SHORT NON-REFEREED PAPER

PREDICTING TRACTOR ENGINE LOADING IN TILLAGE OPERATIONS

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Abstract

Studies show that, cumulatively, grid electricity and diesel fuel account for between 50 % and 70 % of the total energy used in irrigated sugarcane production. With the rapidly increasing cost of energy and global concern over carbon emissions and taxes, modelling tools have been developed to estimate energy use in agricultural production systems. In order to create an ‘energy calculator tool specific to sugarcane production in South Africa, it is necessary to assess the accuracy of methods available to estimate in-field tractor performance and energy use. Electricity consumption in irrigation systems can be determined using hydraulic calculations. Estimating diesel use in tractor operations is, however, more subjective and is dependent on the method used to calculate engine loading. The purpose of this paper is to assess the accuracy of three methods of calculating engine loading by comparing estimated loading against measured values obtained during sub-soiling, ploughing and disking operations. Two methods, one by the Department of Agriculture Forestry and Fisheries (DAFF) and the other by Pretorius, were developed in South Africa, and the third method is based on standards published by the American Society for Agricultural and Biological Engineering (ASABE). For all three operations the ASABE method estimated loading most accurately with, on average, 2 % underestimation compared to the actual measured values. A comparison of each method’s ability to define an operation suggests that the ASABE method takes into account more variables, and has greater flexibility in describing field conditions.

Keywords: energy, carbon emissions, diesel, tillage, engine load, draft, power

Introduction

The Life Cycle Assessment (LCA) conducted by Mashoko *et al.* (2010) estimates that 34% of fossil fuel used to produce one ton of raw sugar is consumed in agricultural practices. On a farm level, results from Donovan (1978) indicate that between 20-30% of the total energy used in the production of one ton of sugarcane is accounted for by fuel and lubricant consumption. As a consequence of the growing importance of environmental issues and the rising cost of energy, it is therefore important to quantify on-farm energy use and energy use efficiency.

Initiatives to quantify energy use and the carbon footprint in the agricultural sector have led to the development of modelling tools to estimate fuel consumption in tractor operations. To establish confidence in these models for use as a research and management tool, it is necessary to validate the methods used to calculate tractor engine loading. The objective of this paper is to present preliminary results of the accuracy of three such methods against measured values of engine loading from instrumented tractor drawbar tests.

Materials and Method

Three methods for calculating engine loading were identified for possible use in an energy calculator tool being developed for sugarcane production in South Africa. The mouldboard plough, disk harrow and subsoiler, all conventional tillage implements, are used in the comparison. The methods listed and described below include two locally developed methods and one based on standards published by the ASABE (1998).

(i) Department of Agriculture, Forestry and Fisheries (DAFF)
The DAFF (2013) publish tables of power requirements compiled from field measurement for a range of tractor drawn or mounted implements and machinery. For each implement or machine, power requirements vary depending on the width and depth of operation, and soil classification. Tractor engine loading can thus be calculated by the ratio of the chosen tractor capacity to the recommended power requirement.

(ii) Pretorius
Using experiment data of energy requirements (kW/h/ha) for tractor field operations, Pretorius (1986) developed a method to determine realistic tractor-implement matching. Leading from this, engine loading is estimated from the ratio of operator chosen speed to the theoretical maximum travel speed for a given tractor.

(iii) American Society for Agricultural and Biological Engineering (ASABE)
The ASABE (1998) use implement-specific parameters, soil factors, depth of operation and travel speed to calculate horizontal draft (kN) requirements of the implement. Subsequently, a loading factor can be determined using the power available at the drawbar and the power required for an operation. The power required for an operation is a product of horizontal draft and travel speed. The available drawbar power is estimated by multiplying the rated engine power by factors, defined by ASABE (1998), that account for losses in the drive train and tractive conditions.

Validation and Comparison

Data used to validate and compare the methods were obtained from tractor drawbar tests conducted by the South African Agricultural Research Council – Institute for Agricultural Engineering (van Biljon and Mavundza, 2011) as well as various literature sources (Karlen *et al.*, 1991; Ismail *et al.*, 1993; Smith, 1993; Al-Suhaibani and Al-Janobi, 1997; Serrano *et al.*, 2003; Kheiralla *et al.*, 2004; Abbaspour-Gilandeh *et al.*, 2006; Kichler *et al.*, 2011). The data set consists of measurements from 37 disk harrow, 41 mouldboard plough and 39 subsoiling plots with a soil clay content range of 5-50% and tractive conditions varying between tilled and untilled. The tractors used varied in rated power (50-150 kW) and type (two wheel drive or mechanical front wheel drive). The following parameters were recorded over the trial plot (usually between 50 and 100 m in length) and an average value obtained:

- horizontal draft (kN),
- engine speed (rpm),

- travel speed (km/h),
- wheel slip (%),
- operating depth (mm), and
- fuel consumption (L/h).

Microsoft Excel® was used to develop a spreadsheet to compare the methods. For each plot, the relative error between the calculated and measured engine load was expressed as a percentage, i.e. a positive value indicates an over-estimation and a negative value an under-estimation.

Results and Discussion

Two indicators are used to compare the performance and functional capabilities of the three methods. Each method is scored on how well it defines tractor, implement, soil and operational parameters. A statistical analysis is then used to assess the means and distribution of the calculated outputs.

Rating according to the ability to define infield tractor, implement, soil and operational parameters

All three methods differ in how precisely an operation is defined. For example, they may have the same input requirements but describe the operation in a different manner. Table 1 contains a summary of the required input parameters for all methods. The methods are scored according to their effectiveness in defining the operation and whether any limitations to input values may exist. For each method, input parameters are scored according to the scale rating described in Table 1. The cumulative score, in the 'Totals' column is an indication of how well the method can define an operation.

Table 1. Method of rating according to the level of input parameters used in the experiment.

	Input parameter								
Method	Rated power	Tractor type (2wd, 4wd, MFWA)	Soil texture	Tractive condition	Operator speed	Depth of operation	Number of tools/rows or width cultivated	Tool or row spacing	**Totals**
Pretorius	2	1	2	0	2	1	1	1	**10**
DAFF	2	0	1	0	0	1	1	1	**6**
ASABE	2	2	2	2	2	2	2	2	**16**
Scale rating									
0	Input parameter not used in this method								
1	Input parameter used but limited to how effectively it defines the operation								
2	Input parameter used and not limited to how the operation can be defined								

Both the Pretorius and DAFF methods use databases and empirical equations compiled from field experiments. As such, tractor and implement specifications, details of the operation and field conditions are limited to what was tested during the development of the methods. Also based on empirical equations, the ASABE method has, however, been developed from a more comprehensive set of field experiments. This allows for better modelling of draft and loading over a wider range of operational input parameters. The ASABE standards also contain generalised engine and tractive efficiencies from which a more realistic available drawbar power can be estimated.

Statistical analysis of method comparison

The relative error in calculated loading for each operation is used to compare the accuracy of the methods. This is presented in a box and whisker plot (Figure 1) which summarises the results for all the trial data. The distribution characteristics give an indication of the confidence and consistency of the calculations.

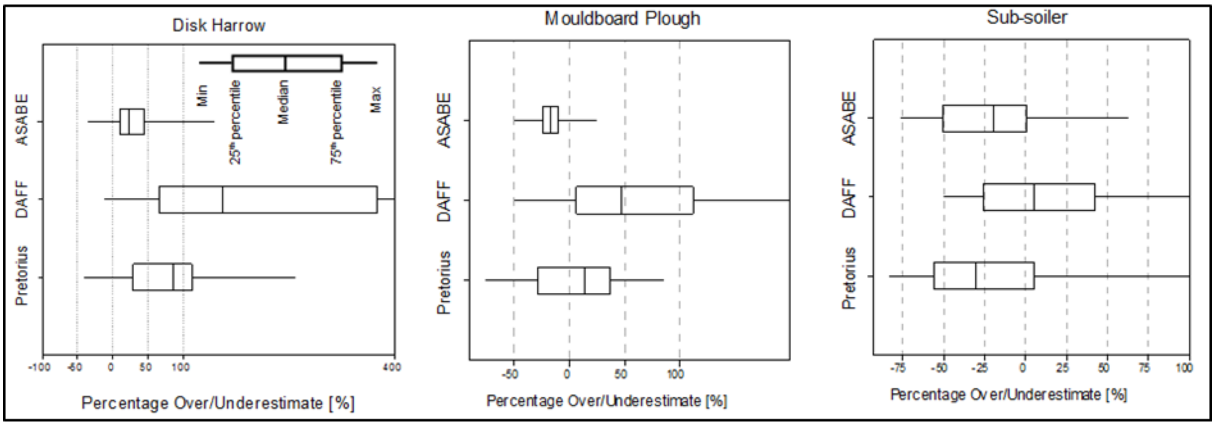

Figure 1. Box and whisker plots of relative error of all method-operation combinations.

For all operations, the ASABE data has the best fit, and relative to the other methods, the most normal distribution. The mean of the ASABE's relative errors (-2%) for all operations also suggest it to be the most accurate. The extreme errors in the DAFF method of calculation for the disking operation can be attributed to the method's limitations in defining an operation.

A statistic comparison, using a REML analysis and Sidak test (Bechhofer *et al.*, 1995), of each of the method's means for all the operations reveals no significant difference ($p<0.05$) between the Pretorius and ASABE methods. The DAFF method is, however, significantly different ($p<0.05$) to both the Pretorius and ASABE methods.

Conclusion

As shown in Table 1, the ASABE method is able to more accurately define an operation than both the DAFF and Pretorius methods. In addition, the ASABE method is also the most accurate when considering the average of its means and variability in comparison to the actual loading values. It is thus concluded that the ASABE method is the best method to use in the development of a tool to predict engine loading and subsequently fuel consumption.

Being preliminary results, there remains scope to increase the database of field trial results against which the methods can be compared. This will further increase the confidence in the above conclusions.

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