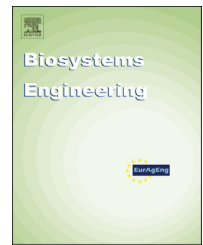


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Research Paper

Development of a fuel consumption equation: Test case for a tractor chisel-ploughing in a clay loam soil

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Fuel consumption and tillage draught were measured when chiselling in a clay loam soil in Badjgah Research Station, Shiraz University, Shiraz, Iran. An 81 kW tractor (MF-399) instrumented with a data acquisition system was used to measure fuel consumption, actual forward speed, theoretical forward speed, slip and implement draught. The effects of blade width (5 and 10 cm), tillage depth (10, 15 and 20 cm) and actual forward speed (3, 4 and 5 km h⁻¹) upon fuel consumption were investigated. Fuel consumption was assumed to be a function of wheel numeric, slip, net traction ratio, rolling resistance ratio, chisel-tool aspect ratio and actual forward speed. Collected data were used to model the tractor fuel consumption using dimensional analysis approach. Results were compared to fuel consumption rates as predicted by ASAE Standards (D497.4). The comparisons showed that the standard overestimates fuel consumption by 26–53%. Results from regression (F-test) between predicted and measured fuel consumption data showed that the slopes for fuel consumption with the 5 and 10 cm blade widths were not significantly different from 1:1 line ($P \leq 0.05$). Consequently, the fuel consumption rate can be successfully predicted by the model with good accuracy.

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1. Introduction

Fuel is the source of energy for the tractor providing for the performance of work and propelling the tractor to overcome implement draught (Smith, 1993). There are many parameters in tillage operation that affect the fuel consumption of a tractor, such as soil texture, climate, relative humidity, tractor

type (two or four wheel drive), tractor size and tractor implement relationship. Therefore, tractor fuel consumption is not constant and varies from one to another situation (Nielsen & Sorensen, 1993).

To increase efficiency of agricultural production; it is necessary to increase machine working efficiency. Taylor (1980) estimated that in the U.S. for each 1% improvement in traction efficiency, 284–303 million litres of fuel could be

Abbreviations: MF, Massey Ferguson; ASAE, American Society of Agricultural Engineers; ASABE, American Society of Agricultural and Biological Engineers; PTO, Power Take-off; NRMSE, Normalised Root Mean Square Error; MBE, Mean Bias Error; RNAM, Regional Network for Agricultural Machinery.

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Nomenclature

Symbols

C	In-field working capability of chisel plough (ha h ⁻¹)
CI	Soil cone index (kPa)
D	Working depth (m)
E _o	Overall energy efficiency (%)
E _t	Tractive efficiency (%)
f	Function
FC	Experimental fuel consumption (l h ⁻¹)
FC _p	Predicted fuel consumption (l kW ⁻¹ h ⁻¹)
F _d	Draught force (N)
F _r	Rolling resistance (N)
g	Gravitational acceleration (m s ⁻²)
K	Intercept of logarithmic line (constant)
L	Length (m)
M	Mass (kg)
N	Slope of logarithmic line (constant)
P _{ab}	Drawbar power (kW)
P _{eq}	Equivalent PTO power (kW)
Q _f	Fuel consumption per unit area (l ha ⁻¹)
Q _i	Hourly fuel consumption (l h ⁻¹)
Q _s	Brake-specific fuel consumption (l kW ⁻¹ h ⁻¹)
S	Driving wheel slip (%)
T _d	Unloaded overall tyre diameter (m)
T _w	Unloaded tyre section width (m)
V _a	Actual forward speed (km h ⁻¹)
V _t	Theoretical forward speed (km h ⁻¹)
W	Blade width (m)
W _d	Dynamic wheel load (N)
W _s	Static wheel load (N)
X	Load ratio define as equivalent PTO power required by an operation to the maximum available from the PTO, dimensionless
X _{wb}	Wheel base (m)
Z	Drawbar height (m)

saved annually. Due to increasing world population and limited non-renewable resources, especially fossil fuels, it is necessary to reduce and manage fuel consumption in various agricultural activities.

Many studies have been conducted to measure draught, power requirement and fuel consumption of tillage implements (Al-Janobi, 2000; Sahu & Raheman, 2006; Serrano et al., 2003, 2007). Predicting tractor fuel consumption can lead to more appropriate decisions on tractor management. Several studies have been conducted in this area. Khalilian, Batchelder, Self, and Summers (1984) presented the fuel equations corresponding to different diesel engine air intake types. Results showed that fuel efficiency equations more nearly reflect actual data than ASAE equations where predictions were at least 20% higher than experimental data. Raper, Schwab, Balkcom, Burmester, and Reeves (2005) developed an equation to estimate fuel consumption during deep tillage for John Deere 8300 tractors. Power-take-off data was converted to drawbar power using data available from the

Nebraska Tractor Test, and they presented a fuel consumption equation based on drawbar power. Fathollahzadeh et al. (2010) developed a fuel consumption model for a John Deere 3140 tractor at various working depths of mouldboard plough. Their results showed a linear relationship between fuel consumption and working depth of the mouldboard plough. Rahimi-Ajdadi and Abbaspour-Gilandeh (2011) presented models based on artificial neural network and stepwise multiple range regression for prediction of tractor fuel consumption. Fuel consumption was assumed to be a function of engine speed, throttle and load conditions, chassis type, total tested weight, drawbar and PTO powers. Results indicated that the artificial neural network and stepwise regression models gave similar determination coefficients ($R^2 = 0.98$ and $R^2 = 0.97$, respectively) while the artificial neural network provided relatively better prediction accuracy ($R^2 = 0.93$) compared to stepwise regression ($R^2 = 0.91$).

Dimensional analysis is a mathematical approach concerning dimensionally homogeneous equations. The form of such equations is independent of the fundamental units used. This is the basis of the theory of dimensional analysis in Buckingham's theorem (Langhaar, 1980). The dimensional analysis is a method by which one can deduce information about a phenomenon from the single premise that the phenomenon can be described by a dimensionally correct equation among pertinent variables. The result of a dimensional analysis of a problem is a reduction in the number of variables in the problem. This results in considerable savings in both cost and labour during the experimental determination of the function (Srivastava, Goering, Rohrbach, & Buckmaster, 2006).

Fakhraei and Karparvarfard (2006) developed a general equation for estimating the tractive efficiency of a Universal tractor (U-445, 30 kW) using dimensional analysis. Drawbar force, rolling resistance force of the drive wheels, slip of drive wheels, soil cone index, theoretical and actual velocity and dynamic load on driving wheels were either measured or calculated. This equation can be employed to estimate tractive efficiency of various combinations of tractors and ploughs provided the range of dimensionless terms fall within the limits experienced in the research. By use of this equation and through employing the initial data for tractor and soil, the tractive efficiency could be well predicted. Hosseini and Karparvarfard (2011) developed appropriate equations for predicting draught and vertical forces on a chisel tine using dimensional analysis. The effects of four levels of rake angle (10, 15, 20 and 25°), three levels of forward speed (1.5, 3 and 4.5 km h⁻¹) and three levels of tine aspect ratio (1.5, 2 and 3) on horizontal and vertical forces acting on a chisel plough tine (100 mm wide) were investigated.

Results of F-test at 5% probability showed no significant differences between values of slope and intercept of measured values vs. predicted values plot as compared to 1:1 line. Statistical indices NRMSE and MBE emphasise precision of the adopted analytical model. In addition, other results showed an increasing trend of draught force for variation in input parameters. This finding is supported by similar results derived from ASABE general equation.

The main objectives of the present study were to develop fuel consumption equation for an 81 kW tractor when carrying implement (chisel plough) in 5 and 10 cm widths.

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