PROPOSAL TO ESTIMATE THE ENGINE OIL CONSUMPTION IN AGRICULTURAL TRACTORS

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ABSTRACT. *Lubrication plays a crucial role in a tractor engines' efficiency and durability. Without suitable lubrication, excessive friction will significantly reduce an engine's power, and high-intensity wear will damage the moving parts in a short period of time. A set of 178 agricultural tractor models from 20 different international manufacturers located in Europe, North America and Asia was used in this study. The tractor models were produced between 2000 and 2015 with rated engine power ranging from 30 to 428.8 kW. Rated engine power, crankcase oil capacity, and oil change intervals were derived from official test reports. Engine oil consumption was calculated using the method described in ASABE Standard D497.7, clause 3.4. A linear relationship between rated engine power and hourly oil consumption rate was confirmed, but the regression coefficients deviated from current values in the ASABE Standard. These results indicate that ASABE equation coefficients should be updated to more accurately estimate engine oil consumption for use in technical/economical evaluations and in the analysis of operating costs of new tractor models.*

Keywords. *Agricultural tractors, Engine oil consumption, Lubrication, Mechanization costs.*

The engines of agricultural machines, like those of other vehicles, contain a large number of parts moving at a high speed and in close contact. Without suitable lubrication, excessive friction will significantly reduce an engine's power and wear will damage the moving parts in a short period of time. Moreover, lubricant fluids remove heat from bearings and coupled parts, improve the pressure work of combustion gases by acting as a seal around piston rings, and remove potentially damaging solid particles from inside the engine. Thus, lubrication plays a crucial role in the efficiency and durability of a tractor's engine (Goering, 1992).

Currently, the agricultural machine industry is producing more efficient and higher-performance engines with tighter tolerances, higher specific power, and increased operating pressures and temperatures. Furthermore, in most current tractor series, the engine is designed to cope with a variety of operative conditions and, consequently, to operate on a wide load range (Wertz et al., 1990).

All of this implies that agricultural machine manufacturers have had to adopt new materials and to develop new solutions for optimizing lubrication, while, on the other hand, the lubricant industry has had to improve the properties of oils to comply with the newer engines' requirements.

Lubricating properties degrade with use, which is why periodical changes are necessary. Typically, oil in a tractor's engine is changed after every 500 to 600 h of work (in any case, every year). The change intervals that manufacturers recommend should be carefully observed and, between oil changes, crankcases must be refilled in case of low level (Goering, 1992).

One of the most used methods to estimate the engine oil hourly consumption is the equation reported in the ASABE Standard D497.7, clause 3.4 (2011). These linear equations are used to estimate hourly engine oil consumption for gasoline, diesel, or liquefied petroleum gas (LPG) tractor engines as a function of their rated power. Equation 1 shows the current coefficients for diesel engines.

$$Q_i = 0.00059 \cdot P_r + 0.02169 \quad (1)$$

where
Q_i = hourly engine oil consumption (L h^{-1}),
P_r = rated engine power (kW).

The ASABE Standard D497.7 defines the hourly engine oil consumption (Q_i in eq. 1) as the "volume per hour of en-

Submitted for review in July 2016 as manuscript number MS 11992; approved for publication as a Technical Note by the Machinery Systems Community of ASABE in November 2016.

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gine crankcase oil replaced at the manufacturer's recommended change interval" (ASABE Standard D497.7, clause 3.4, 2011) as a function of the rated engine power (P_r in eq. 1).

With equation 1, the engine lubricant oil cost C_L (USD h^{-1}), albeit generally small compared to other tractor's operating cost (Calcante et al., 2013; Hawkins and Buckmaster, 2015), can be straightforward computed as (Srivastava et al., 2006):

$$C_L = Q_i \cdot p_L \tag{2}$$

where p_L = engine oil unitary cost (USD L^{-1}).

In this work we applied the approach defined in ASABE Standard D497.7 (2011) to estimate the engine oil consumption rate in recent agricultural tractors. The objective was to obtain updated equation coefficients that would be useful to conduct technical/economical evaluations and for more accurate analysis of operating costs related to new models of tractors.

MATERIALS AND METHODS

THE DATASET

This study considered 178 agricultural tractor models including two-wheel drive (2WD), four-wheel drive (4WD), and crawlers from 20 different international manufacturers located in Europe, North America, and Asia. These models were recently designed and they were all first introduced to the market between the years of 2000 and 2015. The rated engine power of the tractors ranged from 30 to 428.8 kW.

For each tractor, the following data were retrieved from the official test reports conducted in accordance with Organization for Economic Co-operation and Development (OECD) Standard Code 2 (OECD, 2016).

1. rated engine power, P_r (kW);
2. crankcase engine oil capacity, EO (L);
3. recommended engine oil change interval, EOCI (h).

For each tractor, the hourly engine oil consumption Q_i (L h^{-1}) was computed from equation 3:

$$Q_i = \frac{EO}{EOCI} \tag{3}$$

These data were associated with the rated engine power (as measured according OECD Standard Code 2) of the tractors, to statistically analyze their relationship.

STATISTICAL ANALYSIS

The dataset was studied by applying a linear regression analysis (LRA) and an associated analysis of variance (ANOVA) using MINITAB 17.0™ data processing software (Minitab, State College, Pa.). The LRA was used to determine coefficients for equation 1 based on this data set.

Finally, the performance of the new equation in estimating engine oil consumption in tractors was assessed by applying a k-fold cross-validation implemented in Matlab R2015b (Mathworks, Natick, Mass.). With this procedure, the original dataset is randomly partitioned into k equal-sized subsets. One of each is repeatedly retained as validation samples for testing the prediction capability of the model, while the remaining k-1 subsets are used as training data for calibrating the model (Geisser, 1975; Arlot and Celisse, 2010). The cross-validation was repeated 10 times (the folds), with each of the k subsamples (consisting of 18 tractors) used exactly once as validation data. The result obtained with the cross-validation procedure was the root mean square error (RMSE) of the model's prediction capability.

RESULTS AND DISCUSSION

DATASET DESCRIPTION

Table 1 summarizes the main characteristics of the entire dataset in different classes of rated engine power. The values of engine rated power and oil consumption are rather evenly distributed for small-medium tractor classes, while the data of high-power tractors appear to be more homogenously gathered. Indeed, the coefficient of variation (CV) of P_r is greater than 15% for tractors up to 120 kW, while it is about 20% for tractors above 200 kW. Similarly, Q_i has a greater variability for tractors in the lower-power class (30-60 kW), with a CV of 33% and a relatively lower variability (with a CV of about 23%) for power above 120 kW.

LINEAR REGRESSION ANALYSIS AND NEW COEFFICIENTS FOR ENGINE OIL CONSUMPTION EQUATION

The entire dataset was used to assess the relation between Q_i (L h^{-1}) and P_r (kW). The variables resulted in an overall Pearson correlation coefficient of $r = 0.90$ ($p < 0.05$). LRA relating Qi with P_r was therefore assessed, obtaining:

$$Q_i = 0.000239 \cdot P_r + 0.00989 \tag{4}$$

The standard errors of the constant term of the model and the linear coefficient were 1.50 10^{-3} L $h^{-1}$and 9.0 10^{-6} L h^{-1} kW^{-1}, respectively.

EQUATION EVALUATION AND CROSS-VALIDATION

In figure 1, the data for 178 tractors were plotted with a 95% confidence interval. Practically all of the 178 observations were within the 95% CI limits (approximately 0.02 L h^{-1}). Nevertheless, the plot adds to the evidence a group of high-power tractors (P_r between 264 and 288 kW) whose behavior substantially deviated from the behavior predicted by

Table 1. Descriptive statistics of the tractor dataset.

Power Range		Engine Rated Power P_r			Engine Oil Consumption Qi		
(kW)	N	Mean (kW)	SD (kW)	CV (%)	Mean (L h^{-1})	SD (L h^{-1})	CV (%)
30-60	27	46.3	7.92	17.1	0.0245	0.0083	33.9
60-120	63	88.3	15.1	17.1	0.0288	0.0096	33.3
120-200	41	156.3	23.2	14.8	0.0471	0.0114	24.2
>200	47	281.6	57.8	20.5	0.0785	0.0177	22.5
30-428.8	178	148.7	93.2	62.7	0.0455	0.0247	54.3

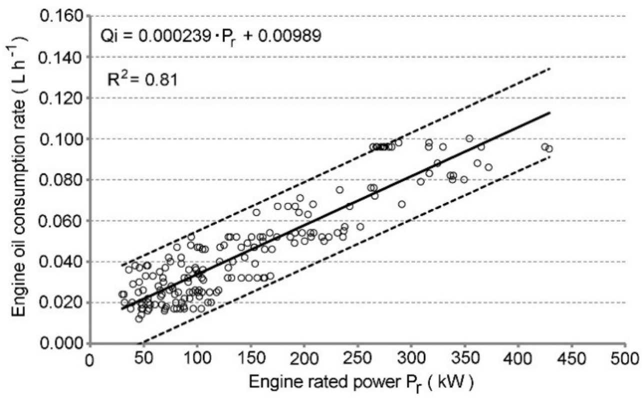

Figure 1. Plot of the hourly oil consumption data for 178 tractor models marketed from 2000 to 2015. The bold line is the linear fit equation proposed, while the dashed lines indicate the ±95% confidence prediction interval.

equation 4, falling very close to the upper confidence limit. These data refer to high-power, articulated tractors by a specific manufacturer, equipped with the same engine (displacement higher than 12 L) with different options resulting in a range of power. This group of tractors is equipped with particularly large crankcase capacity (50 L), relative to the crankcase capacity (25-30 L) of other tractors in this power range. These specific features explain the difficulty of using the equation to accurately model these particular tractors. This suggests to take into account the 95% CI range (±0.02 L h^{-1}) when expressing the hourly oil consumption value calculated from equation 4.

The residual plot shown in figure 2 illustrates an overall random distribution that excludes unwanted biased results except for those of the group of high-powered, articulated tractors, which exhibited a significant deviation as indicated by the pattern of their residuals.

The coefficient of determination (R^2= 0.81) confirmed the fair strength of the relationship between Q_i and P_r in the dataset, indicating that equation 4 accounted for 81% of the variance in the data.

The K-fold cross-validation returned a RMSE value of 0.0012 L h^{-1}, corresponding to less than 2.5% of the mean value of Q_i in the dataset. This indicates that we can expect only very little difference between the measured values of Q_i and those predicted by equation 4 even for tractors not included in the calibration set.

Finally, figure 3 compares the pattern of equation 4 with the equation adopted in ASABE Standard D497.7 clause 3.4 (eq. 1). It shows an evident deviation between the two equations: the ASABE model tended to significantly overestimate the hourly engine oil consumption in the recent tractors used to calibrate the proposed update (eq. 4). This is likely due to the evolution of engine materials and of lubrication characteristics of oils, which led to a relevant increase of its change interval. In the last decade, the typical recommended interval changed from approximately 100-150 h to 500-600 h.

Conclusions

The current reference model for estimating the engine oil hourly consumption is the linear equation reported in the ASABE Standard D497.7 clause 3.4 (2011).

By applying linear regression on a dataset of 178 recent tractors, we obtained an updated linear equation relating engine oil hourly consumption to the rated power. The proposed, new equation predicts oil consumption is less than half that predicted using the current equation in the standard.

After a statistical analysis and cross-validation on the dataset, the equation proposed in this work has proved to be coherent and fairly reliable. Therefore, it is suitable to be used for more accurate estimates of operating costs and to draw technical evaluations on current generation tractors.

References

Arlot, S., & Celisse, A. (2010). A survey of cross-validation procedures for model selection. *Stat. Surv., 4*, 40-79. http://dx.doi.org/10.1214/09-SS054

ASABE Standards. (2011). D497.7: Agricultural machinery management data. St. Joseph, MI: ASABE.

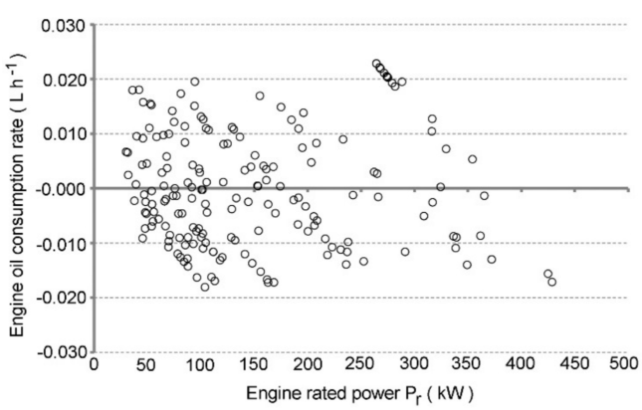

Figure 2. Plot of the residuals from the fitting equation for 178 tractor models.

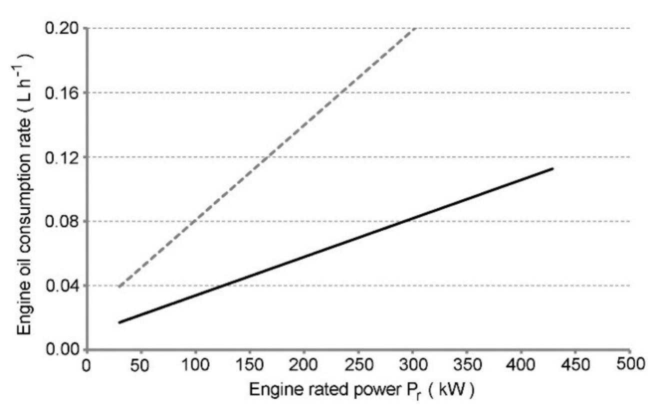

Figure 3. Comparative plot of the linear equations to estimate the engine oil consumption rate as a function of the engine power. The dashed line is the equation established in ASABE Standard D497.7 (2011); the bold line is the updated equation proposed in this work and derived from the data of 178 recent tractor models.

Calcante, A., Fontanini, L., & Mazzetto, F. (2013). Repair and maintenance costs of 4WD tractors in northern Italy. *Trans. ASABE, 56*(2), 355-362. http://dx.doi.org/10.13031/2013.42660

Geisser, S. (1975). The predictive sample reuse method with applications. *J. Am. Stat. Assoc., 70*(350), 320-328. http://dx.doi.org/10.1080/01621459.1975.10479865

Goering, C. E. (1992). *Engine and tractor power* (2nd ed.). St. Joseph, MI: ASAE.

Hawkins, E. M., & Buckmaster, D. R. (2015). Benchmarking costs of fixed-frame, articulated, and tracked tractors. *Appl. Eng. Agric., 31*(5), 741-745. http://dx.doi.org/10.13031/aea.31.11074

OECD. (2016). Code 2. OECD Standard code for the official testing of agricultural and forestry tractor performance. Paris, France: Organization for Economic Co-operation and Development.

Srivastava, A. K., Goering, C. E., Rohrbach, R. P., & Buckmaster, D. R. (2006). Machinery selection and management. In *Engineering principles of agricultural machines* (2nd ed., pp. 538-539). St. Joseph, MI: ASABE. https://doi.org/10.13031/2013.41477

Wertz, K., Grisso, R., & Von Bargen, K. (1990). A survey of ag tractor service intervals: Part I. *Appl. Eng. Agric., 6*(5), 537-541. http://dx.doi.org/10.13031/2013.26424