Optimization of Fuel Consumption for Tractor-tilled Land Area During Harrowing Operation Using Full Factorial Experimental Design

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Abstract:
This study aim is to improve the tractor harrowing operation's fuel consumption efficiency to cut operating costs and boost agricultural output. The field trial was conducted at Rivers Institute of Agricultural Research and Training (RIART) Farm, Rivers State University, Port Harcourt. The 4,480 m^2 experimental land area, which measured 160 by 38 meters, was divided into three blocks of nine plots each. For the alternative treatment choices, each plot was laid out at 50 m by 2 m, with a path dimension of 1 m between each plot and 2 m between each block and 1 m at the sides of the outer blocks. The tilled area fuel consumption and the field test parameters (harrowing depth and tractor forward speed) were measured in accordance with their respective requirements. Statistical studies of the general full factorial design (GFFD), including model fit assessment, analysis of variance (ANOVA), main and interaction effects, multiple linear regression model, and response optimizer, were carried out using MINITAB 19 software. Standard error (SE), coefficient of determination (r^2), adjusted r^2, and prediction r^2 were also used to test the model's validity. The influence of harrowing depth, tractor forward speed, and their interactions are statistically significant on the tilled area fuel consumption during harrowing, according to the Pareto charts of standard effect. The tilled area fuel consumption data during harrowing were nearly normally distributed, as shown by the normal probability plots, which satisfies the first requirement of the model fitness analysis. A roughly normal distribution was also visible on the histogram plot. This observation also provides more evidence in favor of the typical fuel usage distribution in tractor-tilled areas. The residual vs. fitted value graphs showed that there is no discernible pattern in the data points for tilled area fuel consumption data during harrowing, supporting the constant variance condition of the residuals. A plot of the residual versus observation order reveals that the residual points are likewise entirely random. According to the statistical study, the effects of harrowing depths, tractor forward speed, and their interactions on tractor tilled area fuel consumption during harrowing operation were significant with 95 and very significant with 99% confidence ($P<0.05$ and $P<0.01$ levels of significance). Also, it was demonstrated for example that the multiple linear regression could accurately predict the experimental results with a standard error of very small amounts. For the amount of fuel consumed during harrowing in the tilled area, the coefficients of determination (r^2), adjusted r^2, and anticipated r^2 were all equal to 100%. indicating that the estimated multiple linear regression model created for the tractor tilled area fuel consumptions explained 100% of the variability in the dataset. At harrowing depth of 0.09 m and tractor forward speed of 5 Km/h, optimal tractor tilled area fuel consumption during harrowing was achieved. According to this study, the required minimum fuel consumption for tractor-tilled area under operational parameters (harrowing depth and tractor forward speed) was 6.15 L/ha.

Keywords: General full factorial design, Harrowing, Harrowing depth, Optimization, Tractor forward speed, Tractor-tilled land area fuel consumption.

1. Introduction

Using a tractor has grown in importance when doing tillage the efficient use of fuel in agricultural output has been a major concern for agricultural engineers, tractor owners, and farmers as fuel prices have increased. Fuel consumption is the key determining factor in determining an automobile's condition [1]. To ensure effective fuel utilization using chosen parameters impacting tractor fuel consumption, it is necessary to reduce the fuel consumption of tractors. [2], the cultivator + disc harrow combination performs adequately overall and may be useful for tillage operations carried out in clay loam soils.

According to Michalsk et al. [1], the most important problem -solving parameter in detecting the condition of an automobile is fuel consumption . In addition , for the reason that the continuous rise in fuel prices, energy consumption has become one of the most significant factors in agricultural economy [3].

Tractor's fuel consumption is affected by many variables during tillage operation, these include type and structure of soil, climate, tractor type, tractor size, and tractor-implement relationship [4-8]. Ahaneku et al. [8] studied comparative field evaluation of three models of a tractor and found that the high fuel consumed by tractor could be ascribed to tractor forward speed with a higher wheel slip. Fuel consumption in tillage equipment used is affected by fundamental factors such as in power consumption increment by increasing the working speed, actual width of cut, soil strength, moisture content and the working depth [9-14]. Research by Moitzi et al. [12] showed that increasing working depth, raises the drawbar pull and the slip and the effect is an increased fuel consumption rate (L/h) and area-specific fuel consumption (L/ha). Researchers such as [9-11] reported that within the same operating speed and varying the engine speed , there are significant increases in hourly fuel consumption , which range between the lowest to the highest engine speed operation for tillage operation.

Research has demonstrated that the fuel consumption and operating costs of the disc harrow were higher than those of the cultivator and disc harrow combined. According to [15], variations in the soil-implement-machine characteristics influence the variability in tractor fuel consumption during harrowing operations and as a result, these variations become the deciding variables to cut fuel consumption. They also revealed that the rate at which tractor fuel consumption rises correlates with the number of hours worked and the size of the tilled field.

According to [16], the fuel consumption in harrowing operations might be determined based on fuel consumption per hectare measurement, which is the primary technical indicator in the assessment of the efficiency of usage of agricultural machinery. Furthermore, he claimed that this showed how many factors that impact fuel supply can alter how well an engine transforms the work done by the implement. In order to evaluate the operating fuel consumption of a conventional tillage system to a reduction tillage system using a chisel, [17] employed a harrow.

Moreover, according to [18], forward speed and depth should be taken into account when deciding how much fuel to use during harrowing. The optimization is required to reduce energy consumption during harrowing operations, which causes significant waste and financial loss.

The fuel utilization efficiency will be significantly improved if optimization is used to reduce a tractor's fuel consumption when harrowing. With higher agricultural output and lower operating costs, this results in significant profit margins. With this, it would be possible to anticipate how much fuel will be used throughout certain harrowing activities. Also, the optimal field test parameter combinations for usage prior to field operations and optimizing the variations of the process's variables would be achieved. Using the general full factorial design (GFFD) technique of design of experiments, the multiple linear regression model must take into account fuel consumption, forward speed, and tillage depth. All of these ultimately lead to higher agricultural production profitability.

A crucial part of the decision-making process for a harrowing operation utilizing optimization models is managing fuel usage optimally for optimum profit. Many tractor fuel consumption models for harrowing operations have been created in the literature, including those by [3], [19], and [20]. Yet, there is a lack of knowledge on how to create a tilled area fuel consumption model and optimize it using full factorial design (FFD) of experiment design method. In order to lower operating costs and raise agricultural productivity, the aim of this study is to increase the tractor harrowing operation's tilled area fuel consumption efficiency.

2. Materials and Methods

2.1 Experimental Site Description

The experiment was carried out at the Rivers Institute of Agriculture Research and Teaching (RIART) farm in Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Nigeria. Port Harcourt lies on the latitude of 4° 49′ 27″ N, and longitude of 7° 2′ 1″ E; with an altitude of 274mm above mean sea level; and average annual rainfall depth of 2310.9 mm.

2.2 Experimental Design

The impact of two parameters on the tractor tilled area fuel consumption during harrowing operation was investigated using a 3^2 full factorial design (two factors at three levels with replicates). The two variables were the tractor's forward speed (5, 7 and 9 km) and the harrowing depth (0.09, 0.12, and 0.15 m). The tractor tilled area fuel consumption was the analysed response.

Harrowing activities were divided into three blocks based on tractor fuel consumption per tilled area: block 1 for depths of 0.09 m, block 2 for depths of 0.12 m, and block 3 for depths of 0.15 m.

As seen in Table 1, the design included nine experimental treatments with three duplicates. Using the software MINITAB 19, randomization was accomplished in this investigation (Minitab Inc, State College, PA, USA). The 160 m by 28 m (4,480 m^2) experimental field area was divided into three blocks, each with nine plots, for a total of 27 treatments. Each plot was designated as being 50 m by 2 m in size, with an alley dimension of 1 m between each plot and space of 4 m between each block and 1 m at the sides of the outer blocks available for various treatment possibilities.

TABLE 1
TREATMENT RANDOMIZATION BY MINITAB SOFTWARE VERSION 19

StdOrder	RunOrder	Blocks	Depth, d (m)	Speed, V (Km)
22	1	3	0.2	5
23	2	3	0.2	7
26	3	3	0.3	7
20	4	3	0.1	7
21	5	3	0.1	9
19	6	3	0.1	5
25	7	3	0.3	5
27	8	3	0.3	9
24	9	3	0.2	9
13	10	2	0.2	5
15	11	2	0.2	9
18	12	2	0.3	9
17	13	2	0.3	7
11	14	2	0.1	7
12	15	2	0.1	9
16	16	2	0.3	5

14	17	2	0.2	7
10	18	2	0.1	5
9	19	1	0.3	9
4	20	1	0.2	5
3	21	1	0.1	9
5	22	1	0.2	7
6	23	1	0.2	9
1	24	1	0.1	5
2	25	1	0.1	7
7	26	1	0.3	5
8	27	1	0.3	7

2.3 Tractor and Implement Specifications

The tractor employed in this study to perform the harrowing operation weighs a total of 3015 kg, has an engine horsepower of 72 hp, and has a lifting capacity of 2200 kg. The tires on the front and the back were 7.5-16-8 ply and 16.9-28-12 radials, respectively (Figure 1). For the studies, a disc harrow (Baldan Implementos Agricolas, Brazil) with a 508 mm disc diameter and an 1800 mm frame width installed-type was employed. It had a 9-disc bottom mounted on a gauge wheel (Figure 2).

Figure 1: Tractor (Swaraj 978 FE, Indian)

Figure 2: Disc Harrow (Baldan Implementos Agricolas, Brazil)

2.4 Fuel Flow Meter Specification

The DFM 100CD fuel flow meter (Technoton Engineering, Belarus) with a nominal fuel pressure of 0.2 MPa, a maximum fuel pressure of 2.5 MPa, a minimum kinematic viscosity of 1.5 mm^2/s, a maximum kinematic viscosity of 6.0
mm2/s, a minimum supply voltage of 10 V, and a maximum supply voltage of 45 V (Figure 3).

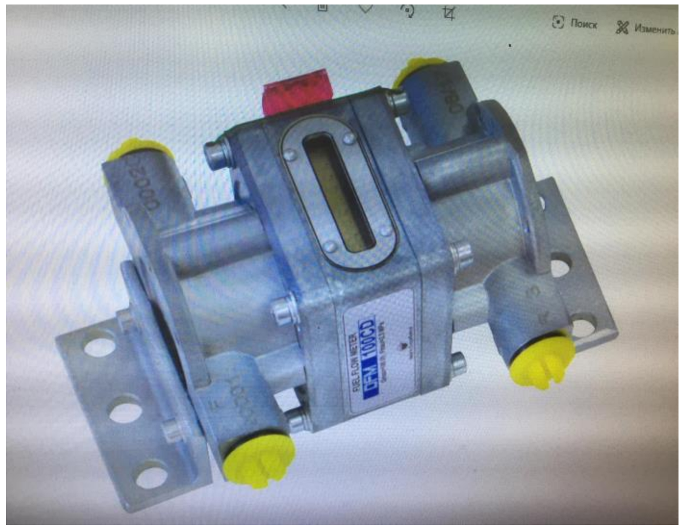

Figure 3: DFM 100CD Fuel Flow Meter (Technoton Engineering, Belarus)

2.5 Experimental Procedures

To lessen parasitic forces, the disc harrow was fastened to the tractor and leveled using the top links of the tractor. The disc harrow was lowered to the desired harrowed depth by adjusting the level control of the lifting mechanism (three-point linkage height). By choosing a certain gear that produced the necessary speed, tractor forward speeds could be calculated. To maintain the desired treatment, this was done in a practice area before each test plot. The width of the cut was measured by placing a steel tape from one side of the furrow wall to the other end, while the depth of the harrowing was measured by setting a meter rule from the bottom of the furrow to the surface of the harrowed field. A stopwatch that was set to zero before each procedure was used to measure the time. To calculate tractor fuel consumption, the digital method of measuring the amount of fuel consumed was utilized. DFM fuel flow meters were used to measure fuel usage during this operation. The fuel line connecting the tractor's fuel tank and the pump had the meter mounted to it. Data from the fuel flow meter was used as display information at the conclusion of each test operation; switching was accomplished by lightly touching the fuel flow meter's top cover while pressing with iButton key. According to equation 1 in mathematics, tilled area fuel consumption was determined [21] as follows:

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

Where:

FC_{ta} = Fuel consumption per tilled area, L/ha;
T_{fc} = Tractor fuel consumption, L;
V = Forward speed, Km/h;
W = Implement width, m

E = Implement field efficiency, %;
h = Working hour h

2.6 Model Fitness Checking

Prior to conducting a more in-depth statistical study, the model fitness checking for tractor tilled area fuel consumption for the examined harrowing operation was carried out. The difference between the measured and expected response value has generally been defined as the residual in statistical contexts. The measured tractor tilled area fuel consumption (actual response) values in this study came from the experimental run and are shown in Tables 2, while the predicted tractor tilled area fuel consumption (predicted response) values came from Table 3 and were obtained by regression analysis, as shown in Section 3 and Table 4.

The following three residuals' assumptions are governed by the fitness checking:

4 the normality assumption of the residuals,
5 constant variance of the residuals, and
6 independent assumption of the residuals.

The validity of these hypotheses would suggest that the developed regression model (Equation 2) generally expresses the measured data accurately. Several statistical residual plots, including the Pareto chart of the standardized effects, the normal probability plot of residuals, the histogram of frequency versus residuals, the plot of residuals versus fitted or predicted values, and the plot of residuals in observation order, can be used to validate these three hypotheses.

2.7 Statistical Analysis

The statistical analyses used in this study were analysis of variance (ANOVA), normal probability plot, residual versus fits plot, interaction plot and response optimizer. A two-way ANOVA was used to analyze the response in this study to determine if there are statistically significant differences between the means of the treatments. Statistical analyses were carried out using MINITAB 19 software (Minitab Inc, State College, PA, USA) with a 95 and 99% confidence level ($p < 0.05$ and $P<0.01$ significance levels) that differences were considered as significant.

2.8 Prediction Equation

The tractor forward speed served as the input variable for the multiple linear regression model reflecting tractor tilled area fuel consumption (response) during harrowing operations, which was expressed as a function of harrowing depth. In order to determine the response equation, harrowing depths (d_1, d_2, and d_3) and tractor forward speed (V_1, V_2, and V_3), are assigned respectively. It is possible to write the multiple linear regression model with two variables (d and V) and their interaction terms as in (equation 2).

The computed linear regression models are as follows:

$$FC_{ta} = \alpha + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 V_1 + \beta_5 V_2 + \beta_6 V_3 + \beta_{11} d_1 V_1 + \beta_{12} d_1 V_2 + \beta_{13} d_1 V_3 + \beta_{21} d_2 V_1 + \beta_{22} d_2 V_2 + \beta_{23} d_2 V_3 + \beta_{31} d_3 V_1 + \beta_{32} d_3 V_2 + \beta_{33} d_3 V_3 \quad (2)$$

Where:
FC_{ta} = Tilled area fuel consumption, L/ha
α = Intercept (Average value of the result),
$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_{11}, \beta_{12}, \beta_{13}, \beta_{21}, \beta_{22}, \beta_{23}, \beta_{31}, \beta_{32}$, and β_{33}, = Interactions' coefficients,
$d_{12,3}$ = depths, m
$V_{1,2,3}$ = velocity, Km/h

The interactive statistical data analysis tool Minitab 19 created the multiple linear regression model for factoring designs.

2.9 Validation of the Multiple Linear Regression Model

The created multiple linear regression model was confirmed by simulating the experimental data with the model, contrasting the experimental and predicted data using standard error, and then comparing the experimental and anticipated data.

2.9.2 Evaluation of Model Prediction Ability

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)] were used to check if the measured and predicted results have good agreement to test its validity. This was carried with Minitab-19 computer software (Minitab Inc, State College, PA, USA).

2.9.2.1 Coefficient of Determination (r^2)

The coefficient of determination (r^2) as a global statistic to assess the fit of the model was determined using (3) ([22]; [23]):

$$r^2 = \frac{SS_{model}}{SS_T} \quad (3)$$

SSmodel was computed using (4) ([22]; [23]):

$$SS_{model} = SS_d + SS_V + SS_{dV} \quad (4)$$

2.9.2.2 Adjusted r^2 (r^2_{Adj})

The adjusted r^2 (r^2_{Adj}) was computed using equation (5) ([22]; [23]):

$$r^2_{Adj} = 1 - \frac{SS_E/(n-p)}{SS_T/(n-1)} \quad (5)$$

2.9.2.3 Predicted r^2

The predicted r^2 (r^2_{Pred}) was computed using (6) ([22]; [23]):

$$r^2_{Prediction} = 1 - \frac{PRESS}{SS_T} \quad (6)$$

Where:
PRESS = Prediction error sum of squares

The PRESS statistic is defined as the sum of squares of the n PRESS residuals and it was calculated using (7) ([22]; [23]):

$$PRESS = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} \left[Y_i - \hat{Y}_{(I)}\right]^2 \quad (7)$$

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

2.10 Optimization of the Tractor Tilled Area Fuel Consumption

The optimization of tractor tilled area fuel usage served as the foundation for this work.

The tractor's disc harrow was used to do the harrowing process. Two variables were changed during the optimization process: varied harrowing depths, and tractor forward speeds. Three different tractor forward speeds of 5, 7, and 9 km/h were used, along with three different depths (0.09, 0.12, and 0.15 m). The response variables (tractor tilled area fuel consumption) were optimized within the 95% confidence and prediction intervals using ANOVA and an optimization graph. With the optimal combination of operating conditions (harrowing depth and tractor forward speed), the response optimizer's desired point was reached at the lowest possible fuel consumption per tractor tilled area. Composite desirability was calculated using (equation 8) [24]:

$$D = \left[n\left(d_i^{w_i}\right)\right]^{\frac{1}{W}} \qquad (8)$$

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

In addition, Individual desirability (d_i) for the minimization ith response was computed as represented in (equation 9) [24]:

$$d_i = \left[\left(U_i - \hat{Y}_i\right)/\left(U_i - T_i\right)\right]^{r_i} \qquad (9)$$

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

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

3 Results and Discussion

3.1 Model Fitness Checking for Tractor Fuel Efficiency Parameters

Figure 4 shows the Pareto chart of the standardized effects on tractor tilled area fuel consumption during the investigated harrowing operation. Finding out the size and significance of an effect is made easier with the help of the Pareto chart of the standardized effects. The t-value limit of a Pareto chart, where t is the quantile of a t-distribution with degrees of freedom equal to the degrees of freedom (24) for the error term, illustrates the absolute value of the effects and delineates a reference line at that point on the chart [25]. Any effect that crosses this reference line and continues beyond it is statistically significant, while effects that cross this reference line and extend along it are statistically insignificant. The graphs demonstrated the statistical significance of the effects of A, B, and AB (i.e., d, V, and dV) (Figures 1). Except for the fact that V and dV had a smaller impact on tilled area fuel consumption during harrowing, the effects of variables d, V, and dV had the maximum standardized influence on tilled area fuel consumption.

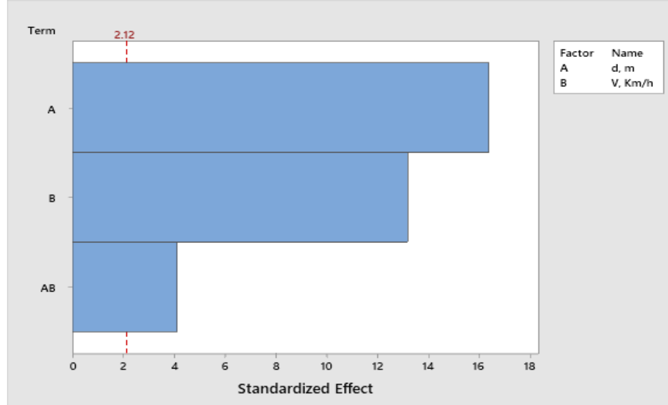

Figure 4: Pareto Chart of Standard Effects (d and V) on Fuel Consumption (FC_{ta}), L/ha for Harrowing ($\alpha = 0.05$)

Figure 5 shows the residual plots for tilled area fuel consumption during harrowing operations. It was discovered by examining all of the normal probability plots that the residual points are dispersed at random on both sides of the straight line. This demonstrated that the fuel consumption data collected during harrowing in tilled areas is roughly regularly distributed, satisfying the first requirement of the model fitness examination. Yet after giving it some thought, it became clear that the histogram plot represented a roughly normal distribution. This observation also provides more evidence in favour of the typical fuel usage distribution in tractor-tilled areas.

In addition, the residual vs fitted value plots demonstrated that the data points for the fuel consumption data collected during harrowing in tilled areas are distributed randomly and without any discernible organization, supporting the residuals' requirement for constant variance. The residual against observation order plot ultimately shown that the residual points are wholly random regardless of observation order. This implies that the residuals were independent of one another and adhered to the third specified residuals assumption. The regression model created in section 3 (Equations 10 and Tables 3) could effectively explain the experimental data for tractor tilled area fuel consumptions during harrowing and operation since all of the residuals' assumptions were generally met.

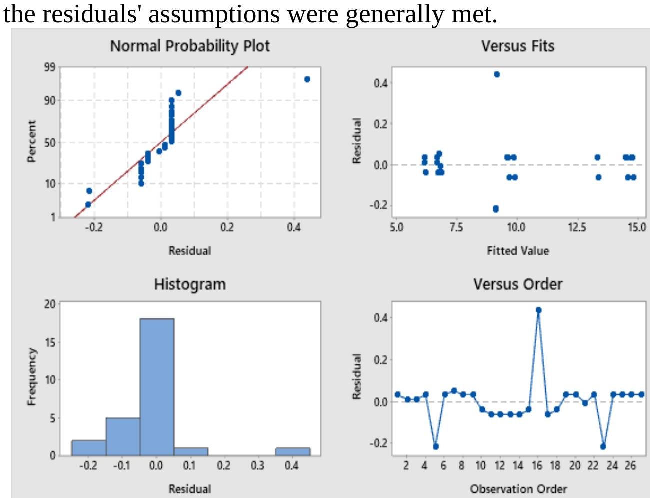

Figure 5: Residual Plots of Model Competence for Tractor Tilled Area Fuel Consumption (L/ha) during Harrowing

3.2 Tilled Area Fuel Consumption during Harrowing Operation

The findings from the field experiment are displayed in Table 1 for the tilled area fuel consumption during the harrowing operation. From the table, it can be noticed that the rise in harrowing depth and tractor forward speed increased the tractor tilled area fuel consumption. It can be assumed that harrowing depth and tractor forward speed have an impact on fuel usage. The results of [21], [26], [27], [15], are comparable to those of this study.

TABLE 2
FIELD TEST RESULTS DURING HARROWING OPERATION

Block	Depth, d (m)	Speed, V (Km/h)	Tilled Area Fuel Consumption, FC_{ta} (L/h)
1	0.09	5.00	6.15
1	0.09	7.00	6.67
1	0.09	9.00	6.8
1	0.12	5.00	8.84
1	0.12	7.00	9.59
1	0.12	9.00	9.83
1	0.13	5.00	13.31
1	0.13	7.00	14.5
1	0.13	9.00	14.74
2	0.09	5.00	6.13
2	0.09	7.00	6.65
2	0.09	9.00	6.82
2	0.12	5.00	8.86
2	0.12	7.00	9.61
2	0.12	9.00	9.85
2	0.13	5.00	13.33
2	0.13	7.00	14.52
2	0.13	9.00	14.76
3	0.09	5.00	6.17
3	0.09	7.00	6.69
3	0.09	9.00	6.78
3	0.12	5.00	8.88
3	0.12	7.00	9.63
3	0.12	9.00	9.87
3	0.13	5.00	13.35
3	0.13	7.00	14.54
3	0.13	9.00	14.78

TABLE 3
FC_{TA} MODEL PREDICTION FOR HARROWING

Block	d (m)	V (Km/h)	FC_{ta} (m) (L/ha)	FC_{ta} (p) (L/ha)	PSE
1	0.09	5.00	6.15	6.15	0.0825014
1	0.09	7.00	6.67	6.67	0.0825014
1	0.09	9.00	6.80	6.80	0.0825014
1	0.12	5.00	9.59	9.11	0.0825014
1	0.12	7.00	9.59	9.61	0.0825014
1	0.12	9.00	9.83	9.85	0.0825014
1	0.15	5.00	13.31	13.33	0.0825014
1	0.15	7.00	14.50	14.52	0.0825014
1	0.15	9.00	14.74	14.76	0.0825014
2	0.09	5.00	6.13	6.15	0.0825014
2	0.09	7.00	6.65	6.67	0.0825014
2	0.09	9.00	6.82	6.80	0.0825014
2	0.12	5.00	8.86	9.11	0.0825014
2	0.12	7.00	9.61	9.61	0.0825014
2	0.12	9.00	9.85	9.85	0.0825014
2	0.15	5.00	13.33	13.33	0.0825014
2	0.15	7.00	14.52	14.52	0.0825014
2	0.15	9.00	14.76	14.76	0.0825014
3	0.09	5.00	6.17	6.15	0.0825014
3	0.09	7.00	6.69	6.67	0.0825014
3	0.09	9.00	6.78	6.80	0.0825014
3	0.12	5.00	8.88	9.11	0.0825014
3	0.12	7.00	9.63	9.61	0.0825014
3	0.12	9.00	9.87	9.85	0.0825014
3	0.15	5.00	13.35	13.33	0.0825014
3	0.15	7.00	14.54	14.52	0.0825014
3	0.15	9.00	14.78	14.76	0.0825014

3.3 Main and Interaction Effects of Harrowing Depth and Tractor Forward Speed on Tractor Fuel Efficiency Parameters for Studied Tillage Operations

Harrowing depth and tractor forward speed were the key variables examined in this study. The main and interaction plots, which are depicted in Figures 3 and 4, reveal the individual and combined effects of the two main factors (with three levels) on the specific response (tractor tilled area fuel consumption during harrowing).

ANOVA is a statistical decision-making tool used to examine performance mean differences and facilitates determining the importance of all major elements. According to [28] and [29], an ANOVA was performed to assess the statistical significance of operational parameters to responses of a certain developed product or application.

In this study, the effects of harrowing depth (d) and tractor forward speed (V) on the response, such as tractor fuel consumption during harrowing, were evaluated using an ANOVA. The significance of these effects was determined by looking at the F value at the 5 and 1% significance levels and the probability value, or "p-value," of the analysis. The null hypothesis (H0) of an ANOVA often asserts that one or more operational factors do not significantly affect the means of any responses; H0: H0: $\mu 1 = \mu 2 = \ldots = \mu a$ [30]. According to the majority of researchers, the p-value must be equal to or lower than 0.05 in order for the operating factors to be statistically significant in influencing the investigated response, which results in the rejection of the null hypothesis for the ANOVA ([31]; [32]; [28]; [29]).

Based on the measurement of fuel consumption per hectare, the primary technical indicator in the evaluation of agricultural machinery efficiency for fuel consumption could be reached [33]. Figures 3 and 4 show the main and interaction plots for the amount of fuel consumed by the tilled area during the harrowing operation. The slope of the plots revealed the relative potency of the effects of the variables (harrowing depth and tractor forward speed). The addition of a center point to the design revealed that the curve between the levels had been noticed. Fuel consumption (L/ha) at the center of the factors is adequate to provide a decent tilled area. A minimum tilled area fuel consumption (L/ha) was attained in Figure 6 at a harrowing depth of 0.09 m and tractor forward speed of 5 Km/h; however, it may grow by increasing the harrowing depth or tractor forward speed or decreasing either of the two or both. The results showed that harrowing depths of 0.09 to 0.15 m and tractor forward speeds of 5 to 9 Km/h result in an increase in the tilled area fuel consumption (L/ha). This is in line with the conclusions reached by [33] and [15]. The results showed that the needed tilled area fuel consumption (L/ha) during the harrowing operation is given by the reduced harrowing depth and tractor forward speed. According to the interaction plots (Figure 7), it was found that by lowering the tractor's forward speed and harrowing depth, less fuel would be used for tilling. The interaction graphs still demonstrated that the lines are not parallel to one another. They suggested that there is a significant interaction between the variables (harrowing depth and tractor forward speed). This supports the conclusions reached by [33] and [15]. When the means of the treatments were compared statistically on the main effects of harrowing depth and tractor forward speed during harrowing, the ANOVA results of tractor tilled area fuel consumption during harrowing showed that there is a significant difference between the means at 5 and 1% levels of significance because the calculated "F" value (6576.77 and 107.81) is higher than the table "F" value (3.63 and 6.23, respectively). At the 5% and 1% levels of significance, the interactions of d and V also had estimated "F" values (8.33) that were higher than the table's "F" values (3.63) and indicated a highly significant difference between the means. Furthermore, it was discovered that the p-value for the linear factors: "d" and "V," as well as the interaction factor "dV," is zero (0.000) for every response (tractor tilled area fuel consumption). The factor is judged to have a greater significant impact on the answer when the p-value is less than 0.05. [34]. According to the analysis, the ANOVA findings indicated that the p-value (0.00) for both components (d and V) and their combinations is less than the probability level (P 0.05). It may be concluded that the tractor tilled area fuel consumption was considerably influenced by both the harrowing depth (d) and tractor forward speed (V) operational parameters. The results of [21], [18], and [15] all support this.

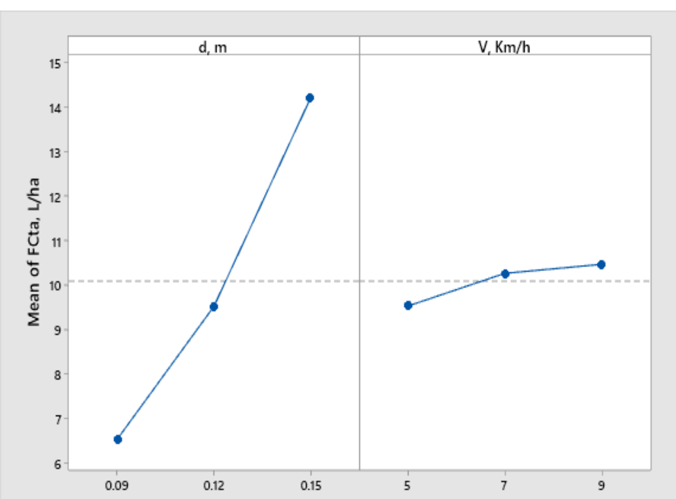

Figure 6: Plot of Main Effects (d and V) on FC_{ta} for Harrowing

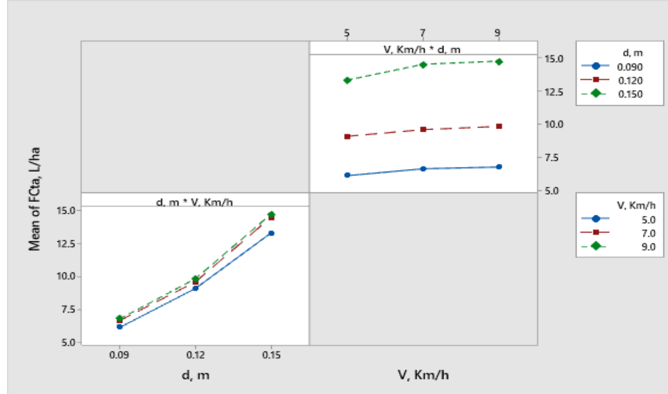

Figure 7: Plot of Interaction (d and V) on FC_{ta} for Harrowing

3.4 Developed Expression of the Effects of Harrowing Depth and Tractor Forward Speed on Tractor Tilled Area Fuel Consumption Using Numerical Approach for Harrowing Operation

In addition to main and interaction effect plots, a numerical technique is also a viable option for expressing how operational parameters affect a particular response. Regression model analysis may be used to do it, as shown in Tables 4 ([30]; [23]; [35]). This regression study includes the r^2 coefficient of determination, the d, V, and dV factor coefficients, the standard error (SE) coefficient, the constant values, the p-value, and finally the regression equation. Tables 4 provide the regression equation and coefficient of determination (r^2).

In the meantime, Tables 4 show thorough information about each factor's coefficient, values of constants, and p-value. The constructed multiple linear regression model (equations 10) used p-value to show the relevance of this constant and regression coefficient.

The calculated coefficients for the multiple linear regression model and the regression analysis for the amount of fuel consumed during harrowing are shown in Table 3. The p-Value for the constant was 0.000, suggesting that it was significant in the multiple linear regression model. The value of the constant for the tilled area fuel consumption during harrowing was 10.0889 and SE of 0.0275. (Equations 10).

The p-value for the coefficient of factor V (tractor forward speed) was 0.000, and the p-value for the coefficient of factor d (harrowing depth) was 0.00, which is less than 0.05. The p-values were 0.000 in regard to the coefficient for interaction factors (dV). This is a review of the generated multiple linear regression model's approval (Equation 10). Additionally, examination of various statistical variables like r^2, r^2(adj.), and r^2(pred.) was also taken into account. The multiple linear regression model of tilled area fuel consumption during harrowing has a high r^2 value of 100%, according to the regression study. This showed that the multiple linear regression model could accurately describe all of the fuel consumption experimental data from the tilled area (Equation 10). Tilled area fuel consumption regression had a r^2(adj.) value of 100% with regard to the constructed multiple linear regression model's correctness. With such high values of r^2(adj.), the multilinear regression model was judged to have excellent accuracy and be a good representation of the real experimental data. Also, the regression model for fuel consumption in tilled areas has a high value of r2(pred.) at

100%. This implied a high likelihood that the fuel consumption data from tilled areas would be anticipated by the regression model. Also, the discrepancy between r2(adj.) and r2(pred.) for the fuel consumption of the tilled area was 0.00, which was much lower than 20. The expression of the measured data by the regression model is therefore very accurate. In general, it could be said that the created multiple linear regression model (Equation 10) for tilled area fuel consumption during harrowing was highly significant based on the p-value, r^2, r^2(adj.), and r2(pred.) criteria. The estimated multiple linear regression model created for the tractor tilled area fuel consumption during harrowing explained 100% of the variability in the dataset.

TABLE 4
ESTIMATED COEFFICIENTS FOR FC_{TA} MULTIPLE LINEAR REGRESSION MODEL DURING HARROWING

Term Blocks	Symbol	Coefficient	SE Coefficient	P-Value
Constant	α	10.0889	0.0275	0.000
d				
0.09	β_1	-3.5489	0.0389	0.000
0.12	β_2	-0.5656	0.0389	0.000
0.15	β_3	4.1144	0.0389	0.000
V				
5	β_4	-0.5589	0.0389	0.000
7	β_5	0.1778	0.0389	0.000
9	β_6	0.3811	0.0389	0.000
dXV				
0.09X5	β_{11}	0.1689	0.0550	0.000
0.09X7	β_{12}	-0.0478	0.0550	0.000
0.09X9	β_{13}	-0.1211	0.0550	0.000
0.12X5	β_{21}	0.1456	0.0550	0.000
0.12X7	β_{22}	-0.0911	0.0550	0.000
0.12X9	β_{23}	-0.0544	0.0550	0.000
0.15X5	β_{31}	-0.3144	0.0550	0.000
0.15X7	β_{32}	0.1389	0.0550	0.000
0.15X9	β_{33}	0.1756	0.0550	0.000

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

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

3.5 Optimal Response (Tractor Fuel Efficiency Parameters) for Studied Tillage Operations

The answers optimizer in MINITAB 19 can be used to identify the ideal condition of controlled factors or variables based on the constructed multiple linear regression model in order to achieve the required operating conditions for tractor fuel consumption for harrowing activities. This study focused only on one response - the fuel consumption during harrowing in tilled areas. The objectives were to harrow at the same levels of fuel consumption as in tilled areas. The optimization plot for tilled area fuel consumption during harrowing is shown in Figure 8, and the results of the best possible solution are shown in Table 4. The research estimated that the minimal amount of fuel needed to harrow an area was 6.15 L/ha. These desired responses were obtained with a composite desirability (D) of 0.997688, which was higher than 0.90 and more closely approaching 1.00, at a harrowing depth of 0.09 m and a tractor forward speed of 5 Km/h. Another statistical parameter to check the accuracy of the optimization plot is the composite desirability (D) [36]. [37] revealed that when the composite desirability (D) is closer to 1.00, the optimization of factors and response gleaned from the statistical analysis is extremely trustworthy and accurate. As a result, the solution in Table 5 and the ideal conditions suggested in the optimization plot (Figure 8) were both generally trustworthy and fully adhered to the constructed multiple linear regression model.

TABLE 5
OPTIMIZATION SIMULATION RESULT FOR FC_{TA} DURING HARROWING

Solution	d, m	V, Km/h	FC_h, L/ha (m)	FC_{ta}, L/ha Fit	Composite Desirability
1	0.09	5	6.15	6.15	0.997688
2	0.09	7	6.67	6.67	0.937572
3	0.09	9	6.80	6.80	0.922543
4	0.12	5	9.59	9.11	0.655491
5	0.12	7	9.59	9.61	0.597688
6	0.12	9	9.83	9.85	0.569942
7	0.15	5	13.31	13.33	0.167630
8	0.15	7	14.50	14.52	0.030058
9	0.15	9	14.74	14.76	0.002312

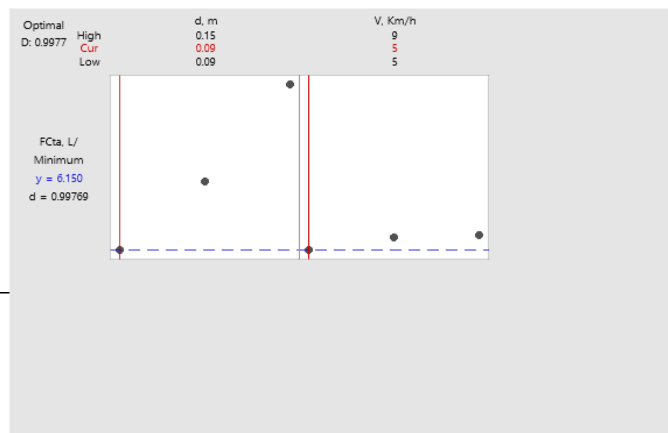

Figure 8: FC_{ta} Optimization Plot for Harrowing

4. Conclusion

In order to minimize the fuel consumption in the tilled land area during harrowing, the use of a full factorial experimental design was effectively used to optimize tractor fuel use. The standard effect Pareto charts showed that the influence of factor A (tillage depth), factor B (tractor forward speed), and interaction of AB (i.e., d, V, and dV) on the tilled area fuel consumption during harrowing are statistically significant. The tilled area fuel consumption data during harrowing is roughly normally distributed, as shown by the normal probability plots, which satisfies the first requirement of the model fitness analysis. A roughly normal distribution was also visible on the histogram plot. This observation also provides more evidence in favor of the typical fuel usage distribution in tractor-tilled areas. The residual vs fitted value plots demonstrated that the data points for the fuel consumption data collected during harrowing in tilled areas are distributed randomly and lack any discernible organization, supporting the residuals' requirement for constant variance. Also, despite observation order being consistent with the third assumption, the residual versus observation order plots indicated that the residual points are fully random. The multiple linear regression model created could effectively explain the experimental data for tractor tilled area fuel consumption during harrowing operations because all of the residuals' main assumptions were met. According to the analysis of variance (ANOVA), the tractor forward speed and harrowing depth had a significant impact ($P<0.05$) on the tilled area fuel consumption during harrowing. This shows that variations in the harrowing depths of 0.09, 0.12, and 0.15 m had an effect on tractor fuel consumptions during the harrowing process. Similar to this, the fuel consumption of the tractor's tilled area was affected by the change in tractor forward speed of 5, 7, and 9 km/h. Moreover, there was a significant ($P<0.05$) relationship between harrowing depth and tractor forward speed that affected how much fuel was used by the tractor. The overall rise in field factors, such as tillage depth and tractor forward speed, has an impact on tilled area fuel consumption during harrowing operations. Utilizing a numerical technique, determine the impact of tractor forward speed and tillage depth on fuel consumption. For the purpose of estimating tractor fuel consumption in tilled areas during harrowing operations, expression (multiple linear regression model) for the impacts of harrowing depth and forward tractor speed on tractor fuel consumption were formulated. According to the model, the coefficients for the multiple regression model of tilled area fuel consumption for the various harrowing operations were produced. The model's ability to accurately anticipate was strongly demonstrated. The optimum tillage depth and tractor forward speed for harrowing were 0.09 m and 5 km/h, respectively.

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