Fuel consumption models of MF285 tractor under various field conditions

Salim Almaliki[1,2], Reza Alimardani [2*], Mahmoud Omid [2]

(1. Department of Agricultural Machinery, University of Basrah, Basrah, Iraq;

2. Department of Agricultural Machinery Engineering, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran)

Abstract: Due to the ascending importance of energy in the world, prediction and optimization of Fuel Consumption (FC) in agricultural tasks is merit to consideration. In this study a Massey Ferguson (MF285) tractor was implemented with a low cost and precise data acquisition system as a means to record and monitor the affectual parameters on FC such as forward speed and instant fuel flow rate during field operation. Field experiments were carried out in the experimental farm of Agricultural Engineering Department of Tehran University, Karaj province, Iran, which had loamy soil texture. A mouldboard plow was used as tillage toll during the experiments at various tillage depths, engine speeds, forward speeds, tire inflation pressures, moisture contents and cone indexes. Acquired data were used to elicit an accurate model for Temporal, Area-specific and Specific Fuel Consumption (TFC, AFC and SFC). Results showed considerable effect of all measured parameters on TFC, AFC and SFC. For instance the TFC, AFC and SFC decreased by 11%, 13% and 56% respectively when the cone index increased from 105 to 1161 kPa. And also augmenting tillage depth from 10 to 20 cm led to 44% increase of TFC while SFC decreased by 164% oppositely. AFC rate was 1.1 liter per cm of tillage depth. Increasing the engine speed from 1200 to 2000 r/min led to increase of TFC, AFC and SFC by 56%, 71% and 46%, respectively. The forward speed was the most influential parameter on TFC, AFC and SFC while the moisture content and tire inflation pressure effects were minor. Models validation was acceptable and the fuel consumption rate could be predicted with accuracy of about 95%.

Keywords: fuel consumption, Massey Ferguson (MF285), modelling, data logging system

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1 Introduction

Fuel Consumption (FC) in agricultural vehicles is a factor that concerns the farmer in order to search for information about maintenance and optimization of the vehicle use. Fuel is the source of energy for most of agricultural vehicles including tractors and provides the required power for performance and propelling the tractor to overcome implement draught (Smith, 1993). FC is directly related to the energy requirements of agricultural tasks and may be reduced by proper understanding of how the tractor power is distributed. An improvement in tractor performance will result in a diminished amount of depleted fuel for a certain operation and thereby leads to both environmental and financial benefits. Ability to anticipate the performance of tractors during field operations has been of great interest to scientists, manufacturers, and users in order to optimize the total operation (Grisso et al. 2006). Hence predicting tractor FC can lead to more appropriate decisions on tractor management. Several studies have been developed for predicting FC in diverse sections in agricultural operations which use power like draught, tillage implements and tire resistance (Al-Janobi, 2000; Sahu and Raheman, 2006; Serrano et al., 2003, 2007). Grisso et al. (2006) developed a new method for predicting FC for individual tractors. Their results showed that about 88% of the tested tractors had an improved prediction with the new methodology. The FC during soil tillage operations varies widely due to various parameters that affect the FC such as soil texture, relative humidity, tractor type (two or

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***Corresponding author: Reza Alimardani,** Department of Agricultural Machinery Engineering, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran. Email: rmardani@ut.ac.ir.

four wheel drive), tractor size and implements. Depending on the soil strength the FC increases by 0.5 to 1.5 L/ha per centimeter of ploughing depth (Filipović et al., 2004; Moitzi et al., 2006). Therefore, tractor FC is not constant and varies in different situations so it can be reduced through proper matching of related parameters (McLaughlin et al., 2008). Reducing fuel consumption in cropland agriculture is a complex and multifactorial process, where farm management plays a key role (Safa et al., 2010). Many researchers believed the increasing of overall energy efficiency for tractor and implements and correct matching of tractor and agricultural machinery can be effective in decreasing FC (Samiei Far et al., 2015). Engine speed and load characteristics are other parameters which FC of the tractor is highly depended on. Usually, the most productive and cost-effective work is obtained when the engine load is less than 80% of its rated power and the engine speed does not exceed 80% of its rated speed (Zoz and Grisso, 2003; Janulevicˇius et al., 2013).

Fathollahzadeh et al. (2010) developed a fuel consumption model for a John Deere 3140 tractor at various working depths of mouldboard plough. They reported a linear relationship between fuel consumption and working depth of the mouldboard plough. Reports from literature indicate that about 20% to 55% of the available tractor energy is wasted wears at the tractive device-soil interface. This energy wears the tires and compacts the soil to a degree that may cause detrimental crop production (Zoz and Grisso, 2003). Mileusnic ́et al. (2010) analyzed the FC of new and old tillage systems and compared them. They reported that by taking advantage of the new technical solutions in tillage mechanization systems and the new technological variants in the tillage process, the systems consume significantly less energy compared to the older systems. AL-Hamed et al. (2013) presented an algorithm to minimize the required energy by a task. The algorithm uses three-dimensional representations of the field characteristics to obtain the optimum tracks angle to minimize energy consumption. Moitzi et al. (2014) studied the effect of different working depths on FC, wheel slip, field capacity and specific energy consumption. Their results showed that the Area-specific Fuel Consumption (AFC) increased linearly with working depth for both the mouldboard plough and the short disc harrow and also wheel slip was proportional to the FC and reversely proportional to field capacity performance at all depths. In a separate experiment they studied the influence of the engine speed on FC in a universal-cultivator and they reported an increase of engine speed from 1,513 r/min to 2,042 r/min which resulted in an increase of 80% for the Temporal Fuel Consumption (TFC) and 35% for the AFC (Adewoyin and Ajav, 2013; Moitzi et al., 2006). Efficient operation of farm tractors includes: (a) maximizing fuel efficiency of the engine and mechanical efficiency of the drive train; (b) maximizing attractive advantage of traction devices; and (c) selecting an optimum travel speed for a given tractor - implement system (Grisso et al., 2008). Therefore, precise and accurate performance modeling of tractors and implements based on effectual parameters is crucial for farmers as well as manufacturers due to increased emphasis on fuel conservation. But measurement of parameters needs a rather complex and expensive measurement and also scrutinize instrumentation. Singh and Singh (2011) developed a computerized instrumentation system for monitoring the tractor performance in the field. The system was intended to be used for the compilation of a database of draft requirements of tillage implements. However, extraction of an accurate model required a precise instrumentation and also a reasonable algorithm for data fusion. On the other hand, accuracy of instrumentation is proportionally connected with the expenditure and that will be a limiting factor. So, a sensible model must compromise between costs and accuracy i.e. an optimized point for costs and accuracy of measurement instruments. The objectives of this research were:

(1) Development of models to predict fuel consumption (TFC, AFC and SFC) of tractor (Massey Ferguson) at different conditions (tillage depths, engine speeds, forward speeds, tire inflation pressure, moisture content and cone index) utilizing Design Expert software (www.statease.com).

(2) Implementation of a low cost, precise and easy-to-install instrumentation package to monitor and record effective parameters on prediction models include: actual and theoretical velocities, slippage, FC rate, drawbar pull and tillage depth.

2 Materials and methods

2.1 Field experiments

Experiments were carried out in the experimental farm of Agricultural Engineering Department of Tehran University located in 3 km south west of the Karaj province. The soil at the experimental site has loamy texture (31.94% sand, 43.79% silt, and 24.27% clay). In this research, a conventional tillage system which includes a mouldboard plow with three furrows (width of mouldboard was 100 cm) was used for collecting data from Massey Ferguson tractor (Model MF285) and the specifications of tractor were shown in Table 1.

Table 1 Specifications of Massey Ferguson MF285

Effective output, hp	75	Lifting capacity, kg	2227
Type of fuel	Diesel	Rated engine speed, r/min	2000
Type of steering system	Mechanical- hydraulic	Type of cooling system	Liquid-cooled
Transmission	Gears	Front tires size, inch	12.4-24
Type of injector pump	Rotary	Rear tires size, inch	18.4-30
Firing order	1342	Front weight, kg	1420
Fuel tank capacity, L	90	Rear weight, kg	1694

2.1 The experiment parameters

The experiments were carried out in the field with different conditions using three engine speeds, four tractor forward speeds (as shown in Table 2), three depths of mouldboard plow and three tire inflation pressures. These parameters were used at two levels of moisture contents and four cone indexes of soils as shown in Table 3. All experiments had three replications resulting in a total of 1293 tests.

Table 2 Measured velocity, m/s

Engine Speed, r/min	Gear			
	1st	2nd	3rd	4th
1200	0.39	0.56	0.79	1.09
1600	0.48	0.67	0.95	1.28
2000	0.61	0.90	1.2	1.56

Table 3 Input parameters used in experiments

Depth, cm	Inflation pressure, kPa	Engine speed, r/min	Moisture content, %	Cone index, kPa	Gear
10	50	1200	6	160	1st
15	100	1600		1160	2nd
20	150	2000	23	100	3rd
				930	4th

2.3 Transducers and data logging system

An instrumentation package for measuring the tractor performance was developed. This package included the data logging system and the transducers for measuring fuel consumption, actual velocity, theoretical velocity, drawbar pull and plow depth. The data logging system consisted of an Arduino electronic board (which is a simple microcontroller board, open source, more modern, cheaper, and easier to use than the designs available at that moment) and portable computer (laptop) linked via a USB port. Specifications of the instrumentation used in the package are listed in Table 4. Data were sampled at 50 ms intervals.

Table 4 Specification of instrumentation utilized

Name of transducer	Specification	Manufacture	Use for
VISION-1000	0.1- 2.5 l/min (22000 pulse per liter) ± 3%	Remag, Bern, Switzerland	input fuel consumption to injection pump
turbine type model (RS256-225)	0.1-3 l/min 1200 pulse per liter ± 1.5%	China	output fuel from injection pump to tank
E5S8-360-6-1-	360 pulses per revolution ±5%	Autonics, South Korea	Actual and theoretical velocity.
Load cell model H3-C3-3.0t-6B-D55	S type 0- 30 kN ±0.1%	Zemic-China	draft force
Ultrasonic distance sensor (HY-SRF05)	Detection distance: 2 cm-450 cm. High precision: Up to 0.2cm	China	depth plowing
Electronic board Arduino Atmega2560	Digital I/O Pins54 (of which 15 provide PWM output) Analog Input Pins 16 Clock speed 16 MHz	Italy	Data logging

The theoretical velocity-sensing unit was mounted on the left axle side of the tractor. Sensing unit comprises of an encoder sensor (Autonics, South Korea) and two involved gears; an eight teeth gear installed on the encoder's shaft and another gear fixed to the inner side of rear wheel flange which makes 13.125 gear ratio. The encoder sensor was attached on the rear axle housing, using a special made nearby mounting bracket. The encoder sensor generates 360 pulses per revolution and by taking gear ratio into account, each revolution of rear tire will produce 4725 pulses. Hence, in accordance with the rear tire diameter each pulse would indicate 1 millimeter of the tractor movement. The actual velocity was measured using another encoder (Autonics, South Korea) fixed to the front wheel flange. As there were different gear ratios as well as tire size in front wheel, since the smaller diameter front tire thus each pulse is equal to 0.6 millimeter of the tractor movement.

The velocity data were sent to the data logging and processing unit in order to calculate the wheel slippage. The following Equation was used to calculate the slip percentage:

$$slip = 1 - \frac{Actual\ Velocity}{Theaotrical\ velosity} \times 100 = (1 - \frac{Va}{Vt}) \times 100 \quad (1)$$

The fuel consumption at each tillage operation was measured by two flow sensors. The first one (VISION-1000, Remag, Bern, Switzerland) had a range of 0.1-2.5 l/min accommodated between the fuel filter and the injector pump of the tractor for measuring input fuel to injector pump and the other (RS256-225) on by-pass line for measuring the extra fuel returning to the fuel tank. These sensors were calibrated by counting the generated pulses during flow of a known volume (100 ml) of diesel fuel.

In this study, the characteristics of the fuel consumption of the engine farm tractor were expressed in three terms as follows:

(1) Temporal Fuel Consumption [TFC (L/h)]: Which represents the amount of fuel consumed for the unit of time according to the following Equation:

$$TFC = \frac{fc}{T} \quad (2)$$

where:

fc = amount of fuel consumed, L;

T = time taken, h;

(2) Area-specific Fuel Consumption [AFC, L/ha]: Which represents the amount of fuel consumed to cover an area of one hectare and calculated according to the following Equation:

$$AFC = \frac{10 \times TFC}{Va \times W} \quad (3)$$

W= implement working width, m ;

Va = actual velocity, m/s;

(3) Specific Fuel Consumption [SFC, kg/kW.h]: Which represents the amount of fuel

consumed during a specified time on the basis of the drawbar power available at the drawbar, it was calculated from the following Equation:

$$SFC = \frac{TFC}{Pdb} \qquad (4)$$

Pdb = drawbar power required for the implement, kW.

Drawbar power was evaluated using the relation between draft and travel speed as follows:

$$Pdb = NT * Va \qquad (5)$$

where, *NT* is net traction, kN.

The drawbar load cell was an S shaped (Model H3-C3-3.0t-6B-D55 from Zemic with capacity of 30kN) mounted between two tractors. The first one was a Massey Fergusson 285 as puller and the other one was Massey Fergusson 165 as towed. The force exerted by the implement is measured by a strain gauge Wheatstone bridge arrangement. The load cell was calibrated by means of a hydraulic loading calibration device (Model INSTRON).

Two ultrasonic distance sensors (HY-SRF05) were attached to the left side of the frame of the plow to measure tillage depth accurately in reference of undistributed and flat terrain. These sensors were fixed at the front and the rear of the plow's frame to overcome the fluctuation that occurs in the horizontal plane of the plow. The average of sensors distance has been considered as the depth of the plow. The detailed electronic circuit diagram for measuring performance parameters and displaying them on the portable computer screen is given in Figure 1.

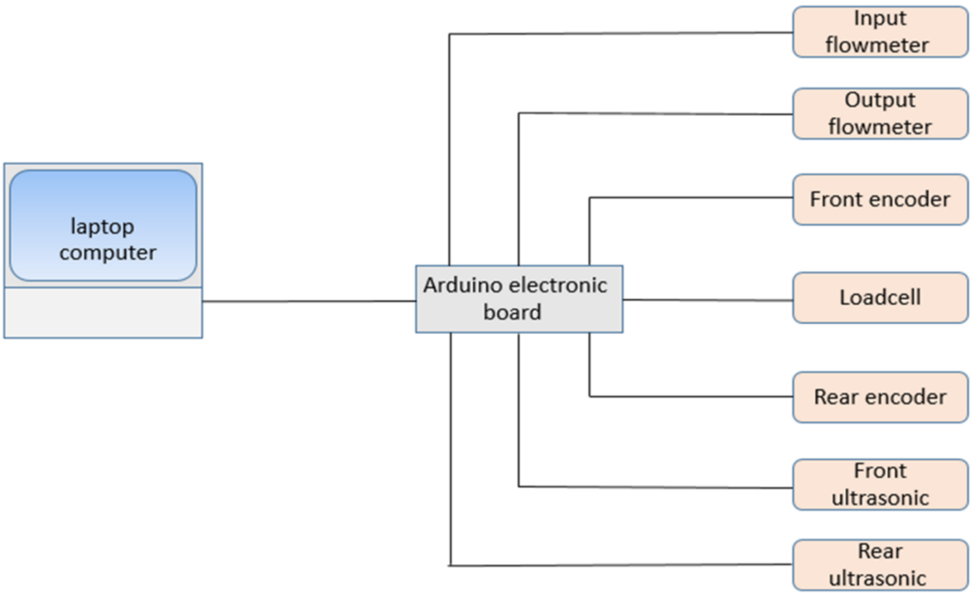

Figure 1 Schematic diagram of data logging system

3 Result and discussion

A total of 1293 tests (431 different tests with 3 replications) were performed for finding appropriate models of fuel consumption including Temporal Fuel Consumption, Area-specific Fuel Consumption, and Specific Fuel Consumption for Massey Ferguson tractor (MF285). After averaging treatments, for choosing more accurate or more reliable models, a set of different polynomial models were compared with Design Expert software. The quadratic model was chosen with respect to a good trade-off between the highest coefficient of determination, the lowest standard deviation, P-value and degrees of freedom. Finally, in order to optimize and reduce the number of candidate regressors, a stepwise regression algorithm, as a most widely used variable selection technique (Montgomery and Runger, 2014), was then applied, resulting in the reduced models (Table 5).

Table 5 Summary of statistics of reduced quadratic models

Response of interest	Standard deviation	Mean	C.V. %	R-Squared	Adj R-Squared	Degrees of freedom	Sequentil p-value
TFC	0.00805	0.12	6.82	0.9376	0.9363	9	<0.0001
AFC	0.00821	0.23	3.52	0.9192	0.9173	10	<0.0001
SFC	0.029	0.84	3.47	0.9633	0.9626	8	<0.0001

3.1 Temporal Fuel Consumption (TFC)

ANOVA Table was carried out using Design Expert software to determine the level of significance of effect of the moisture content, tire pressure, cone index, tillage depth, engine speed and the forward speed on Temporal Fuel Consumption (Table 6).

Table 6 Analysis of variance table for Temporal Fuel Consumption

Source	Sum of Squares	df	F-Value	p- value Prob > F
Model	0.41	9	704.41	< 0.0001
MC	0.00062	1	9.66	0.0020
CI	0.0079	1	122.65	< 0.0001
Pr	0.00029	1	4.55	0.0335
Depth	0.04	1	626.55	<0.0001
Vt	0.08	1	1829.35	< 0.0001
ES	0.12	1	1269.30	< 0.0001
CI-ES	0.00074	1	11.57	0.0007
Depth-Vt	0.0020	1	31.38	< 0.0001
Depth-ES	0.01	1	174.91	< 0.0001
Residual	0.02	422		
Cor Total	0.44	431		

Results indicated each of these parameters had a highly significant effect on the TFC at various probability values (lower than 0.05). Also, the results revealed augmented TFC with increasing the moisture content, tire pressure, depth of tillage, engine speed and forward speed whereas the results of TFC were counteractive with increasing cone index. The Figure 2a-c shows the interactions influence of the depth of tillage-engine speed, depth of tillage-forward speed and cone index-engine speed on TFC. TFC decreased by 11% when the cone index increased from 105 to 1161 kPa, this is due to increase of soil strength with increasing cone index which leads to reducing the energy lost due to slip and rolling resistance thus reduce fuel consumption. The results demonstrated a linear relationship between TFC with depth of tillage and engine speed. TFC increased by 44% when the depth of tillage increased from 10 to 20 cm while increasing the engine speed from 1200 to 2000 r/min increased fuel consumption by 56%. In other hands, the greatest TFC is reached at a depth of 20 cm and engine speed of 2000 r/min. This finding is supported by other researchers (Adewoyin and Ajav, 2013; Moitzi et al., 2006; Moitzi et al., 2014). The results also showed an increase of TFC by 61% when the forward speed goes from 0.39 m/s to 1.56 m/s. The overlap effect between forward speed and tillage depth on TFC appeared greater impact on rising of fuel consumption where record 12.23 L/h at forward speed 1.56 m/s and depth 20 cm. Figure 3a shows the perturbation plot of parameters affecting on TFC. The perturbation (or trace) plot facilitated to contrast the impact of all the independent variables at a particular point, at the midpoint (coded 0) of all the factors, in the design space. The results revealed that the most influential factor in fuel consumption is the forward speed, followed by the engine speed, depth of tillage and cone index, while the effect of inflation pressure of tire and soil moisture are the lowest among the effective factors. Figure 3B shows the scatter plot of actual values of TFC vs. predicted values using final model.

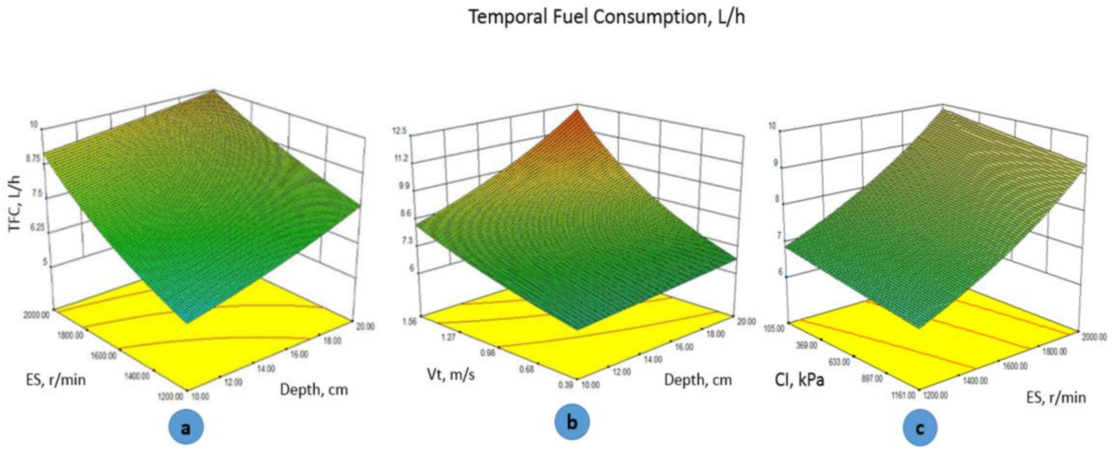

Figure 2 (a) Interaction between Engine Speed-Depth, (b) Theoretical Velocity-Depth and (c) Cone Index-Engine Speed for the Temporal Fuel Consumption

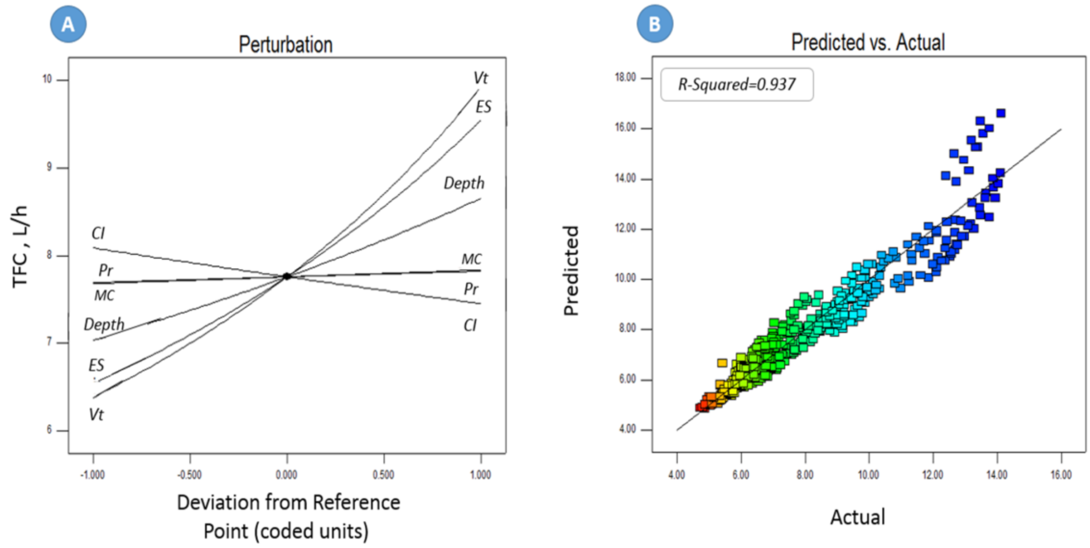

Figure 3 (A) Perturbation plot, (B) Predicted TFC values versus actual ones

The appropriate model for the Temporal Fuel Consumption TFC (Liter/hour) is represented in Equation 6, in which the coefficients are in the coded unit form.

$$(TFC)^{-1.06} = +0.38 - 0.00015*MC + 2.41E{-}005*CI - 2.15E{-}005*Pr - 0.0079*depth - 0.02*Vt - 0.00012*ES - 8.90E{-}009*CI*ES - 0.0018*depth*Vt + 4.46E{-}006*depth*ES. \quad (6)$$

3.2 Area-specific Fuel Consumption (AFC)

AFC affected significantly with tire inflation pressure, cone index moisture content, tillage depth engine speed, and forward speed (Table 7). The results showed a direct correlation between AFC with both of the moisture content and the engine speed and the depth of tillage in Figure 4a to 4d. In terms of AFC increased to 11 liters per hectare when increasing the depth of tillage from 10 to 20 cm with an average of 1.1 liter per cm of tillage depth. Furthermore AFC increased by 71% when increasing the engine speed from 1200 to 2000 r/min. The results also indicated the reverse effect for both forward speed and cone index to AFC. The AFC decreased 2.9 L/ha when increasing the cone index from 105 to 1160 kPa, this goes back to increased ability of tractor to take advantage of the available power at the wheels with the increase in soil strength. AFC is reduced by 96% when the forward speed increased from 0.39 to 1.56 m/s where increase in forward speed leads to reduce the time required to accomplish the work required (tillage operation). The results also indicated the effect of interactions among the studied parameters on AFC where occurred the largest increase in AFC by 48 liters per hectare with the depth of tillage 20 cm and forward speed 0.39 m/s. In general, the forward speed is the most influential factor on AFC, followed by the engine speed, the depth of tillage, tire inflation pressure and moisture content respectively (Figure 5a). Moreover, the scatter plot of actual values of AFC vs. predicted values using final model are displayed in Figure 5b.

Table 7 Analysis of variance table for Area-specific Fuel Consumption

Source	Sum of Square	df	F-Value	p-value Prob > F
Model	0.32	10	479.13	< 0.0001
MC	0.00056	1	8.39	0.0040
CI	0.01	1	274.51	< 0.0001
Pr	0.0024	1	36.06	< 0.0001
Depth	0.08	1	1233.57	< 0.0001
Vt	0.19	1	2820.81	< 0.0001
ES	0.11	1	1609.66	< 0.0001
CI×Depth	0.00027	1	4.13	0.0426
Depth×Vt	0.0070	1	104.19	< 0.000
Depth×ES	0.0070	1	104.75	< 0.0001
Vt×ES	0.03	1	526.43	< 0.0001
Residual	0.02	421		
Cor Total	0.35	431		

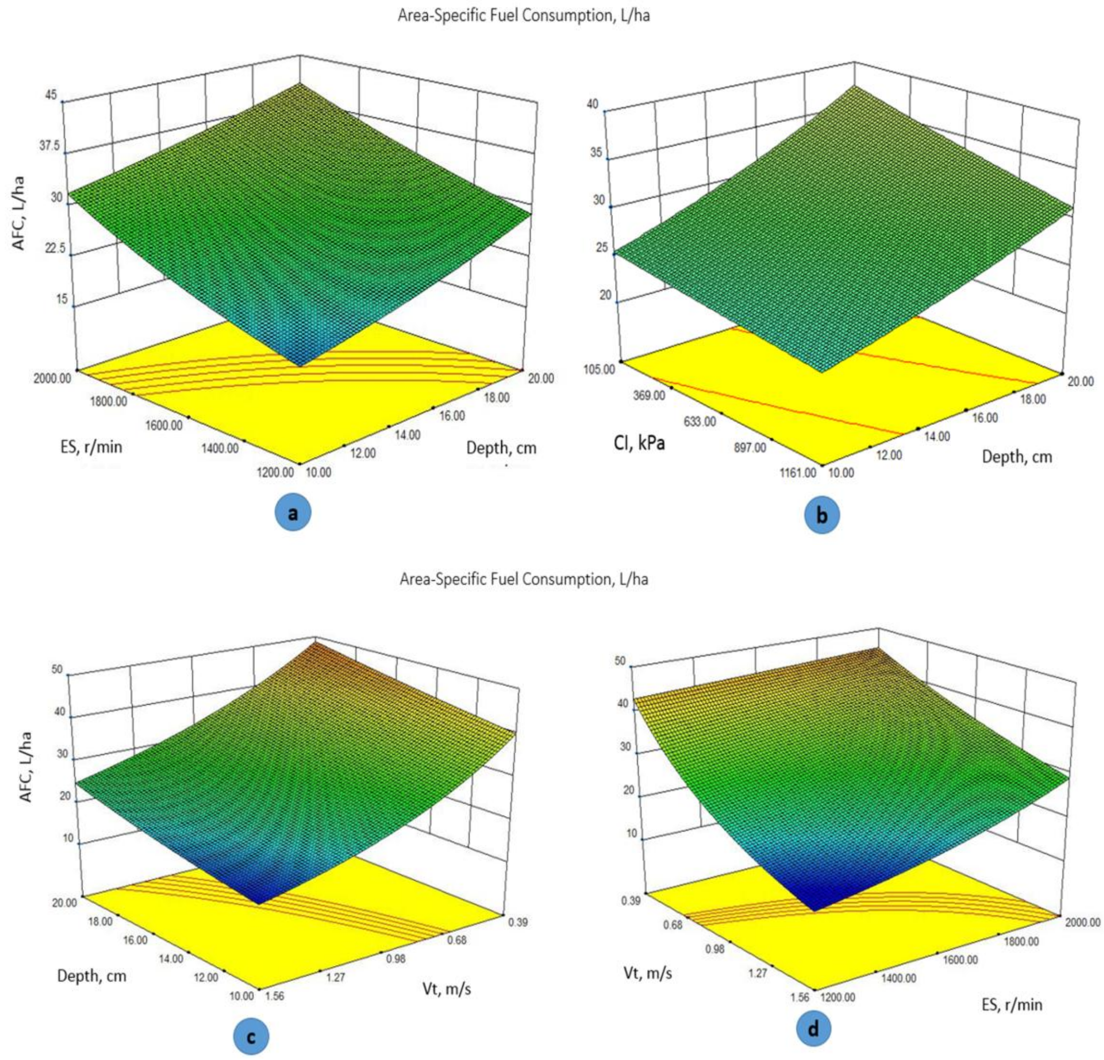

Figure 4 (a) Interaction between Engine Speed-Depth, (b) Cone Index-Depth, (c) Depth-Theoretical Velocity, (d) Theoretical Velocity-Engine Speed for the Area-Specific Fuel Consumption

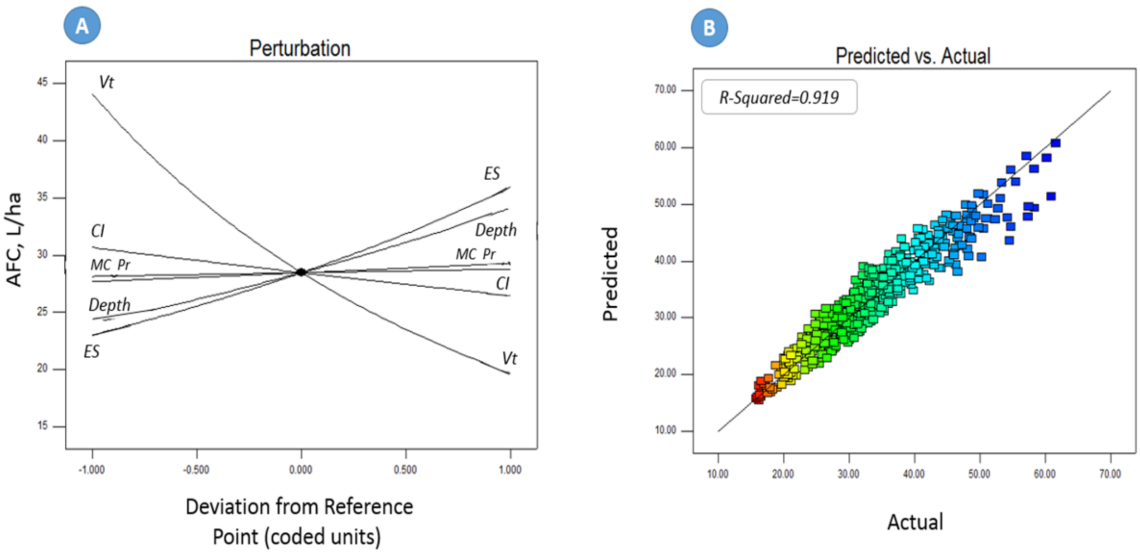

Figure 5(A) Perturbation plot, (B) Predicted AFC values versus actual ones

The fitted equation for the Area-specific Fuel Consumption AFC (liter/hectare) is represented in Equation 7, in which the coefficients are in the coded unit form.

$$(AFC)^{-0.42} = +0.22-0.00013*MC+7.90E-006*CI-5.81E-005*Pr-0.0061*depth+0.25*Vt-2.21E-005*ES+4.23E-007*CI*depth-0.0032*depth*Vt+3.36E-006*depth-8.74E-005*Vt*ES. \quad (7)$$

3.3 Specific Fuel Consumption (SFC)

It can be intrepreted from Table 8 that all studied parameters had significant effect on SFC, however, interactions among these factors did not effect the SFC significantly, except moisture content-cone index and engine speed-forward speed in Figure 6a to 6b. Relative importance of the factors are shown in perturbation plot Figure 7A. This figure represents a positive relationship between moisture content, tire inflation pressure and engine speed with the SFC. On the other hand, cone index, depth of tillage and forward speed effected the SFC, inversely. The forward speed was the most influential factor on the specific fuel consumption, so that increasing forward speed from 0.39 to 1.56 m/s reduced the SFC by 233%. Increased drawbar power as a result of more forward speed caused a meaningful reduction on SFC followed by the depth of tillage, cone index, engine speed, tire inflation pressure and soil moisture, respectively. The effect of increasing depth of tillage from 10 to 20 cm led to a decrease in SFC by 164% and this is due to the increase in the ratio of achieved drawbar power that resulting from the increase of the depth of tillage which is greater than the rate of TFC (liter per hour). The rate of decline in SFC was up 56% when increasing cone index from 104 to 1160 kPa. This return to diminishing fuel consumed due to decreasing slip and rolling resistance with increasing cone index, which is the indicator of the strength of the soil. The results also showed that increasing the engine speed from 1200 to 2000 r/min led to the increase of SFC by 46%. This is due to the rate of TFC which is greater than the increase power resulting from the engine speed. The cause of increase in SFC with the increase in both moisture content and tire pressure is to increase the slippage, which leads to reduced forward speed then drawbar power, which reflects a rise in SFC. Moreover, the scatter plot of actual values of SFC vs. predicted values using final model are displayed in Figure 7B.

The appropriateness model for the specific fuel consumption SFC [kg (kW h)-1] is represented in Equation 8.

$$(SFC)^{-0.31} = -0.03-0.00026*MC+8.99E-005*C-0.00018*Pr+0.02*depth+0.71*Vt+0.00011*ES+1.04E-006*MC*CI-0.00025*Vt*ES. \quad (8)$$

Table 8 Analysis of variance table for Specific Fuel Consumption

Source	Sum of Square	df	F-Value	p-value Prob > F
Model	9.47	8	1389.37	< 0.0001
MC	0.0048	1	5.70	0.0174
CI	0.97	1	1137.82	< 0.0001
Pr	0.02	1	30.07	< 0.0001
depth	4.91	1	4113.71	< 0.0001
Vt	3.51	1	5759.81	< 0.0001
ES	0.58	1	683.71	< 0.0001
MC×CI	0.0069	1	8.18	0.0045
Vt×ES	0.31	1	361.50	< 0.0001
Residual	0.36	423		
Cor Total	9.83	431		

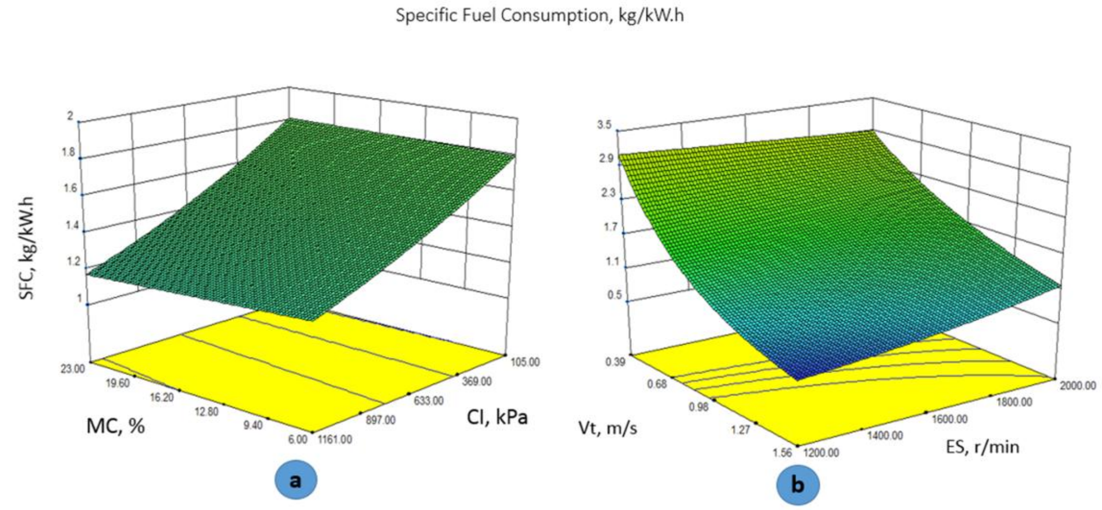

Figure 6 (a) Interaction between Moisture Content-Cone Index, and (b) Theoretical Velocity-Engine Speed for the Specific Fuel Consumption

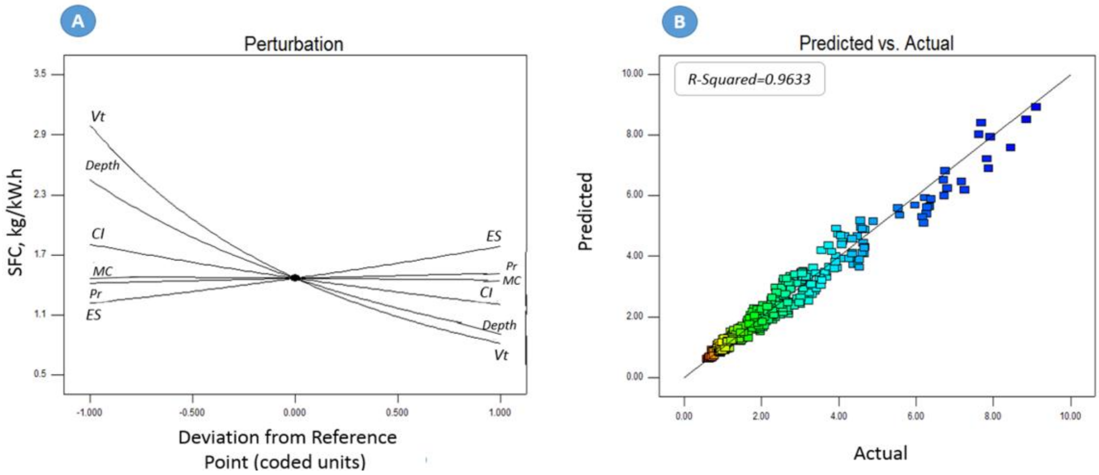

Figure 7 (A) Perturbation plot, (B) Predicted SFC values versus actual ones

4 Conclusion

Fuel consumption in three forms of TFC, AFC, and SFC is significantly affected by the studied factors (tillage depth, moisture content, tire inflation pressure, cone index, engine speed and forward speed). With increasing the tillage depth, the drawbar pull rises as well as the slip. The result is an increased fuel consumption rate of TFC and AFC, whereas SFC is reduced. Increasing engine speed, tire pressure and moisture content led to increased fuel consumption of three forms (TFC, AFC and SFC). The results obtained from this study indicate reducing of the TFC, AFC and SFC with incrementing the cone index. With increasing forward speed, TFC increases whereas AFC and SFC reduce. The effect of interactions among studied factors in this experiment was to determine their impact on fuel consumption (TFC, AFC and SFC). The results also demonstrated relative importance of these parameters in their effects on fuel consumption. The forward speed was the most influential parameter on the specific fuel consumption (TFC, AFC and SFC) while the moisture content and tire inflation pressure had lowest influence. The appropriate models for the fuel consumption in three forms (TFC, AFC and SFC) were obtained from 431 experiments. The models validation was acceptable. Consequently, the fuel consumption rate magnitudes could be successfully predicted by the proposed models with high accuracy ($P > 0.05$).

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Nomenclature

AFC	*[L/ha]*	*Area-specific Fuel Consumption*	*S*	*[%]*	*Slip*
CI	*[kPa]*	*Cone index value*	*SFC*	*[kg/kW.h]*	*Specific Fuel Consumption*
ES	*[rpm]*	*Engine speed*	*T*	*[sec]*	*Time*
fc	*[L or kg]*	*Amount of fuel consumed*	*TFC*	*[L/h]*	*Temporal Fuel Consumption*
MC	*[%]*	*Moisture Content*	*Va*	*[m/sec]*	*Actual velocity*
NT	*[kN]*	*Net traction*	*Vt*	*[m/sec]*	*Theoretical velocity*
Pdb	*[kW]*	*Drawbar Power*	*W*	*[m]*	*Implement working width*
Pr	*[kPa]*	*Tire inflation pressure*			