diameter of 711.20 mm and 330 mm depth of cut (Figure 2).

Figure 1. Tractor (Swaraj 978 FE, Indian)

Figure 2. Disc Ridger (BaldanImplementosAgricolas, Brazil)

2.4 *Fuel Flow Meter Specification*

The DFM 100CD fuel flow meter (Technoton Engineering, Belarus) features the following specifications: a minimum kinematic viscosity of 1.5 mm²/s, a maximum kinematic viscosity of 6.0 mm²/s, a minimum and a maximum supply voltage of 10 V and 45 V respectively. (Figure 3).

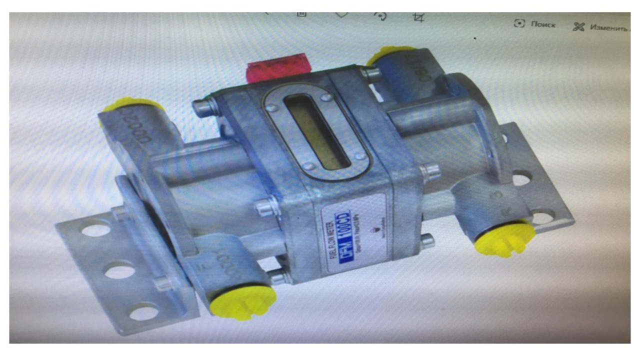

Figure 3. DFM 100CD Fuel Flow Meter (Technoton Engineering, Belarus)

2.5 *Procedure for the Experiments*

The tractor's top links were used to level the disc ridger and reduce parasitic forces. By adjusting the lifting mechanism's level control (three-point linkage height), the disc ridger was lowered to the appropriate ridged cut in order to determine the requisite ridge heights. Tractor forward speeds were adjusted by selecting a certain gear that yielded the required speed. This was done in a practice area prior to each test plot in order to maintain the planned treatment. The meter rule was used to measure the ridging height by moving it from the bottom of the furrow to the top of the ridged surface. A stopwatch with a zero setting was used to measure the time before each procedure. Using the digital fuel measurement method, the fuel consumption of the tractor was calculated. The DFM fuel flow meter was used to monitor fuel use during the process. The meter was fitted on the fuel line between the tractor's fuel tank and the pump. Following each test operation, data was taken from the fuel flow meter and displayed, and switching was achieved by lightly tapping the top cover of the fuel flow meter with an iButton key. The fuel consumption per ridged area was determined mathematically using the formula found in Eqn. (1) (Shafaei et al., 2018):

$$FC_{ta} = \frac{10 \times T_{fc}}{V \times W \times E \times h} \quad (1)$$

Where:
FC_{ta} = Fuel consumption per ridged area, L/ha;
T_{fc} = Tractor fuel consumption, L;
V = Forward speed, Km/h;
W = Implement width, m
E = Implement field efficiency, %;
h = Working hours h

Implement field efficiency (E) was computed using Eqn. (2)

$$E = \frac{F_{ce}}{F_{Tc}} \times 100 \quad (2)$$

Where:
F_{ce} = Effective field capacity, ha/ha
F_{Tc} = Theoretical field capacity, ha/h

2.6 *Statistical Analysis*

This research employed statistical methods such as analysis of variance (ANOVA), normal probability plots, residual versus fits plots, interaction plots, and response optimization. A two-way ANOVA was employed in this study for response analysis to ascertain whether statistically significant differences exist between the means of the treatments. Statistical analyses were conducted at 95% and 99% confidence levels ($p < 0.05$ and $p < 0.01$ significance levels), utilizing MINITAB 19 software (Minitab Inc, State College, PA, USA).

Analysis of variance (ANOVA) was employed to assess the statistical significance of operational parameters about the responses of a certain generated product or application (L'Hocine & Pitre, 2016; Mohammed et al., 2020). ANOVA is a statistical method utilized to assess the significance of primary factors and to evaluate mean differences in performance. This study utilized ANOVA to ascertain the significance of ridge height (h) and tractor forward speed (V) on the response variable (fuel consumption in ridged areas during ridging) by examining the F value at 5% and 1% significance levels, as well as the probability value, commonly referred to as the 'p-value' of the analysis. In an ANOVA, the null hypothesis (H0) often posits that one or more independent variables do not produce a statistically significant difference in the means of the responses; H0: $\mu 1 = \mu 2 = \ldots = \mu a$ (Anderson, 2001; Montgomery, 2013). For the operational factors to exert a statistically significant influence on the answer being examined and for the ANOVA to reject the null hypothesis, it is widely accepted among academics that the p-value must be equal to or less than 0.05 (Salleh et al., 2015; L'Hocine & Pitre, 2016; Mohammed et al., 2020).

The primary technical criterion for evaluating the fuel consumption efficiency of agricultural machinery is the measurement of fuel consumption per hectare (Serrano, 2007).

2.7 *Prediction Equations*

The multiple linear regression model that characterizes fuel consumption per ridged area during the ridging operation is expressed as a function of ridging height. The ridging heights, h_1, h_2, and h_3 are assigned, and the tractor forward speed, V_1, V_2, and V_3, are assigned, in order to get the response equation. The two variables (h and V) in the multiple linear regression models along with their interaction terms can be written as in Eqn. (3). As a result, the models for estimated linear regression are:

$$FC_{ta} = \alpha + \beta_1 h_1 + \beta_2 h_2 + \beta_3 h_3 + \beta_4 V_1 + \beta_5 V_2 + \beta_6 V_3 + \beta_{11} h_1 V_1 + \beta_{12} h_1 V_2 + \beta_{13} h_1 V_3 + \beta_{21} h_2 V_1 + \beta_{22} h_2 V_2 + \beta_{23} h_2 V_3 + \beta_{31} h_3 V_1 + \beta_{32} h_2 V_2 + \beta_{33} h_3 V_3 \quad (3)$$

Where:
FC_{ta} = Fuel consumption per ridged area, (L/ha),
α = Intercept (Average value of the result),
β_1, β_2, β_3, β_4, β_5, β_{11}, β_{12}, β_{13}, β_{21}, β_{22}, β_{23}, β_{31}, β_{32}, and
β_{33}, = Interactions' coefficients,
$h_{12,3}$ = heights, (m)
$V_{1,2,3}$= velocity, (Km/h)
The multiple linear regression models were formulated by the Minitab 19 interactive statistical data analysis tool for factoring designs.

2.8 *Validation of the Multiple Linear Regression Model*

The developed multiple linear regression models were validated by utilizing the model to simulate the experimental data and then use standard error to compare the experimental and predicted data.

2.8.1 Evaluation of Model Prediction Ability

The statistical software Minitab-19 (Minitab Inc., State College, PA, USA) was used to calculate the 95% confidence interval and prediction interval, coefficient of determination (R^2), adjusted R^2 (Adj R^2), and predicted R^2 [R^2 (Pred)] as well as to assess the validity of the measured and forecasted results (Ekemube et al., 2023a, 2023b, Ekemube et al., 2024).

2.8.2 Coefficient of Determination (R^2)

To evaluate the model's fit, the coefficient of determination (R^2) was calculated globally using Eqn. (4) (Montgomery & Runger, 2014; Montgomery 2017):

$$R^2 = \frac{SS_{model}}{SS_T} \qquad (4)$$

SS model was computed using Eqn. (5) (Montgomery & Runger, 2014; Montgomery 2017):

$$SS_{model} = SS_d + SS_V + SS_{dV} \qquad (5)$$

2.8.3 Adjusted R^2 (R^2_{Adj})

The adjusted R^2 (R^2_{Adj}) was computed using Eqn. (6) (Montgomery & Runger, 2014; Montgomery 2017):

$$R^2_{Adj} = 1 - \frac{SS_E/(n-p)}{SS_T/(n-1)} \qquad (6)$$

2.8.4 Predicted R^2

The predicted R^2 (R^2_{Pred}) was computed using Eqn. (7) (Montgomery &Runger, 2014; Montgomery 2017):

$$R^2_{Prediction} = 1 - \frac{PRESS}{SS_T} \qquad (7)$$

Where:
PRESS = Prediction error sum of squares
The PRESS statistic which is the sum of squares of the 'n' PRESS residuals was computed using
Eqn. (8) (Montgomery &Runger, 2014; Montgomery 2017):

$$PRESS = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} \left[Y_i - \hat{Y}_{(I)}\right]^2 \qquad (8)$$

Where:
e_i = Prediction error (ith PRESS residual)
Y_i = Predicted data
$\hat{Y}_{(I)}$ = Mean of predicted data

2.9 Optimization of the Fuel Consumption of Tractor

The optimization of tractor fuel usage per tilled area served as the basis for this research. A tractor-mounted disc ridger was used for the ridging operation. To optimize the process, two variables were changed: the tractor's forward speed and the ridging height. Three tractor's forward speeds—5, 7, and 9 km/h—as well as three separate heights—0.10, 0.20, and 0.30 m—were employed. The response variable (tractor hourly fuel usage) was optimized within the 95% confidence and prediction intervals with ANOVA and an optimization graph. The interplay of operating parameters (ridging height and tractor forward speed) yielded the optimal minimal ridged area tractor fuel consumption, as the target value for the response optimizer.

Composite desirability was computed using Eqn. (9) (Minitab 18 Support, 2019a):

$$D = \left[n\left(d_i^{w_i}\right)\right]^{\frac{1}{W}} \qquad (9)$$

Where:
D = Desirability,
w_i = Importance of the i^th^ response,
d_i = Individual desirability for the i^th^ response,
n = Number of responses,
W = Summation of w_i.

In addition, Individual desirability (d_i) for the minimization i^{th} response was computed as represented in (equation 10) (Minitab 18 Support, 2019b):

$$d_i = \left[\left(U_i - \hat{Y}_i\right)/\left(U_i - T_i\right)\right]^{r_i} \qquad (10)$$

Where:
U_i = Highest acceptable value of i^{th} response,
$\hat{Y}_i$ = Predicted value of i^{th} response,
r_i = Weight of desirability function of i^{th} response
T_i = Targeted value of i^{th} response,

The optimization process was performed with Minitab-19 (Minitab Inc, State College, PA, USA).

3. RESULTS AND DISCUSSIONS

3.1 Fuel Consumption in each ridged area

The results of fuel consumption for each ridged area during the ridging operation obtained from the field experiment and the prediction results are presented in Tables 2 and 3. The tables show that the tractor fuel consumption in each ridged area was improved by raising the ridging heights and tractor forward speed. It follows that tractor forward speed and ridge height have an effect on fuel consumption. This is similar to the findings of (Igoni et al., 2019 & 2020); (Ekemube et al., 2022).

Table 2: Experimental Results of Ridging Operation

Block	Depth, d (m)	Speed, V (Km/h)	Ridged Area Fuel Consumption, FC_{ta} (L/h)
1	0.10	5.00	6.27
1	0.10	7.00	6.78
1	0.10	9.00	6.90
1	0.20	5.00	9.03
1	0.20	7.00	9.70
1	0.20	9.00	9.99
1	0.30	5.00	13.44
1	0.30	7.00	14.59
1	0.30	9.00	14.91
2	0.10	5.00	6.25
2	0.10	7.00	6.80
2	0.10	9.00	6.88
2	0.20	5.00	9.01
2	0.20	7.00	9.72
2	0.20	9.00	9.99
2	0.30	5.00	13.46
2	0.30	7.00	14.61
2	0.30	9.00	14.93
3	0.10	5.00	6.29
3	0.10	7.00	6.82
3	0.10	9.00	6.92
3	0.20	5.00	9.05
3	0.20	7.00	9.74
3	0.20	9.00	9.99
3	0.30	5.00	13.48
3	0.30	7.00	14.63
3	0.30	9.00	14.95

Table 3: Results of FC_{ta} Model equation for Ridging Operation

Block	h (m)	V (Km/h)	FC_{ta}(m) (L/h)	FC_{ta}(p) (L/h)	PSE
1	0.10	5.00	6.27	6.27	0.0065263
1	0.10	7.00	6.78	6.80	0.0065263
1	0.10	9.00	6.90	6.90	0.0065263
1	0.20	5.00	9.03	9.03	0.0065263
1	0.20	7.00	9.70	9.72	0.0065263
1	0.20	9.00	9.99	9.99	0.0065263
1	0.30	5.00	13.44	13.46	0.0065263
1	0.30	7.00	14.59	14.61	0.0065263
1	0.30	9.00	14.91	14.93	0.0065263
2	0.10	5.00	6.25	6.27	0.0065263
2	0.10	7.00	6.80	6.80	0.0065263
2	0.10	9.00	6.88	6.90	0.0065263
2	0.20	5.00	9.01	9.03	0.0065263
2	0.20	7.00	9.72	9.72	0.0065263
2	0.20	9.00	9.99	9.99	0.0065263
2	0.30	5.00	13.46	13.46	0.0065263
2	0.30	7.00	14.61	14.61	0.0065263
2	0.30	9.00	14.93	14.93	0.0065263
3	0.10	5.00	6.29	6.27	0.0065263
3	0.10	7.00	6.82	6.80	0.0065263
3	0.10	9.00	6.92	6.90	0.0065263
3	0.20	5.00	9.05	9.03	0.0065263
3	0.20	7.00	9.74	9.72	0.0065263
3	0.20	9.00	9.99	9.99	0.0065263
3	0.30	5.00	13.48	13.46	0.0065263
3	0.30	7.00	14.63	14.61	0.0065263
3	0.30	9.00	14.95	14.93	0.0065263

Where,
h = ridge height,
V = tractor forward speed,
FC_{ta}= fuel consumption per ridged area,
PSE = pseudo standard error

3.2 Effects of Main and Interactions for Ridge Height and Forward Speed of Tractor on Fuel Consumption per Ridged Area for Ridging Operation

Figures 4 and 5 illustrate the primary and interaction plots, which demonstrate the independent and synergistic effects of both main components (at three distinct values) on the specific response of fuel consumption during ridging.

The plot slopes demonstrated the strength of the correlation between ridge height and tractor forward speed. The addition of a central point to the design revealed a curve between the levels. In Figure 6, a minimal ridged area fuel consumption of 0.10 L/ha was attained at a tractor forward speed of 5 km/h; however, this consumption might grow by augmenting either the ridge height or tractor speed, or by reducing either or both parameters. The central element is adequate to provide a favourable ridged area fuel consumption (L/ha). The findings indicated that a tractor's forward velocity escalates from 5 to 9 km/h, while fuel consumption in ridged terrains (L/ha) rises from a ridge height of 0.1 to 0.3 m. This corroborates the findings of Igoni et al. (2020) that increased in forward speed and height increased tractor fuel consumption. The data indicate that ridge height reduction and tractor forward speed influence the required fuel consumption (L/ha) for ridged areas during ridging operations. According to the interaction plots (Figure 7), fuel consumption in ridged areas can be reduced by decreasing ridge height and tractor forward speed. The interaction graphs indicated that the lines are non-parallel. These indicate a substantial correlation between the tractor's forward velocity and the ridge elevation. The findings of Igoni et al. (2019; 2020) corroborate this. The ANOVA results for the amount of tractor fuel used per ridged area during ridging are shown in Table 4. When the means of the treatments were compared statistically on the main effects of ridge height and tractor forward speed during ridging, the calculated "F" value (1057358.35 and 20160.78) is greater than the table "F" value (3.63 and 6.23 respectively), indicating that there is a significant difference between the means at 5 and 1% levels of significance. Additionally, the "F" value (1158.26) from the interactions between h and V was computed. This value is higher than the "F" value (3.63) from the table, which indicated a very significant difference in the means at the 5 and 1 percent significance levels. Furthermore, it was discovered that for all responses (fuel consumption in tractor-ridged areas), the p-value for the "h" and "V" linear factors as well as the "hV" interaction factor is zero (0.000). Since the p-value is smaller than 0.05, it was found that the factors have a greater meaningful impact on the response. According to Prakash et al. (2008), a factor is considered to have a more significant effect on the response when the p-value is less than 0.05. The ANOVA findings, derived from the study, indicate that the p-value (0.00) for both components (h and V) and their combinations is below the significance level ($P < 0.05$). The tractor-ridged area fuel consumption during ridging was shown to be considerably impacted by the operating elements of ridge height (h) and tractor forward speed (V). The findings are comparable to that of (Igoni et al. 2019, 2020; Ekemube et al., 2022).

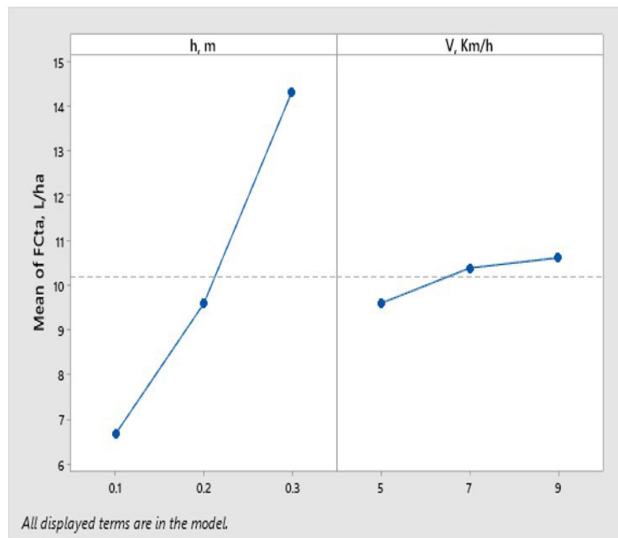

Figure 4.Plot of Main Effects (D and V) on FC_{ra} for ridging

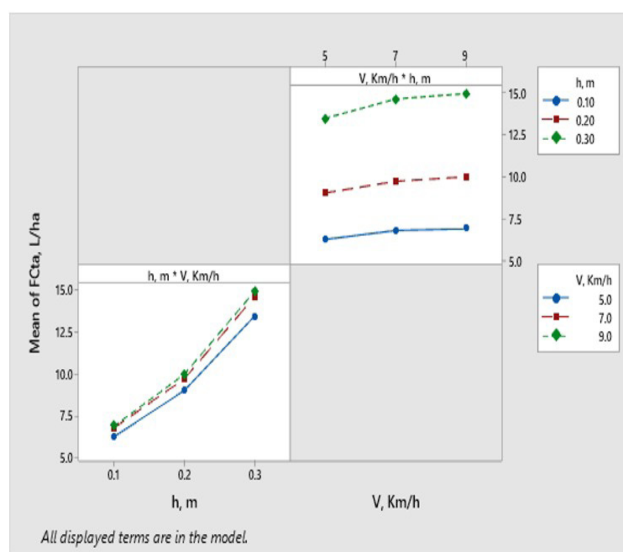

Figure 5: Plot of Interaction (d and V) on FC_{ta}during ridging

Table 4: 2-Way Analysis of Variance for FC_{ta} during ridging

Source	DF	Adj SS	Adj MS	Computed F-Value	Tabular F-Value 5 %	Tabular F-Value 1 %	P-Value
Model	10	275.962	27.596	215970.54**	2.49	2.69	0.000
Blocks	2	0.004	0.002	17.04**	3.63	6.23	0.000
Linear	4	275.366	68.842	538759.57**	3.01	4.77	0.000
H	2	270.214	135.107	1057358.35**	3.63	6.23	0.000
V	2	5.152	2.576	20160.78**	3.63	6.23	0.000
2-Way Interactions	4	0.592	0.148	1158.26**	3.01	4.77	0.000
hV	4	0.592	0.148	1158.26**	3.01	4.77	0.000
Error	16	0.002	0.000				
Total	26	275.964					

3.2.1 Developed Expression of the Effects of Ridge Height and Tractor Forward Speed on Tractor Fuel Consumption per Ridged Area Using Numerical Approach

In addition to a plot of main and interaction effects, a numerical method is another way to represent how operational factors affect particular responses. Use of regression model analysis could be one way to achieve that (Montgomery, 2013; Montgomery, 2017; Javedet et al., 2020), as displayed in Table 5. The coefficient of determination (R^2), coefficient of each factor (h, V, and hV), coefficient of standard error (SE), constant values, p-value, and regression equation are the components of this regression study. Table 5 displays the predictive equation and coefficient of determination (R^2). Meanwhile, Table 5 shows the complete information of each factor's coefficient, constant values, and p-value. The p-value in the multiple linear regression model (Eqn. 10) established revealed the significance of this constant and regression coefficient.

Table 5 shows the estimated coefficients for the fuel usage during ridging in ridged areas and the multiple linear regression model. In the multiple linear regression model (Eqn. 10), the fuel consumption in the ridged area during the ridging operation was found to have a constant value of 10.1900, with a standard error of 0.0022 and a p-value of zero (0.000). This suggests that the constant is significant. In contrast, the p-value for the coefficients of factors h (ridge height) and V (tractor forward speeds) was both 0.0.00. Every combination had a p-value of 0.00 for interaction terms (hV). An acceptance of the established multiple linear regression model was demonstrated by the p-value of 0.00 for the coefficient of factors (h and V) and their interaction terms (for fuel consumption per ridged area during ridging). Similar to this, the coefficient of determination (R^2) value of the multiple linear regression model that has been developed also affects the regression equation's significant level. Regression analysis yielded a correlation coefficient, or R^2, between the expected response (derived from a multi-linear regression model) and the observed response (obtained from the experimental run). As a result, the generated regression model's precision level increases with the R^2 value's proximity to 100%. This was also reported by Al-Hassani et al. (2014). In other words, the effective representation of the measured data could be by the multiple linear regression model. From Table 5, the R^2 value for the hourly fuel consumption multiple linear regression equation was exactly 100 %. This indicates that 100 % of the variation in the ridged area fuel consumption in the experimental data could be adequately explained by the multi-linear regression model (Eqn. 10). This is similar to Solaiman et al. (2016) revealed that The experimental data could be adequately explained when R^2 of the regression model is close to 100 %.

An additional metric to assess a regression model's level of accuracy is the adjusted R^2 (Adj R^2) (Mutuk & Mesci, 2014). This is the correction of R^2 given the number of variables in the regression equation and sample size (Al-Hassani et al., 2014). From the analysis, the ridged area fuel consumption multiple linear regression model during ridging had an Adj R^2 value of 100 %. Hence, it could be assumed that the accuracy of the model is 100%. This model could well represent the actual measurement data of fuel consumption per ridged area during ridging. In addition, the predicted R^2 or R^2 (pred.) of the ridged area fuel consumption during ridging was 100%. This indicated that 100 % of the ridged area fuel consumption data during ridging could be predicted by the multiple linear regression model

(Eqn. 10). It has been proposed by Palkar & Shilapuram (2015) the generated multiple linear regression model is very reliable if the difference between R^2 (adj.) and R^2 (pred.) is less than 20. The investigation revealed that there is a 0.00 difference in the fuel consumption per ridged area during ridging between R^2 (adj.) and R^2 (pred.). The multiple linear regression model (Eqn. 10) developed for fuel consumption in tractor ridged areas during ridging was found to be highly significant, as indicated by the p-value, R^2, adjusted R^2, and predicted R^2 metrics. Indicating that the estimated multiple linear regression models created for fuel usage during tractor-riding tasks explained 100% of the variability in the dataset.

Table 5: Estimated Multiple Linear Regression Model Coefficients for FC_{ta} during Ridging

Term		Coefficient	SE Coefficient	P-Value
Blocks	Symbol			
Constant	α	10.1900	0.0022	0.000
H				
0.1	β_1	-3.53333	0.00308	0.000
0.2	β_2	-0.61000	0.00308	0.000
0.3	β_3	4.14333	0.00308	0.000
V				
5	β_4	-0.60333	0.00308	0.000
7	β_5	0.18667	0.00308	0.000
9	β_6	0.41677	0.00308	0.000
h*V				
0.1*5	β_{11}	0.21667	0.00435	0.000
0.1*7	β_{12}	-0.04333	0.00435	0.000
0.1*9	β_{13}	-0.17333	0.00435	0.000
0.2*5	β_{21}	0.05333	0.00435	0.000
0.2*7	β_{22}	-0.04667	0.00435	0.000
0.2*9	β_{23}	-0.00667	0.00435	0.000
0.3*5	β_{31}	-0.27000	0.00435	0.000
0.3*7	β_{32}	0.09000	0.00435	0.000
0.3*9	β_{33}	0.18000	0.00435	0.000

R^2 = 100 %, Adj R^2 = 100 %, R^2(Pred) = 100 %

$$FC_{ta} = \alpha + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 V_1 + \beta_5 V_2 + \beta_6 V_3 + \beta_{11} d_1 V_1 + \beta_{12} d_1 V_2 + \beta_{13} d_1 V_3 + \beta_{21} d_2 V_1 + \beta_{22} d_2 V_2 + \beta_{23} d_2 V_3 + \beta_{31} d_3 V_1 + \beta_{32} d_2 V_2 + \beta_{33} d_3 V_3 \quad (10)$$

3.3 Optimum Fuel Consumption per Tilled Area for Ridging Operation

The responses optimizer in MINITAB 19 was used to identify the optimum value of controlled factors or variables from the multiple linear regression model. This will allow for the achievement of desired operating conditions for tractor fuel consumption per ridged area during ridging operation. The fuel usage in ridged areas during ridging was the focus of this investigation. The goal was to attain fuel consumption in ridged areas during ridging operation.

Fuel consumption in ridged areas during ridging is shown in Figure 6, and Table 6 shows the outcomes of the optimum solution. Based on the analysis, it was estimated that 6.27 L/ha of fuel will be used at the very least during ridging in ridged areas. With a composite desirability (D) of 0.997701—a value that was higher than 0.90 and closer to 1.00—these desired responses were attained at a ridge height of 0.10 metres with tractor forward speed of 5 km/hr. The composite desirability (D) serves as an additional statistical measure to validate the accuracy of the optimization plot (Ciopec et al., 2012). According to Chang et al. (2015), when the composite desirability (D) approaches 1.00, the optimization of factors and responses obtained from the statistical analysis is highly precise and reliable. The solution presented in Table 6, along with the optimal conditions indicated in the optimization plot (Figure 6), demonstrated full compliance with the various linear regression models developed and were found to be generally reliable.

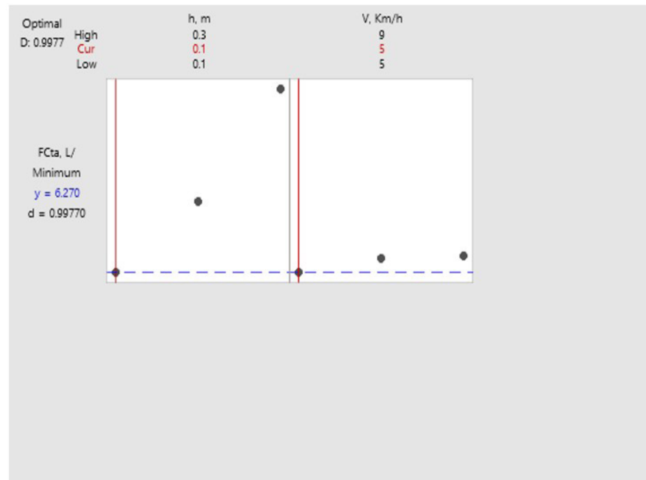

Figure 6: FC_{ta} Optimization Plot for Ridging

Table 6: Result of Optimization Simulation for FC_{ta} during Ridging

Solution	h, m	V, Km/h	FC_{ta}, L/ha (m)	FC_{ta}, L/ha (Fit)	Composite Desirability
1	0.1	5	6.27	6.27	0.997701
2	0.1	7	6.78	6.80	0.936782
3	0.1	9	6.90	6.90	0.925287
4	0.2	5	9.03	9.03	0.680460
5	0.2	7	9.70	9.72	0.601149
6	0.2	9	9.99	9.99	0.570115
7	0.3	5	13.44	13.46	0.171264
8	0.3	7	14.59	14.61	0.039080
9	0.3	9	14.91	14.93	0.002299

4. CONCLUSION

The optimization of tractor fuel consumption per ridged area during ridging operation was achieved by the effective use of the General Full Factorial Design (GFFD) method of statistical experimental design. This was done to guarantee that the least amount of fuel was used per ridged surface and to determine the ideal operating parameters.

1 The plot illustrating the residuals in relation to the observation order demonstrated that, despite adhering to the third assumption regarding observation order, the residual points exhibit complete randomness. The multiple linear regression model developed demonstrates a good fit for the experimental data concerning fuel consumption in tractor-tilled areas during ridging operations, as the assumptions regarding the residuals were largely satisfied.

2 The analysis of variance (ANOVA) indicated that during ridging operations, fuel consumption in the

ridged area was significantly affected (P<0.05) by ridge height and tractor forward speed. This indicates that during a ridging operation, variations in ridge height of 0.10, 0.20, and 0.30 m influenced the fuel consumption of the tractor per unit area of ridging. Fuel consumption during ridging operations was observed to be affected by variations in tractor forward speed of 5, 7, and 9 Km/h. Furthermore, a significant interaction effect (P0.05) was observed between ridge height and tractor forward speed. In conclusion, an elevation in the field variables, including ridge height and tractor forward speed, was observed to influence fuel consumption.

3 Using a numerical method, multiple linear regression models have been developed to predict the amount of fuel that a tractor will use per ridged area during a ridging operation.The model was significantly proven to predict 100%.

4 The optimized tractor fuel consumption per ridged area during ridging was achieved at a tractor forward speed of 5 km/h and ridge height of 0.10 m.

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