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Optimization of Fuel Consumption during Ploughing Operation on Tractor Tilled Area

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Abstract

This study aims to optimize fuel consumption during ploughing operations on tractor-tilled areas to reduce operating costs and increase agricultural output. A 3 x 3 factorial design experiment with three replicates was carried out to examine the effects of ploughing depth and tractor forward speed on fuel consumption. The ploughing depths tested were 0.10, 0.20, and 0.30 m, and the tractor forward speeds were 5, 7, and 9 km/h. Fuel consumption was measured according to their respective requirements. Statistical analyses, including analysis of variance (ANOVA), main and interaction effects, multiple linear regression model, standard error, coefficient of determination (r^2), adjusted r^2, prediction r^2, and response optimizer, were performed using MINITAB 19 software to validate the model. The results of the statistical analysis indicated a significant impact of ploughing depth, tractor forward speed, and their interactions on tractor fuel consumption per tilled area at a 95% confidence level. The small standard error values confirmed the accuracy of the multiple linear regression model in predicting the experimental data, with r^2, adjusted r^2, and predicted r^2 values all at 100%. The estimated multiple linear regression model accounted for 100% of the variability in the dataset, with an optimal fuel consumption of 6.08 L/ha achieved at a ploughing depth of 0.10 m and a forward tractor speed of 5 km/h.

Introduction

Tillage operation is an essential farm operation that is done to prepare land for crop production, at a suitable soil strength and moisture content level for traction to be developed by the tractor. The disc plough is an effective and extensively used tool for tillage operations on virgin, rocky, and wet soils. Pandy (2004) identified the type of crops to be planted, the properties of soil and the available power source as major factors that determines the depth of the plough. On power source, Ismail *et al.* (2009) signify that a tractor with 47.81 Kw is suitable for all plough widths and forward speeds and this can be applied to tillage operations based on their recommendations. According to Nkakini (2015), the ideal speed for ploughing ahead on loamy sand soil is 1.94 m/s (7 km/h). Additionally, Ranjbarian *et al*. (2015) demonstrated that the rise in results brought about by forward speed also resulted in an increase in the need for draught while wheelslip and fuel consumption increase in response to increases in ploughing depth and traction power (Vilde, 2004; Soltani and Loghavi, 2007; Aday *et al*., 2011; Tayel *et al*., 2015). It is known that fuel consumption during tillage operations is influenced by variations in soil texture while some researchers (Ekemube *et al*., 2020; Nkakini and Ekemube, 2020) proposed that the two most important factors in reducing fuel usage are forward speed and ploughing/harrowing depth. Also,

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selecting an appropriate driving strategy that dictates operating around the ideal engine operating point is the most effective way to save fuel (Moitzi *et al*., 2014). Leghari *et al*. (2016) investigated the relative effectiveness of various tillage techniques and their impact on the physical characteristics of the soil in the semi-arid region of Tandojam, Pakistan. They found that the disc plough required more fuel (23.3 L/ha) to operate at a slower speed (4.1 km/h) and reduced travel distance (27.5%). However, they observed reduced journey reduction (21.8%) and fuel usage (14.9 L/ha) at higher cultivator running speeds (4.76 km h^{-1}). Overall, increases in the field factors, such as tractor forward speed and harrowing depth, have an impact on the hourly fuel consumption during harrowing operations (Ekemube *et al*., 2023a, 2023c). Thereby employing a numerical technique to determine the impact of harrowing depth and tractor forward speed on tractor hourly fuel consumption was achieved at the lowest speed and depth (Ekemube *et al*., 2023a, 2023b).

Agriculture is becoming more productive with the prediction of quality of produce using infrared thermography (Atta *et al.,* 2022) and this makes the prediction of fuel usage for various operations very important. Smart technology extends beyond the production and processing of crops, Jongbo and Atta (2019) used different state of the art technologies to assess the thermal comfort of livestock. A fuel consumption equation was developed by Nkakini *et al*. (2019) to predict fuel consumption during ploughing operations. They suggested utilizing this model to estimate fuel usage when employing a disc plough in plowing operations. In order to determine fuel use during harsh operations, they developed another equation to predict fuel consumption. Al-Dosary *et al*. (2019) predicted tractor-chisel systems' fuel usage using the k-nearest neighbors (KNN) algorithm with k = 2. According to their report, this can assist farmers choose the right tractors and equipment, which will lower the cost of tillage. The use of the Buckingham pi theorem to the building of a tractor fuel consumption model for ploughing operations was investigated by Ekemube and Atta (2023). Shahakar *et al*. (2019) define optimization technique as a mathematical method for resolving the problem of selecting the optimal option among the available options given the constraints.

Using the energy-based mathematical model of tillage units, Nurmiev *et al.* (2018) conducted research on the optimization of the tractor's primary parameters when operating with soil-processing implements based on computational tests using Matlab. It was reported that the range of power variation limits is more significant, specifically between 300 and 450 horsepower; lower power tractors are more effective because they have less seasonal load on the unit and increase the coefficient of shifts, or the amount of work done during the day; the optimal width of the tillage implements stays between 7 and 9 meters, usually between 7.5 and 9 meters; and the optimal speed can vary between 6 and 13 kilometers per hour, most frequently between 8 and 11 kilometers per hour. Aboukarima (2016) investigated the use of response surface methods to maximize a disk plow's fuel efficiency in loamy sand soil. He stated that it was possible to accept the ideal circumstances for the fuel consumption that the MINITAB program Version 16 had forecasted. Within the researched range of the explored factors, the model can be used to estimate the fuel consumption of a disk plow operating on loamy sand soil. Additionally, Ekemube *et al*. (2023a, 2023b) optimized the fuel consumption of tractors for harrowing operations on tilled areas and hourly basis, respectively. Hence, the aim of this study was to optimize fuel consumption during ploughing operation on tractor tilled area in order to lower operating costs and boost agricultural output.

Materials and Methods

Experimental site description

The experiment was conducted 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.

Experimental design

The 3 x 3 factorial design (two factors at three levels) with three (3) replicates was carried out to investigate the impact of two factors on the tractor fuel consumption during ploughing operation. The two factors were the ploughing depth (0.10, 0.20 and 0.30 m) and the tractor forward speed (5, 7 and 9 km/h). The analyzed response was the tractor hourly fuel consumption. Based on tractor fuel hourly, ploughing operations were divided into block 1 for depths of 0.10 m, block 2 for 0.20 m depths, and block 3 for 0.30 m depths for ploughing respectively. The design consisted of 9 experimental treatments with three replicates as explained in Table 1. In this study randomization was achieved by general full factorial design (GFFD) of design of experiment using MINITAB 19 software program (Minitab Inc, State College, PA, USA). The experimental land area was 160 m by 28 m (4,480 m^2) which was divided into three blocks of 9 plots each making a total of 27 treatments. Each plot was marked 50 m by 2 m each along with alley dimension of 1 m between each plot was provided for different treatment options and with a space of 4 m between each block and 1 m at the sides of the of the outer blocks.

Tractor and implement specifications

The tractor used to carry out ploughing operation in this study has a total weight of 3015kg, engine horsepower of 72 hp and lifting power of 2200 kg. Front and the rear tyres were 7.5 –16, 8 ply and 16.9 – 28, 12 radials respectively (Plate 1). A 1180 mm frame width mounted-type disc plough with disc diameter of 300 mm of disc plough (Baldan Implementos Agricolas, Brazil) with 3-disc bottom mounted on a gauge wheel was used for the experiments (Plate 2).

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
'E	'E	'E	'E	'E
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

Plate 1: Tractor (Swaraj 978 FE)

Plate 2: Disc Plough

Fuel flow meter specification

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

Plate 3: DFM 100CD fuel flow meter (Technoton Engineering, Belarus)

Experimental procedures

The particle size distribution analysis was carried out using the hydrometer method modified by Juo (1979). The percentage sand, silt and clay were determined based on gravitational sedimentation as governed by stokes law. The percentage proportion of the soils were simulated in excel spreadsheet by TAL for window and the soil class was determined. Finally, the soil texture was also established using soil textural triangle according to United State Department of Agriculture (USDA). The disc plough was attached to the tractor and levelled using the top links of the tractor in order to reduce parasitic forces. The ploughing depths were determined by setting the level control of the lifting mechanism (three-point linkage height) to lower the disc plough to the desired ploughed depth. Tractor forward speeds were determined by selecting a particular gear that gave the desired speed. This was done in a practice area in advance for each test plot to maintain the desired treatment. The ploughing depth measurement was done by placing the meter rule from furrow bottom to the surface of the ploughed land. Time was determined with a stopwatch set at zero before each operation. The digital method of measuring the quantity of fuel used was adopted to determine tractor fuel consumption. During this process, the use of DFM fuel flow meter was employed to measure fuel consumption. The metre was mounted on the fuel line between the tractor's fuel tank and the pump. At the end of each test operation, the data was taken from the fuel flow meter as display information, switching is performed by light touch to the top cover of fuel flow meter by iButton key. Mathematically, fuel consumption per tilled area was calculated by expression in equation 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 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

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.

Prediction equations

The multiple linear regression model representing tractor fuel consumption per tilled area during ploughing operation were expressed as a function of ploughing depth and tractor forward speed being the input variable of tractor fuel consumption per tilled area (response). The multiple linear regression models with two variables (d and V) with their interaction terms can be expressed as in (equation 2). To estimate the parameters, α and 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}, the means, the corrected sums of squares and the corrected sum of cross products of variables were computed. Thus, the estimated linear regression model is:

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

where:
FC_{ta} = Fuel consumption per tilled 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,
$d_{12,3}$ = depths, m
$V_{1,2,3}$ = velocity, Km/h

The multiple linear regression models were formulated by Minitab 19 interactive statistical data analysis tool for factoring designs.

Validation of the multiple linear regression model

The formulated multiple linear regression models were validated by simulating the experimental data with the model and then comparing the experimental with the predicted data using standard error.

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). These were expressed in equations 3 to 6 (Montgomery and Runger, 2014; Montgomery 2017):

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

$$r^2_{Adj} = 1 - \frac{SS_E/(n-p)}{SS_T/(n-1)} \quad (4)$$

$$r^2_{Prediction} = 1 - \frac{PRESS}{SS_T} \quad (5)$$

where:

PRESS = Prediction error sum of squares

$$PRESS = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} \left[Y_i - \hat{Y}_{(I)}\right]^2 \quad (6)$$

Where:

e_i = Prediction error (ith PRESS residual)

Y_i = Predicted data

$\hat{Y}_{(I)}$ = Mean of predicted data

Optimization of the tractor fuel consumption

Optimization graph were employed for the optimization of the response variables (tractor fuel consumption per tilled area) within the 95% confidence and prediction intervals. The desirable point for the response optimizer was achieved at the best corresponding minimum tractor fuel consumption per tilled area with the combination of operating conditions (ploughing depth and tractor forward speed). The optimization process was performed with Minitab-19 (Minitab Inc, State College, PA, USA).

Results and Discussion

Soil textural classification

The result of the particle size distribution (PSD) of the air-dried soil before each of the studied tillage operations indicated the relative contents of soil particles of various sizes such as sand, silt and clay in the soil (Table 2). Using the United State Department Agriculture (USDA) soil textural classification scheme, it was revealed that the soil texture was loamy sand for the depths of 0 – 10 cm, and 10 – 20 cm, and sandy loam for depth of 20 – 30 cm, respectively.

Main and interaction effects of tillage depth and forward speed on tractor fuel consumption

The results of the fuel consumption per tilled area during ploughing operation obtained from the field experiment results are presented in Table 3. From the Table it can be observed that the increase in ploughing depths and tractor forward speed increased the tractor fuel consumption per tilled area. It can be inferred fuel consumption is affected by ploughing depth and tractor forward speed. This is similar to the findings of Ekemube and Atta (2023).

In this study, the main factors evaluated were ploughing depth and tractor forward speed. The main and interaction plots illustrate the single and the combination effects of both main factors (with three different levels) to the particular response (tractor tilled area fuel consumption during ploughing, as shown in Figs. 1 and 2. ANOVA was conducted to evaluate the statistical significance of operating factors to responses of a particular developed product or application (Abdel-Ghani *et al*., 2009; L’Hocine and Pitre, 2016; Mohammed Razzaq *et al*., 2020).

Table 2: Soil textural class (particle size distribution)

Sample	Depth, d (cm)	Percentage, % by Mass			Textural Class
		Clay	Silt	Sand	(USDA)
A	0 – 10	9.60	6.80	83.60	Loamy sand
B	11 – 20	8.60	9.80	81.60	Loamy sand
C	21 – 30	12.60	6.80	80.60	Sandy loam

Table 3: Field test results during ploughing operation

Block	Depth, d (m)	Speed, V (km/h)	Tilled area fuel consumption, FC_{ta} (L/ha)
1	0.10	5.00	6.08
1	0.10	7.00	6.59
1	0.10	9.00	6.78
1	0.20	5.00	8.80
1	0.20	7.00	9.49
1	0.20	9.00	9.86
1	0.30	5.00	13.16
1	0.30	7.00	14.23
1	0.30	9.00	14.64
2	0.10	5.00	6.06
2	0.10	7.00	6.61
2	0.10	9.00	6.76
2	0.20	5.00	8.78
2	0.20	7.00	9.47
2	0.20	9.00	9.84
2	0.30	5.00	13.14
2	0.30	7.00	14.21
2	0.30	9.00	14.62
3	0.10	5.00	6.10
3	0.10	7.00	6.57
3	0.10	9.00	6.80
3	0.20	5.00	8.82
3	0.20	7.00	9.51
3	0.20	9.00	9.88
3	0.30	5.00	13.18
3	0.30	7.00	14.25
3	0.30	9.00	14.66

Figures 1 and 2 displayed the main and interaction effects plots for tilled area fuel consumption during ploughing operation. The relative strength for the effect of the factors (tillage depth and tractor forward speed) was indicated by the slope of the plots. In Figure 1, the result showed that the tilled area fuel consumption (L/ha) increases from ploughing depth of 0.1 to 0.3 m and tractor forward speed of 5 to 9 Km/h. This agrees with the findings of Moitzi *et al*. (2014); Leghari *et al*. (2016); Nasir (2016); Almaliki *et al*. (2016). Results showed that reduced tillage depth and tractor forward speed are giving a desirable tilled area fuel consumption (L/ha) during ploughing operation. Considering the interaction plots (Fig. 2), it was observed that the interaction plots showed that the lines are not parallel to each other. These imply that there is strong interaction effect between the factors (ploughing depth and tractor forward speed). This is in agreement with the finding of of Aboukarima (2016); Shafaei *et al*. (2018); Nkakini and Ekemube (2020).

The ANOVA results of tractor tilled area fuel consumption during ploughing is displayed in Table 4. When the means of the treatments were compared statistically on the main effects of ploughing depth and tractor forward speed, it was revealed that there is significant difference between the means at 5 and 1% levels of significance. The interactions of d and V showed a highly significant difference among the means at 5 and 1 % levels of significance. Based on the analysis, the ANOVA results showed that the p-value (0.00) in both factors (d and V) and their combinations is less than probability level ($P < 0.05$). It can be inferred that both tillage depth (d) and tractor forward speed (V) operating factors significantly influenced the tractor tilled area fuel consumption during ploughing, This similar to the finding of Moitzi *et al*. (2014); Leghari *et al*. (2016); Nasr (201Almaliki *et al*. (2016a); Aboukarima (2016); Shafaei *et al*. (2018); Nkakini and Ekemube (2020), Igoni *et al*. (2020); Ekemube *et al*. (2020).

Table 4: Two-yay Analysis of Variance for FC_{ta} during Ploughing

Source	DF	Adj SS	Adj MS	Computed F-Value	Tabular F-Value		P-Value
					5 %	1 %	
Model	10	265.431	26.543	149304.84**	2.49	2.69	0.000
Blocks	2	0.004	0.002	12.25**	3.63	6.23	0.000
Linear	4	264.931	66.233	372558.84**	3.01	4.77	0.000
D	2	259.400	129.700	729563.25**	3.63	6.23	0.000
V	2	5.530	2.765	15554.44**	3.63	6.23	0.000
2-Way Interactions	4	0.496	0.124	697.12**	3.01	4.77	0.000
dV	4	0.496	0.124	697.12**	3.01	4.77	0.000
Error	16	0.003	0.000				
Total	26	265.434					

****-** highly significant

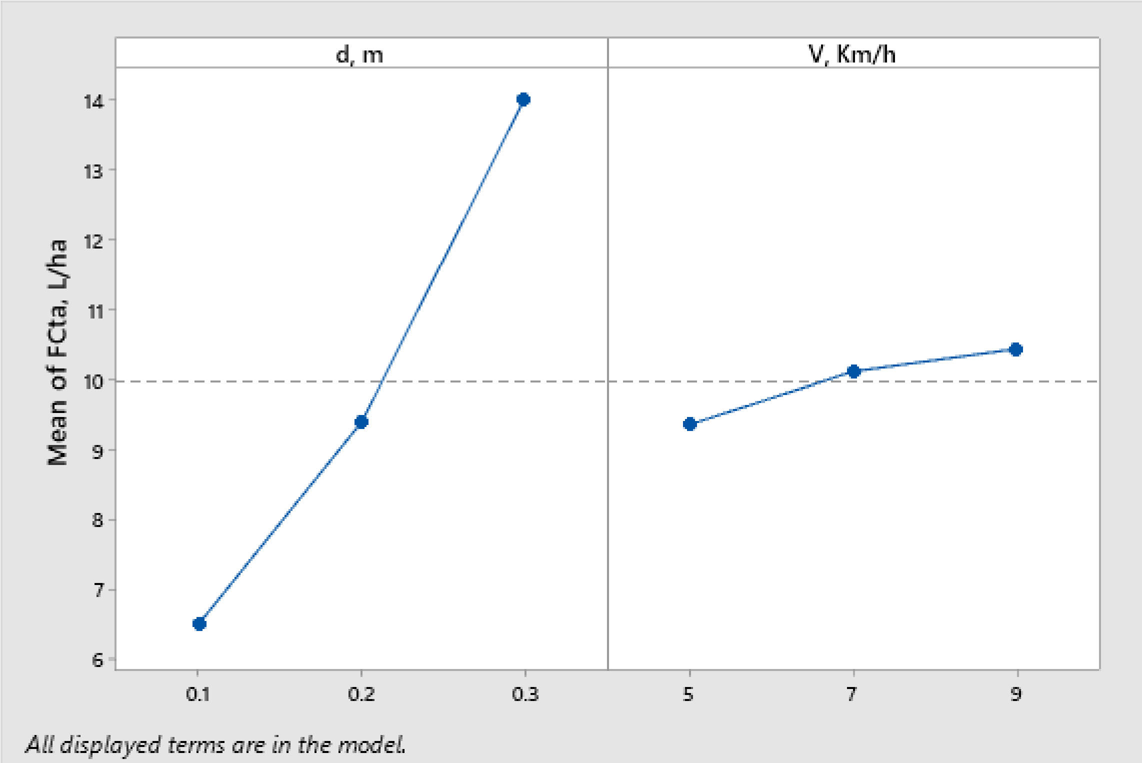

Fig. 1: Plot of main effects (d and V) on FC_{ta} for ploughing

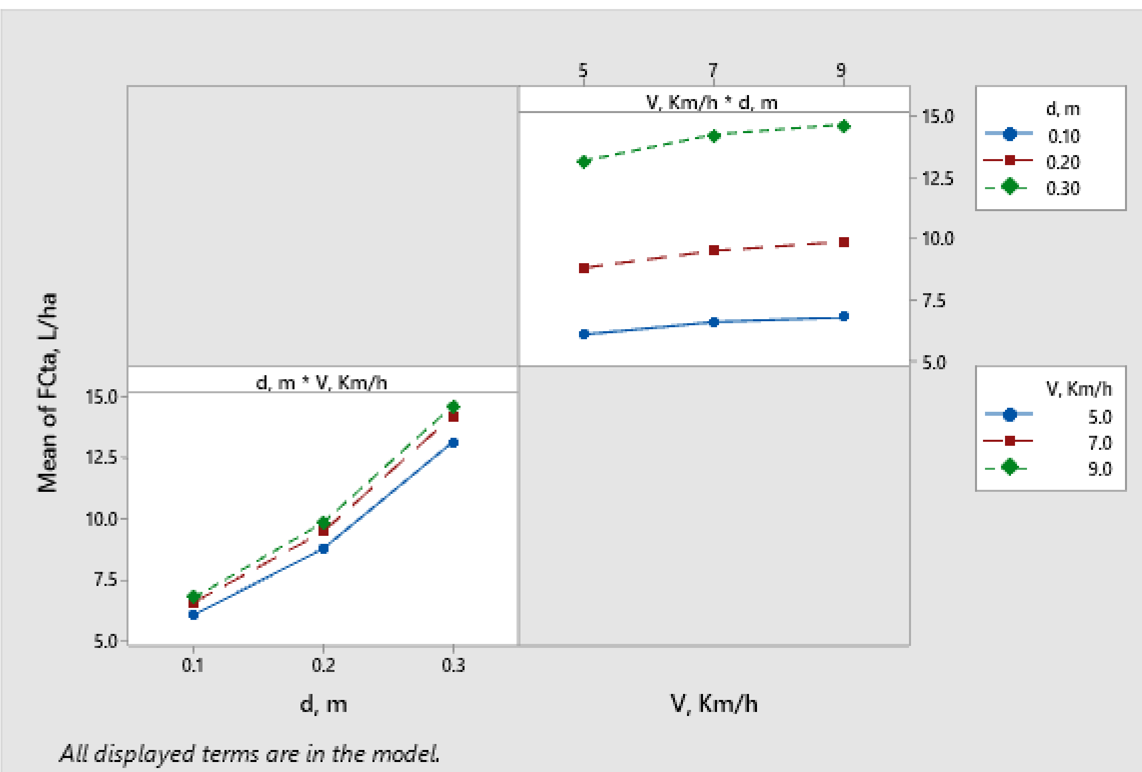

Fig. 2: Plot of interaction (D and V) on FC_{ta} for Ploughing

Empirical model for the optimization of fuel consumption at different treatments

Irrespective of main and interaction effects plots, there is also available alternative for the expression of the effect of operating factors on specific responses in a numerical approach. It may well be accomplished by means of regression model analysis (Montgomery, 2013; Montgomery, 2017; Javed *et al*., 2020), as displayed in Table 4. This regression analysis comprises coefficient of determination (r^2), coefficient of each factor (d, V and dV), standard error (SE) coefficient, values of constant, p-value and then, regression equation. The coefficient of determination (r^2) and regression equation are presented below Table 5. In the meantime, the comprehensive details of each factor's coefficient, values of constant and p-value are displayed in Table 6. The significance of this constant and regression coefficient in the developed multiple linear regression models (equation 10) were indicated by p-value.

Table 5: FC_{ta} model prediction for ploughing

Block	d (m)	V (Km/h)	FC_{ta} (m) (L/ha)	FC_{ta} (p) (L/ha)	PSE
1	0.10	5.00	6.08	6.08	0.0076980
1	0.10	7.00	6.59	6.59	0.0076980
1	0.10	9.00	6.78	6.78	0.0076980
1	0.20	5.00	8.80	8.80	0.0076980
1	0.20	7.00	9.49	9.49	0.0076980
1	0.20	9.00	9.86	9.86	0.0076980
1	0.30	5.00	13.16	13.16	0.0099070
1	0.30	7.00	14.23	14.23	0.0076980
1	0.30	9.00	14.64	14.64	0.0076980
2	0.10	5.00	6.06	6.08	0.0076980
2	0.10	7.00	6.61	6.59	0.0076980
2	0.10	9.00	6.76	6.78	0.0076980
2	0.20	5.00	8.78	8.80	0.0076980
2	0.20	7.00	9.47	9.49	0.0076980
2	0.20	9.00	9.84	9.86	0.0076980
2	0.30	5.00	13.14	13.16	0.0076980
2	0.30	7.00	14.21	14.23	0.0076980
2	0.30	9.00	14.62	14.64	0.0076980
3	0.10	5.00	6.10	6.08	0.0076980
3	0.10	7.00	6.57	6.59	0.0076980
3	0.10	9.00	6.80	6.78	0.0076980
3	0.20	5.00	8.82	8.80	0.0076980
3	0.20	7.00	9.51	9.49	0.0076980
3	0.20	9.00	9.88	9.86	0.0076980
3	0.30	5.00	13.18	13.16	0.0076980
3	0.30	7.00	14.25	14.23	0.0076980
3	0.30	9.00	14.66	14.64	0.0076980

Table 6: Estimated coefficients for fc_{ta} multiple linear regression model during ploughing

Term Blocks	Symbol	Coefficient	SE Coefficient	P-Value
Constant	α	9.95889	0.00257	0.000
D				
0.1	β_1	-3.47556	0.00363	0.000
0.2	β_2	-0.57556	0.00363	0.000
0.3	β_3	4.05111	0.00363	0.000
V				
5	β_4	-0.61222	0.00363	0.000
7	β_5	0.14444	0.00363	0.000
9	β_6	0.46778	0.00363	0.000
dXV				
0.1X5	β_{11}	0.20889	0.00513	0.000
0.1X7	β_{12}	-0.03778	0.00513	0.000
0.1X9	β_{13}	-0.17111	0.00513	0.000
0.2X5	β_{21}	0.02889	0.00513	0.000
0.2X7	β_{22}	-0.03778	0.00513	0.000
0.2X9	β_{23}	-0.00889	0.00513	0.000
0.3X5	β_{31}	-0.23778	0.00513	0.000
0.3X7	β_{32}	0.07556	0.00513	0.000
0.3X9	β_{33}	0.16222	0.00513	0.000

r^2 = 100 %, Adj r^2 = 99.99 %, r^2(Pred) = 99.99 %

$$FC_{ta} = \alpha + \beta_1 d_1 + \beta_2 d_2 + \beta_3 d_3 + \beta_4 V_1 + \beta_5 V_2 + \beta_6 V_3 + \beta_{11} d_1 V_1 + \beta_{12} d_1 V_2 + \beta_{13} d_1 V_3 + \beta_{21} d_2 V_1 + \beta_{22} d_2 V_2 + \beta_{23} d_2 V_3 + \beta_{31} d_3 V_1 + \beta_{32} d_2 V_2 + \beta_{33} d_3 V_3 \qquad (7)$$

Table 6 depicts estimated coefficients for multiple linear regression model during and the regression analysis for tilled area fuel consumption during ploughing. Values of constant for the tilled area fuel consumption during ploughing was 9.95889 and SE of 0.00257. The p-value for the constant was 0.000, indicating that the constant was significant in the multiple linear regression model (Equations 10). The p-value for the coefficient of factor d (tillage depth) was 0.00 which is less than 0.05, and p-Value for coefficient of factor V (tractor forward speed) was 0.000. In relations to the coefficient for interaction factors (dV), the p-values were 0.000. This is reviewed the acceptance of generated multiple linear regression model (Equation 10). From the regression analysis, it was observed that the multiple linear regression model of tilled area fuel consumption during ploughing had a high r^2 value of 100 %. This indicated that 100 % of the tilled area fuel consumption experimental data could be represented by the multiple linear regression model (Equation 10). With respect of accuracy of the developed multiple linear regression model, tilled area fuel consumption regression had r^2 (adj.) value of 99.99%. With these large values of r^2 (adj.), it can be said that the multiple linear regression model had high accuracy, and it could well represent the actual experimental data.

Optimal response (tractor fuel efficiency parameters) for the studied ploughing operation

Based on the multiple linear regression model developed, the optimal condition of controlled factors or variables might be determined in order to achieve desired operating conditions for tractor fuel consumption per tilled area during operations, using responses optimizer in MINITAB 19. In this study, one response (tilled area fuel consumption during ploughing) was targeted. The target was to achieve tilled area fuel consumption during ploughing.

The optimization plot and the results of the optimal solution of tilled area fuel consumption during ploughing were shown in Fig. 3 and Table 7. In view of the analysis, it was predicted that the minimum tilled area fuel consumption during ploughing was 6.08 L/ha. These desired responses were achieved at 0.10 m tillage depth and tractor forward speed of 5 Km/h with composite desirability (D) of 0.997674 that was greater than 0.90 and closer to 1.00. The composite desirability (D) is also a statistical parameter to validate accuracy of the optimization plot (Ciopec *et al*., 2012). It has been reported by to Chang *et al*. (2015) that the optimization of factors and responses obtained from the statistical analysis is highly reliable and accurate when the composite desirability (D) is closer to 1.00. Hence, the optimal conditions proposed in the optimization plot (Fig. 6) and the optimal solution results in Table 3 were generally reliable, and they fully conformed the multiple linear regression model developed.

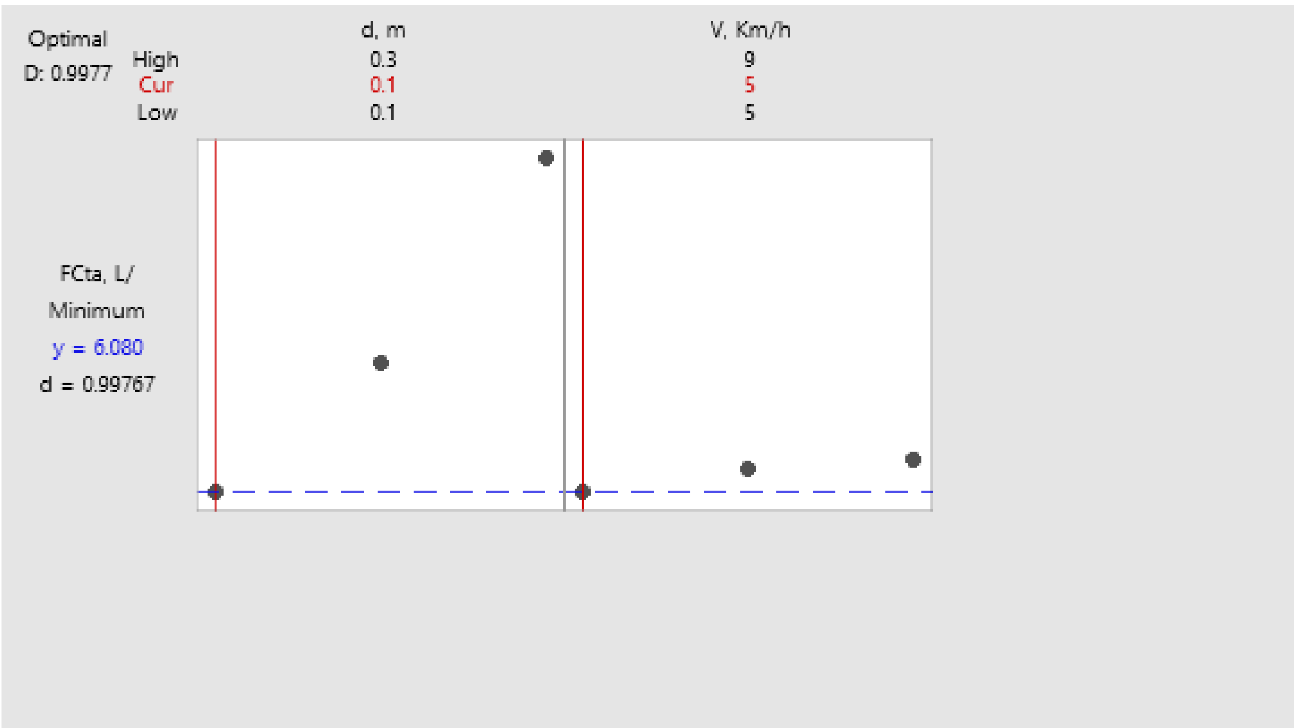

Figure 3: FC_{ta} Optimization Plot for Ploughing

Table 7: Optimization simulation result for fc_{ta} during ploughing

Solution	d, m	V, Km/h	FC_{ta}, L/ha (m)	FCta, L/ha Fit	Composite Desirability
1	0.1	5	6.08	6.08	0.997674
2	0.1	7	6.59	6.59	0.938372
3	0.1	9	6.78	6.78	0.916279
4	0.2	5	8.80	8.80	0.681395
5	0.2	7	9.49	9.49	0.601163
6	0.2	9	9.86	9.86	0.558140
7	0.3	5	13.16	13.16	0.174419
8	0.3	7	14.23	14.23	0.050000
9	0.3	9	14.64	14.64	0.002326

Conclusion

The general full factorial design (GFFD) approach of design of experiment has successfully optimized tractor tilled area fuel consumption during ploughing to ensure minization of fuel and established the best operating conditions. In view of the GFFD's statistical analysis, it was revealed that the soil texture was loamy sand for the depths of 0 – 10 cm, and 10 – 20 cm, and sandy loam for depth of 20 – 30 cm, respectively. Tilled area fuel consumption during ploughing operation is influenced by increase in the field variables including ploughing depth and tractor forward speed. Empirical model for the optimization of fuel consumption at different treatments using numerical approach was developed for predicting tractor tilled area fuel consumption in the course of ploughing operation. The coefficients for the tilled area fuel consumption multiple regression model for the ploughing operation was obtained as shown in the model. The model was significantly proven to predict 100%. The optimized tractor fuel consumption per tilled area during ploughing was achieved at tillage depth of 0.10 m and tractor forward speed of 5 Km/h for ploughing.

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