2004

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Grisso, Robert D.; Kocher, Michael F.; and Vaughan, David H., "Predicting Tractor Fuel Consumption" (2004). *Biological Systems Engineering: Papers and Publications*. 164.
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PREDICTING TRACTOR FUEL CONSUMPTION

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ABSTRACT. *Reports from the Nebraska Tractor Test Laboratory (NTTL) show improved fuel efficiency during the past 20 years. A 4.8% decrease in average annual specific volumetric fuel consumption for the data used in the*ASAE Standards *was shown. Using fuel consumption and power data from the NTTL reports, new equations for fuel consumption were established that predict fuel consumption for diesel engines during full and partial loads and under conditions when engine speeds are reduced from full throttle.*

Keywords*. Fuel consumption, Machinery management, Tractors, Standardized tests.*

The primary purpose of agricultural tractors, especially those in the middle to high power range, is to perform drawbar work (Zoz and Grisso, 2003). The value of a tractor is measured by the amount of work accomplished relative to the cost incurred in getting the work done. Drawbar power is defined by pull (or draft) and travel speed. Therefore, the ideal tractor converts all the energy from fuel into useful work at the drawbar.

Efficient operation of farm tractors includes: (1) maximizing the fuel efficiency of the engine and mechanical efficiency of the drive train, (2) maximizing tractive advantage of the traction devices, and (3) selecting an optimum travel speed for a given tractor−implement system. This article focuses on fuel efficiency.

According to Siemens and Bowers (1999), "depending on the type of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs will usually represent at least 16 percent to over 45 percent of the total machine costs…" Most cropping and machinery budgets developed by state Extension specialists and others contain estimates from the *ASAE Standards* (2002a; 2002b). Recently, several managers of these budgets questioned whether the fuel estimates were reflective of the new engine designs. This article reviews tractor test data over the past 20 years and examines the accuracy of the *ASAE Standards* for predicting fuel consumption. New equations and the inclusion of fuel consumption estimates from reduced engine speed operations were developed.

TERMINOLOGY

Manufacturers specify the power output from several sources [power take−off (PTO), drawbar, or hydraulic outlets]. Each tractor model has a rated power that has been measured at the rated engine speed. Typically this power is measured at the PTO and is referred to in the remainder of this article as rated PTO power. For most current tractors, the rated power will not be the maximum power. With new engine designs, operating engine speeds, other than rated speed, produce more power. Standardized tractor test codes specify power and fuel consumption measurements at rated engine speed, standard PTO speed (either 540 or 1000 rpm), and at engine speed and load conditions that produce maximum PTO power.

Nebraska Tractor Test Laboratory (NTTL) has a long history of testing tractors and disseminating power and fuel consumption data. During standardized tests, the power is calculated and the corresponding fuel consumption is measured. The power at the PTO is calculated from the torque and the PTO speed. Drawbar power is calculated from the drawbar pull (or draft) and forward speed of the tractor.

Fuel consumption is measured by the amount of fuel used during a specific time period. The most common measure of the energy efficiency of a tractor is referred to here as specific volumetric fuel consumption (SVFC), which is given in units of L/kW•h (gal/hp•h). SVFC is generally not affected by the engine size and can be used to compare energy efficiencies of tractors having different sizes and under different operating conditions. SVFC for diesel engines typically range from 0.244 to 0.57 L/kW•h (0.0476 to 0.111 gal/hp•h). For ease of computation, the reciprocal of SVFC is often used and is called specific volumetric fuel efficiency (SVFE) with units of kW•h/L (hp•h/gal) with corresponding ranges from 2.36 to 4.1 kW•h/L (12 to 21 hp•h/gal). The NTTL reports the SVFE for drawbar load tests, rated PTO speed and varying PTO power tests. Figure 1 shows an example NTTL Report and the SVFE for these test are shown under the columns labeled with units of "hp•h/gal (kW•h/L)."

Article was submitted for review in June 2003; approved for publication by the Power & Machinery Division of ASAE in March 2004. Presented at the 2003 ASAE Annual Meeting as Paper No. 031107.

A contribution of the University of Nebraska Agricultural Research Division, Lincoln, Nebraska, Journal Series No. 14185. Mention of trade and company names are for the reader and do not infer endorsement or preferential treatment of the products by Virginia Tech or University of Nebraska, Lincoln.

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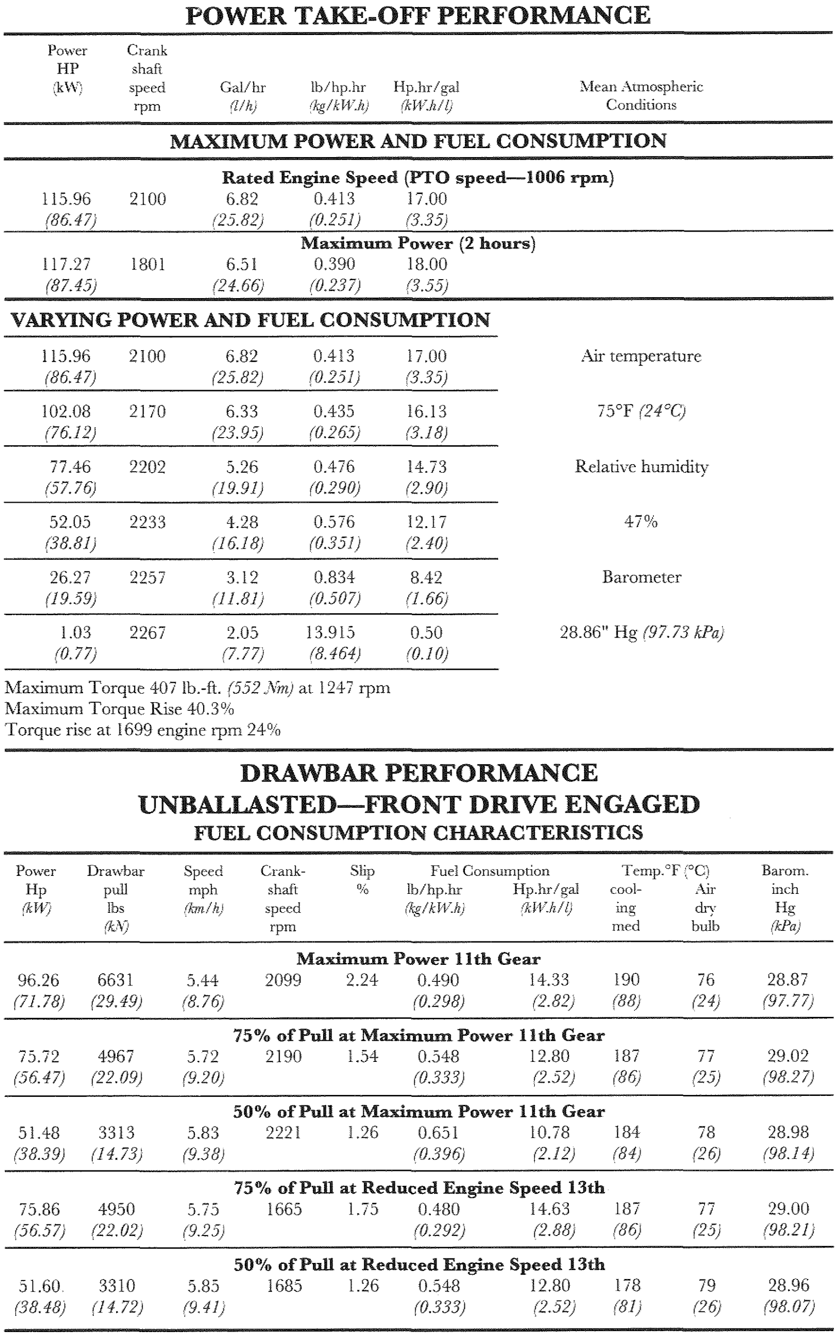

POWER TAKE-OFF PERFORMANCE

Power HP (kW)	Crank shaft speed rpm	Gal/hr *(l/h)*	lb/hp.hr *(kg/kW.h)*	Hp.hr/gal *(kW.h/l)*	Mean Atmospheric Conditions
MAXIMUM POWER AND FUEL CONSUMPTION					
Rated Engine Speed (PTO speed—1006 rpm)					
115.96 *(86.47)*	2100	6.82 *(25.82)*	0.413 *(0.251)*	17.00 *(3.35)*	
Maximum Power (2 hours)					
117.27 *(87.45)*	1801	6.51 *(24.66)*	0.390 *(0.237)*	18.00 *(3.55)*	
VARYING POWER AND FUEL CONSUMPTION					
115.96 *(86.47)*	2100	6.82 *(25.82)*	0.413 *(0.251)*	17.00 *(3.35)*	Air temperature
102.08 *(76.12)*	2170	6.33 *(23.95)*	0.435 *(0.265)*	16.13 *(3.18)*	75°F *(24°C)*
77.46 *(57.76)*	2202	5.26 *(19.91)*	0.476 *(0.290)*	14.73 *(2.90)*	Relative humidity
52.05 *(38.81)*	2233	4.28 *(16.18)*	0.576 *(0.351)*	12.17 *(2.40)*	47%
26.27 *(19.59)*	2257	3.12 *(11.81)*	0.834 *(0.507)*	8.42 *(1.66)*	Barometer
1.03 *(0.77)*	2267	2.05 *(7.77)*	13.915 *(8.464)*	0.50 *(0.10)*	28.86" Hg *(97.73 kPa)*

Maximum Torque 407 lb.-ft. *(552 Nm)* at 1247 rpm
Maximum Torque Rise 40.3%
Torque rise at 1699 engine rpm 24%

DRAWBAR PERFORMANCE
UNBALLASTED—FRONT DRIVE ENGAGED
FUEL CONSUMPTION CHARACTERISTICS

Power Hp *(kW)*	Drawbar pull lbs *(kN)*	Speed mph *(km/h)*	Crank-shaft speed rpm	Slip %	Fuel Consumption lb/hp.hr *(kg/kW.h)*	Fuel Consumption Hp.hr/gal *(kW.h/l)*	Temp.°F (°C) cooling med	Temp.°F (°C) Air dry bulb	Barom. inch Hg *(kPa)*
Maximum Power 11th Gear									
96.26 *(71.78)*	6631 *(29.49)*	5.44 *(8.76)*	2099	2.24	0.490 *(0.298)*	14.33 *(2.82)*	190 *(88)*	76 *(24)*	28.87 *(97.77)*
75% of Pull at Maximum Power 11th Gear									
75.72 *(56.47)*	4967 *(22.09)*	5.72 *(9.20)*	2190	1.54	0.548 *(0.333)*	12.80 *(2.52)*	187 *(86)*	77 *(25)*	29.02 *(98.27)*
50% of Pull at Maximum Power 11th Gear									
51.48 *(38.39)*	3313 *(14.73)*	5.83 *(9.38)*	2221	1.26	0.651 *(0.396)*	10.78 *(2.12)*	184 *(84)*	78 *(26)*	28.98 *(98.14)*
75% of Pull at Reduced Engine Speed 13th									
75.86 *(56.57)*	4950 *(22.02)*	5.75 *(9.25)*	1665	1.75	0.480 *(0.292)*	14.63 *(2.88)*	187 *(86)*	77 *(25)*	29.00 *(98.21)*
50% of Pull at Reduced Engine Speed 13th									
51.60 *(38.48)*	3310 *(14.72)*	5.85 *(9.41)*	1685	1.26	0.548 *(0.333)*	12.80 *(2.52)*	178 *(81)*	79 *(26)*	28.96 *(98.07)*

Figure 1. Example of a tractor test report. This section shows the PTO performance tests (top), the varying power (middle) tests, and the drawbar performance test (bottom) results. This report is taken from Nebraska OECD Tractor Test 1725 – Summary 225 for John Deere 7610 PowerShift.

CURRENT *ASAE* STANDARDS

The fuel consumption estimates used in cropping and machinery budgets are based on the average annual fuel consumption from Agricultural Machinery Management engineering practice (*ASAE Standards*, 2002a). According to the respective sections 6.3.2.1, 6.3.2.1.1, and 6.3.2.1.2 of the ASAE EP496.2, fuel consumed over the year for a tractor is characterized by the following definitions and equations:

"**6.3.2.1.** Average fuel consumption for tractors. Annual average fuel requirements for tractors may be used in calculating overall machinery costs for a particular enterprise. However, in determining the cost for a particular operation such as plowing, the fuel requirement should be based on the actual power required."

"**6.3.2.1.1.** Average annual fuel consumption for a specific make and model tractor can be approximated from the Nebraska Tractor Test Data. Average gasoline consumption over a whole year can be estimated by the following formula:

$$Q_{avg} = 0.305 \times P_{pto} \qquad \text{(SI)} \quad (1)$$

where

Q_{avg} = average gasoline consumption, L/h;
P_{pto} = maximum PTO power, kW;

or

$$Q_{avg} = 0.06 \times P_{pto} \qquad \text{(English)} \quad (2)$$

where

Q_{avg} = average gasoline consumption, gal/h;

P_{pto} = maximum PTO power, hp."

(The unit specifications and equations numbers have been added to highlight unit differences and ease of reference. This information is not part of the quotation.)

"**6.3.2.1.2** A diesel tractor will use approximately 73% as much fuel in volume as a gasoline tractor, and liquefied petroleum LP gas tractors will use approximately 120% as much."

Since most tractors tested and used for agricultural purposes in the last 25 years have had diesel engines, the above equations converted for diesel engines become:

$$Q_{avg} = 0.305 \times 0.73 \times P_{pto} = 0.223 \times P_{pto} \quad \text{(SI)} \quad (3)$$

$$Q_{avg} = 0.06 \times 0.73 \times P_{pto} = 0.044 \times P_{pto} \quad \text{(English)} \quad (4)$$

These equations were used by Siemens and Bowers (1999, pg. 65 and 153). Bowers (2001) stated that these average fuel consumption data were estimated from the varying PTO power tests from the NTTL Reports. The fuel consumption over the varying PTO power tests (approximately 100%, 85%, 65%, 45%, 20%, and 0% of rated PTO power) were averaged and then the average was divided by the rated PTO power. This calculation was a line at the bottom of the varying PTO power data in the Nebraska Tractor Test Reports prior to 1970. One implication of this method is that the estimated annual fuel consumption is based on operation of the tractor for equal amounts of time at each of these partial loads.

It is interesting to note that the reciprocal of the coefficients in equations 3 and 4 have the same units as SVFE, however, these values are not the same because of the differences in the way these values and the SVFE values are determined. The reciprocal of the coefficients in equations 3 and 4 yield 4.48 kW•h/L (22.7 hp•h/gal), which are higher than the normal range of SVFE, which is 2.36 to 4.1 kW•h/L (12 to 21 hp•h/gal).

Some budgets use the estimated fuel consumption for a specific operation given by ASAE EP496.2 (*ASAE Standards*, 2002a):

"**6.3.2.2** Fuel consumption for a specific operation. Predicting fuel consumption for a specific operation requires determination of the total tractor power for that operation (see clause 4). The equivalent PTO power is then divided by the rated maximum to get a percent load for the engine. The fuel consumption at that load is obtained from ASAE D497, clause 3. Fuel consumption for a particular operation can be estimated by the following calculation:

$$Q_i = Q_s \times P_T \quad (5)$$

where

Q_i = estimated fuel consumption for a particular operation, L/h (gal/h)

Q_s = specific volumetric fuel consumption for the given tractor, determined from ASAE D497, clause 3, L/kW•h (gal/hp•h)

P_T = total tractor power (PTO equivalent) for the particular operation, kW (hp)

A fuel consumption of 15% above that for Nebraska Tractor Tests is included for loss of efficiency under field conditions."

Clause 3 mentioned above is found in the Agricultural Machinery Management Data, D497.4 (ASAE Standards, 2002b) and states:

"**3.3** Fuel efficiency varies by type of fuel and by percent load on the engine. Typical farm tractor and combine engines above 20% load are modeled by the equations below. Typical fuel consumption for a specific operation is given in L/kW•h (gal/hp•h) where X is the ratio of equivalent PTO power required by an operation to that maximum available from the PTO. These equations model fuel consumptions 15% higher than typical Nebraska Tractor Test performance to reflect loss of efficiency under field conditions. To determine the average fuel consumption of a tractor operating under a range of load conditions, over a period of time, refer to ASAE EP496.

Gasoline: $$2.74X + 3.15 - 0.203\sqrt{697X} \quad \text{(SI)} \quad (6)$$

$$(0.54X + 0.62 - 0.04\sqrt{697X}) \quad \text{(English)} \quad (7)$$

Diesel: $$2.64X + 3.91 - 0.203\sqrt{738X + 173} \quad \text{(SI)} \quad (8)$$

$$(0.52X + 0.77 - 0.04\sqrt{738X + 173}) \quad \text{(English)} \quad (9)$$

LPG (liquefied petroleum gas):

$$2.69X + 3.41 - 0.203\sqrt{646X} \quad \text{(SI)} \quad (10)$$

$$(0.53X + 0.62 - 0.04\sqrt{646X}) \quad \text{(English)} \quad (11)\text{"}$$

These equations are estimates of specific volumetric fuel consumption, SVFC [L/kW•h (gal/hp•h)] along the full throttle or governor response curve. They do not provide estimates of the fuel consumption during reduced engine speed settings that are often recommended for partial load applications (Kotzabassis, et al. 1994; Grisso and Pitman, 2001). Thus, the volumetric fuel consumption for a diesel engine at partial loads and full throttle can be calculated as:

$$Q = (2.64X + 3.91 - 0.203\sqrt{738X + 173}) \times X \times P_{pto} \quad \text{(SI)} \quad (12)$$

$$Q = (0.52X + 0.77 - 0.04\sqrt{738X + 173}) \times X \times P_{pto} \quad \text{(English)} \quad (13)$$

where

Q = diesel fuel consumption at partial load, L/h (gal/h)

X = the ratio of equivalent PTO power (P_T) to rated PTO power (P_{pto}), decimal

P_{pto} = the rated PTO power, kW (hp)

DATA MANAGEMENT AND ANALYSIS

A spreadsheet was used to develop a database of fuel consumption from the NTTL reports from 1979 through 2002. The databases were separated in two files; one each for drawbar loads of 50% and 75%. The fuel consumption and power data for PTO and drawbar tests were compiled along with engine and chassis configurations including tractor weight during testing and unballasted weights. The fuel consumption data from the varying PTO power tests were entered but the power levels were assumed to be 100%, 85%, 65%, 45%, 20%, and 0.1% of the rated PTO power. From these data the specific volumetric fuel consumption [SVFC, L/kW•h (gal/hp•h)] was calculated.

To compare the average annual fuel consumption data with the estimates as presented in equation 3, the fuel consumption data for the varying PTO tests were divided by the estimated power level and then averaged over 720 tractors. During this analysis, specific volumetric fuel consumption at rated engine power was developed by dividing the fuel consumption at each power level of the varying PTO test by the rated PTO power and a simplified regression equation was developed.

To compare fuel efficiency improvements of the reduced engine speed during the 50% and 75% drawbar load tests, the decrease in SVFC and engine speed were based on percentages as follows:

$$\text{Decrease in SVFC} = \left(\frac{\text{SVFC}_\text{F} - \text{SVFC}_\text{R}}{\text{SVFC}_\text{F}} \right) \times 100 \quad (14)$$

$$\text{N}_\text{Red} = \left(\frac{\text{RPM}_\text{F} - \text{RPM}_\text{R}}{\text{RPM}_\text{F}} \right) \times 100 \quad (15)$$

where

SVFC = the specific volumetric fuel consumption at full throttle (F), and reduced throttle (R), during the 50% and 75% drawbar load tests, respectively, L/kW•h (gal/hp•h)

N_Red = the percentage engine speed (rpm) reduction during the 50% and 75% drawbar load tests at reduced throttle (R), compared to full throttle (F), respectively, %

The data measured in NTTL Report 1725 (shown in fig. 1) will be used to show the computation for equations 14 and 15. For the drawbar performance at “75% of Pull at Maximum Power,” the engine speed was 2190 rpm and SVFE of 2.52 kW•h/L (12.80 hp•h/gal). The corresponding test during reduced throttle setting had an engine speed of 1665 rpm and SVFE of 2.88 kW•h/L (14.63 hp•h/gal). The SVFC is calculated as 0.397 L/kW•h (0.078 gal/hp•h) for full throttle and 0.347 L/kW•h (0.068 gal/hp•h) for the reduced throttle test. Using equation 14, the decrease in SVFC was 12.6% while the engine speed was reduced (N_Red) by 24%. Similarly, the “50% of Pull at Maximum Power” tests have a reduction of engine speed of 24% and a decrease of SVFC of 15.8%.

The percentages calculated in equations 14 and 15 were used to predict the changes in fuel consumption based on engine speed reduction. It was expected that the fuel consumption could be predicted from reduced engine speed percentage and the fuel consumption predicted from full throttle data (along the governor response power curve).

RESULTS AND DISCUSSIONS

COMPARING NTTL DATA TO ASAE STANDARDS

The results have some interesting implications. The data from 20+ years of tractor testing were averaged for SVFC for the varying PTO power tests and shown in figure 2 along with results from equations 8 and 9 of the ASAE D497.4 (*ASAE Standards*, 2002b). The data from the NTTL report were entered without the corresponding power so the SVFC was estimated by dividing the fuel consumption by the power at estimated load percentage (100%, 85%, 65%, 45%, and 20%). The results were averaged for each load and then graphed along with 115% of the averages. The 15% increase curve accounted for field operations and wear of the engine as stated in the ASAE D497.4. The data from the varying power were in good agreement with equations 8 and 9. A slight decrease is shown for the SVFC data, which indicates that some improvement in engine efficiency has been gained over the last 20 years as predicted by ASAE D497.4.

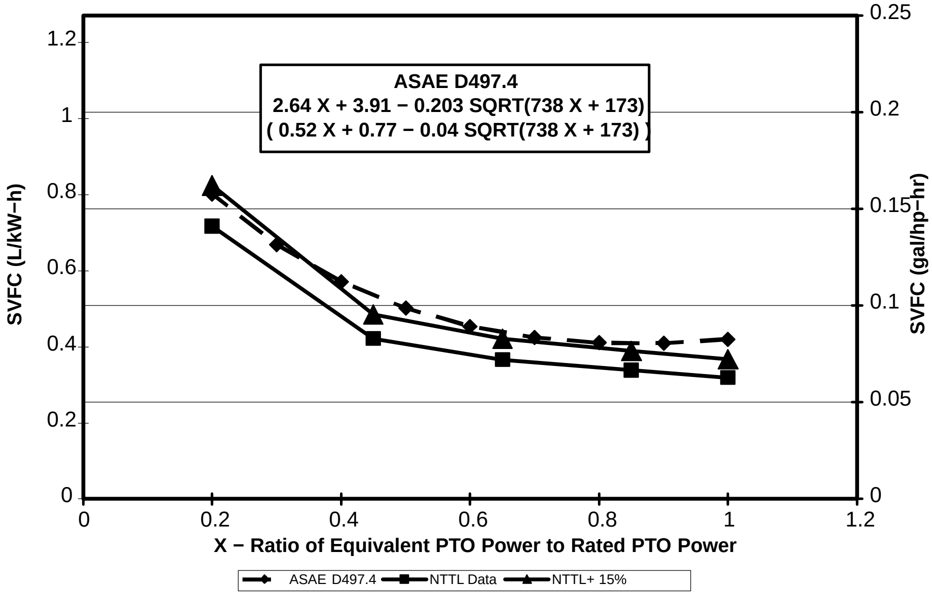

Figure 2. Comparison of the specific volumetric fuel consumption (SVFC) predicted by equations 8 and 9 (from ASAE D497.4) and the averages from the varying PTO power at each load level. A curve is shown of the averages, which is increased by 15% to account for field losses.

NEW FUEL CONSUMPTION RELATIONSHIP AT FULL THROTTLE

Equations 8, 9, 12, and 13 are complex since SVFC is calculated using the ratio of equivalent PTO power for a particular load to rated PTO power. Then specific volumetric fuel consumption and the equivalent PTO power at the particular load are used to calculate the fuel consumption (eqs. 3 and 4). While working with the data, instead of dividing the fuel consumption by the equivalent PTO power, the fuel consumption at each load level was divided by the rated PTO power for each tractor and then averaged for each load level for all tractors. The resulting graph is shown in figure 3. The points are linear and result in a simpler equation than using equations 12 and 13. The resulting equation for fuel consumption for full− and partial−load tests (with full−throttle) is:

$$Q = (0.22\ X + 0.096\ ) \times P_{pto} \qquad \text{(SI)} \quad (16)$$

$$Q = (0.0434\ X + 0.019\ ) \times P_{pto} \qquad \text{(English)} \quad (17)$$

where

Q = diesel fuel consumption at partial load, L/h (gal/h)

X = the ratio of equivalent PTO power to rated PTO power, decimal

P_{pto} = the rated PTO power, kW (hp)

The statistical fit for equations 16 and 17 using the average values was excellent (R^2 = 0.998). Figure 3 shows the maximum and minimum (dashed lines) for each load level as well as one standard deviation above and below the average.

The statistical fit for equations 16 and 17 using the average values was excellent (R^2 = 0.998). Figure 3 shows the maximum and minimum (dashed lines) for each load level as well as one standard deviation above and below the average.

Using the above regression equation, the predicted fuel consumption and the actual measurements from the varying power data were compared. The Pearson correlation coefficient was 0.989 for over 4900 comparisons.

FUEL CONSUMPTION DURING REDUCED ENGINE SPEEDS

Equations 16 and 17 predict fuel consumption for any load at full throttle. The only fuel consumption data from the NTTL reports, with reduced engine speed, are taken during the drawbar power tests. Figure 4 was developed to establish the relationship between fuel consumption during the PTO power tests and the drawbar power tests at full load. This figure shows that the fuel consumption during the PTO power tests and the drawbar power tests are almost identical. Thus, the varying PTO power fuel consumption data should apply to the drawbar load data as well as to the PTO load data if the load factor is known. During the drawbar test, losses occur due to tire/surface interface and transmission; thus, the SVFE decreases due to these losses, as shown in figure 5.

The SVFE data for full throttle and reduced throttle settings during 50% and 75% drawbar loads are compared in figure 6. Increased scatter of the data is evident due to less controlled conditions of the track surfaces, ambient conditions, test tractor configuration and tractor setup; including tire types, ballast amounts, axle weight distributions and engine speed/gear selection. But the data do show that reducing the throttle while maintaining travel speed and pull by gearing up will save an average of 21% and 13% (fig. 6) for 50% and 75% drawbar loads, respectively.

In order to predict the savings in fuel consumption for reduced engine speeds, the data were analyzed and graphed using the definitions in equations 14 and 15. The equations in figure 7 were developed by dividing the decrease in SVFC by the engine speed reduction to normalize the decrease in SVFC for the reduction in engine speed. While the R^2 values for the relationships at 50% and 75% loads were low due to the scatter of the data, the linear relationship gave the following surface equation:

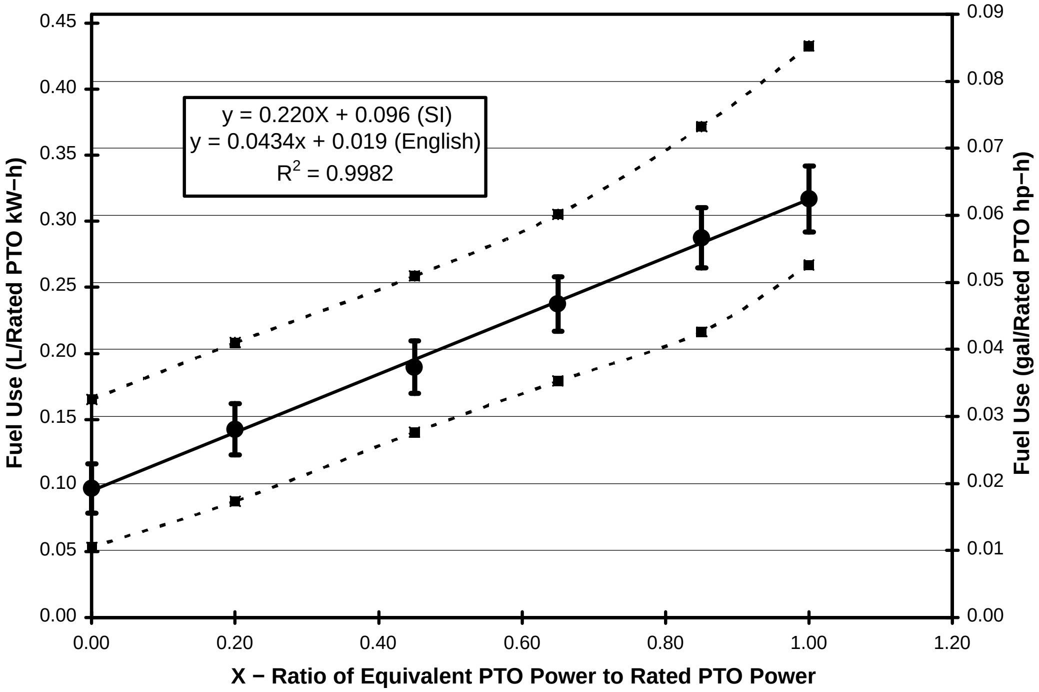

Figure 3. Predicted fuel use based on rated PTO power. Data shown are averaged for all tractors at each power level for the varying PTO power tests. The dashed lines are the maximum and minimum for each load level and the bars surrounding the averages (circle) show one standard deviation above and below the mean.

$$D = (-0.0045\ X\ N_{Red} + 0.00877\ N_{Red}) \qquad (18)$$

where

D = diesel fuel SVFC decrease between full and reduced engine speed, decimal

X = the ratio of equivalent PTO power to rated PTO power, decimal

N_{Red} = the percentage of reduced engine speed for a partial load from full throttle, %

Combining equations 16 and 17 with 18, the fuel consumption equations become:

$$Q = (0.22\ X + 0.096\ )(1 - (-0.0045\ X\ N_{Red} + 0.00877\ N_{Red})) \times P_{pto} \qquad \text{(SI)} \quad (19)$$

$$Q = (0.0434\ X + 0.019\ )(1 - (-0.0045\ X\ N_{Red} + 0.00877\ N_{Red})) \times P_{pto} \qquad \text{(English)} \quad (20)$$

where

Q = diesel fuel consumption at partial load and full/reduced throttle, L/h (gal/h)

N_{Red} = the percentage of reduced engine speed for a partial load from full throttle, %

X = the ratio of equivalent PTO power to rated PTO power, decimal

P_{pto} = the rated PTO power, kW (hp)

The predicted results of equations 19 and 20 were plotted versus the actual fuel consumption as reported by NTTL in figure 8. Each tractor has fuel consumption for varying PTO runs (100%, 85%, 65%, 45%, 20%, and 0% of PTO power), and most tractors tested have a full drawbar complement of 100%, 50%, and 75% drawbar loads at full throttle setting, and 50% and 75% drawbar loads at reduced engine throttle setting. The Pearson correlation coefficient for over 8000 comparisons was 0.989, which shows excellent agreement.

The relationship between the ASAE D497.4 equations 12 and 13 and the new equations 16 and 17 was compared in figure 9 at various equivalent and rated PTO power levels. The results of equations 16 and 17 were increased by 15% as suggested by the *ASAE Standards* to compensate for field and wear losses. The differences between the two equations are small in the midrange and at low rated PTO power levels; however, as the power levels increased, differences also increased. Also, increased deviations occurred at the low equivalent and near full power levels. The average annual specific volumetric fuel consumption from the NTTL data was 0.213 L/kW•h (0.042 gal/hp•h), which is a 4.8% decrease over the ASAE EP496.2 estimates given in equations 3 and 4.

CONCLUSIONS

During the past 20 years of tractor testing, improved fuel efficiency from NTTL reports was shown. A 4.8% decrease in average annual specific volumetric fuel consumption, for the data used in the *ASAE Standards*, was estimated. New equations for fuel consumption were established using fuel consumption and power data from the NTTL reports. These equations are useful to predict fuel consumption for diesel engines during full and partial loads and under conditions when engine speeds are reduced from full throttle.

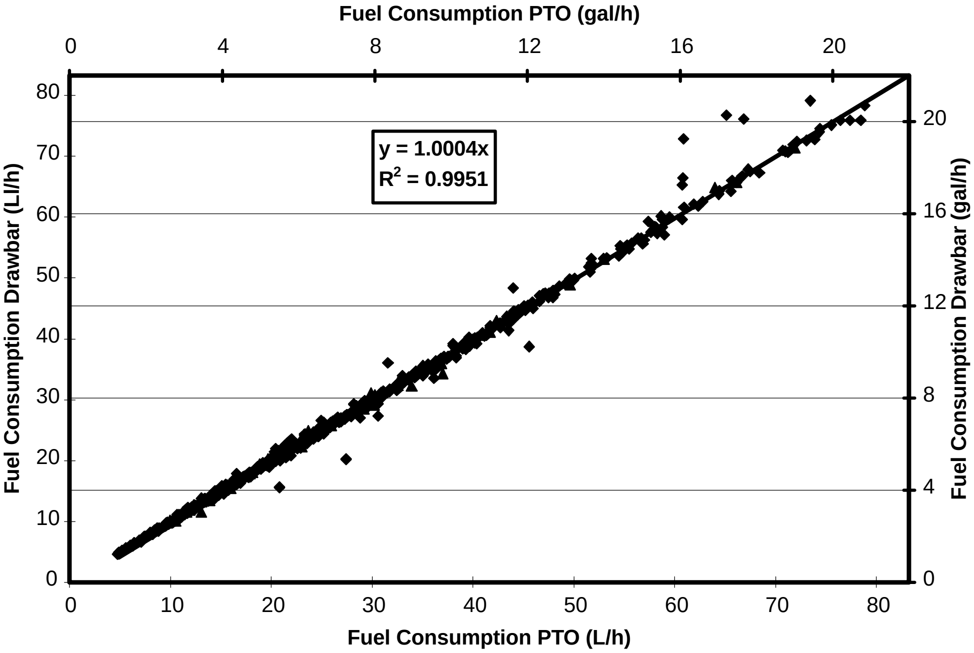

Figure 4. Fuel consumption at rated engine speed for PTO and drawbar power tests at full load.

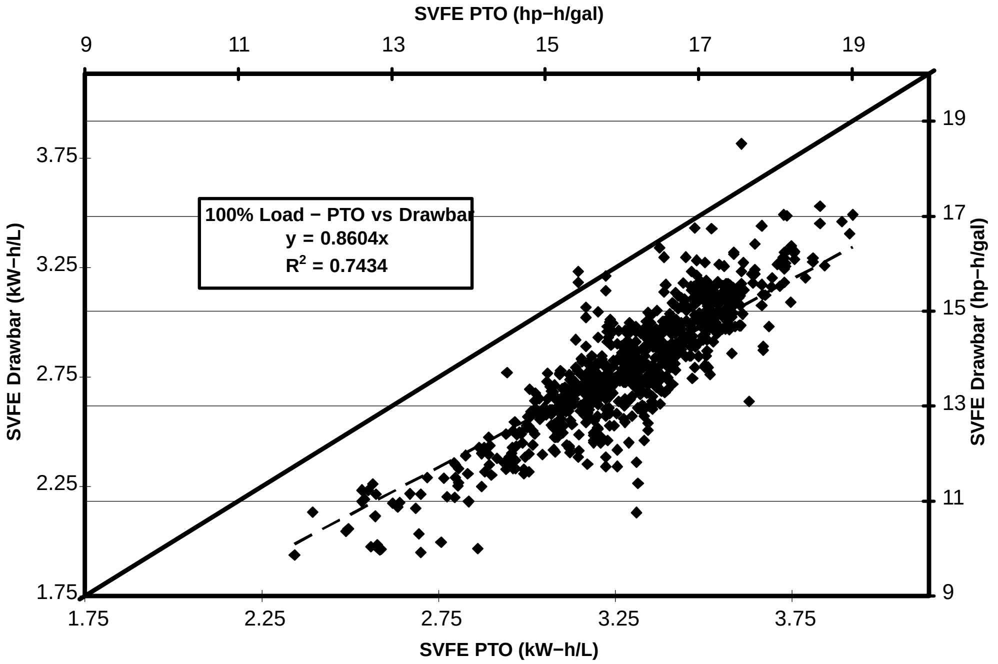

Figure 5. Specific volumetric fuel efficiency (SVFE) related at rated engine speed for the PTO and drawbar power tests at full load (The solid line is an 1:1 relationship and the dash line is the linear regression.).

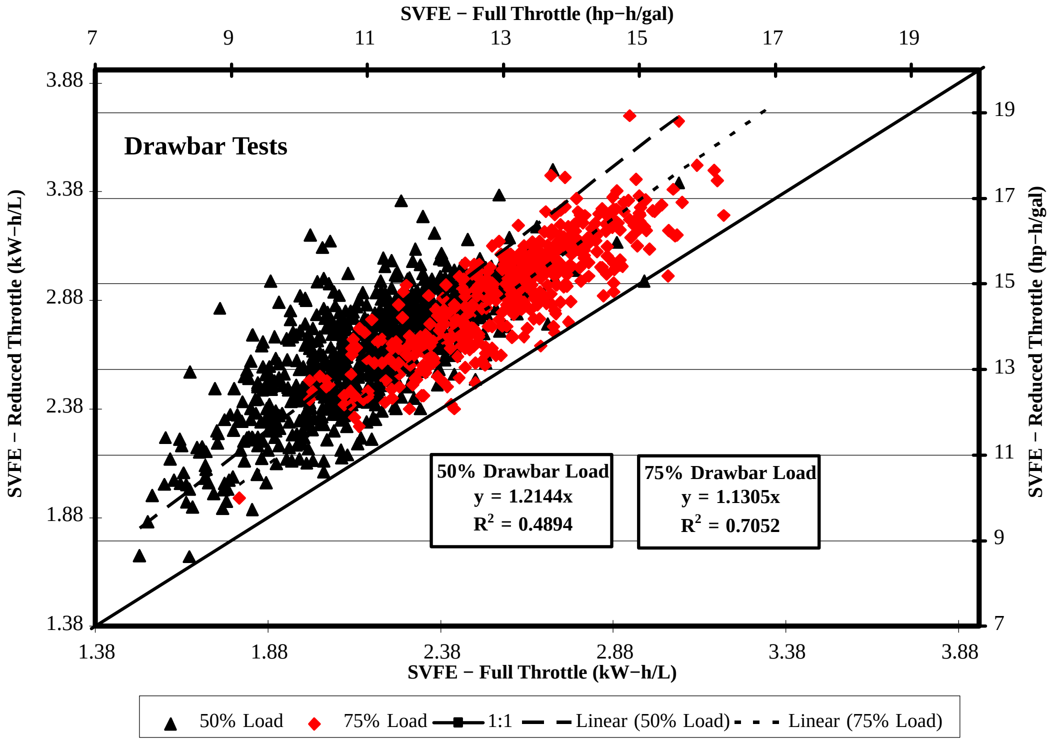

Figure 6. Specific volumetric fuel efficiency (SVFE) at full and reduced engine speeds for 50% and 75% drawbar load tests.

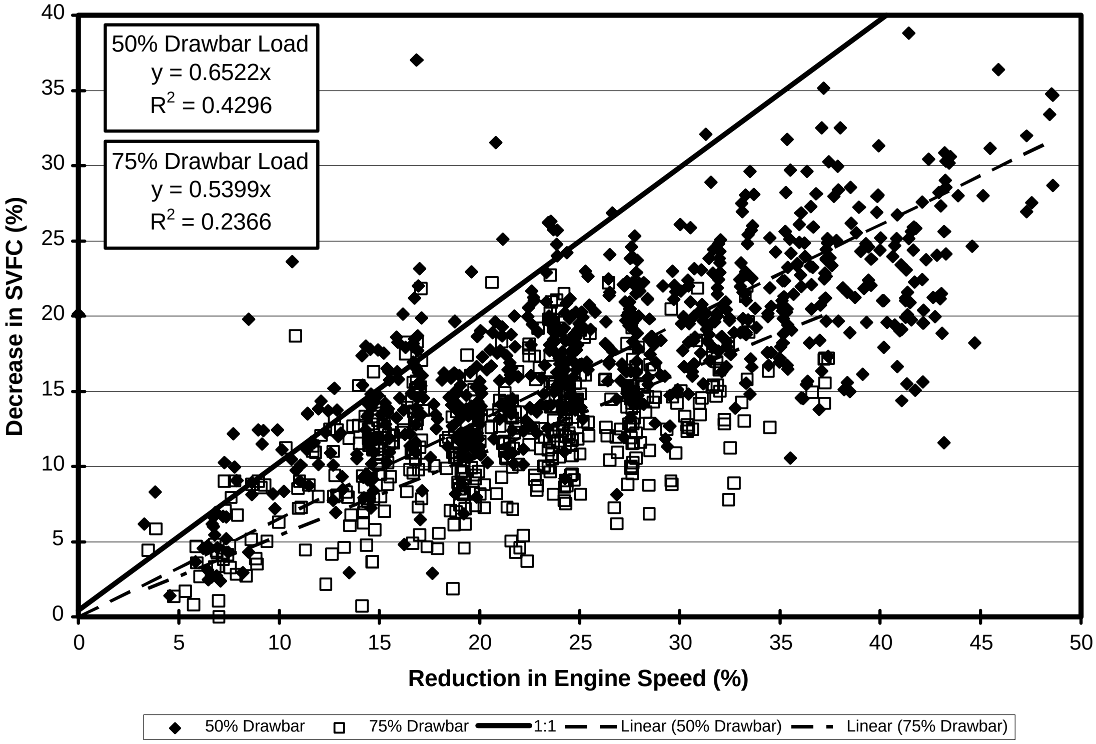

Figure 7. The relationship between the decrease of specific fuel consumption (SVFC) and reduction of engine speed during the 50% and 75% drawbar load tests.

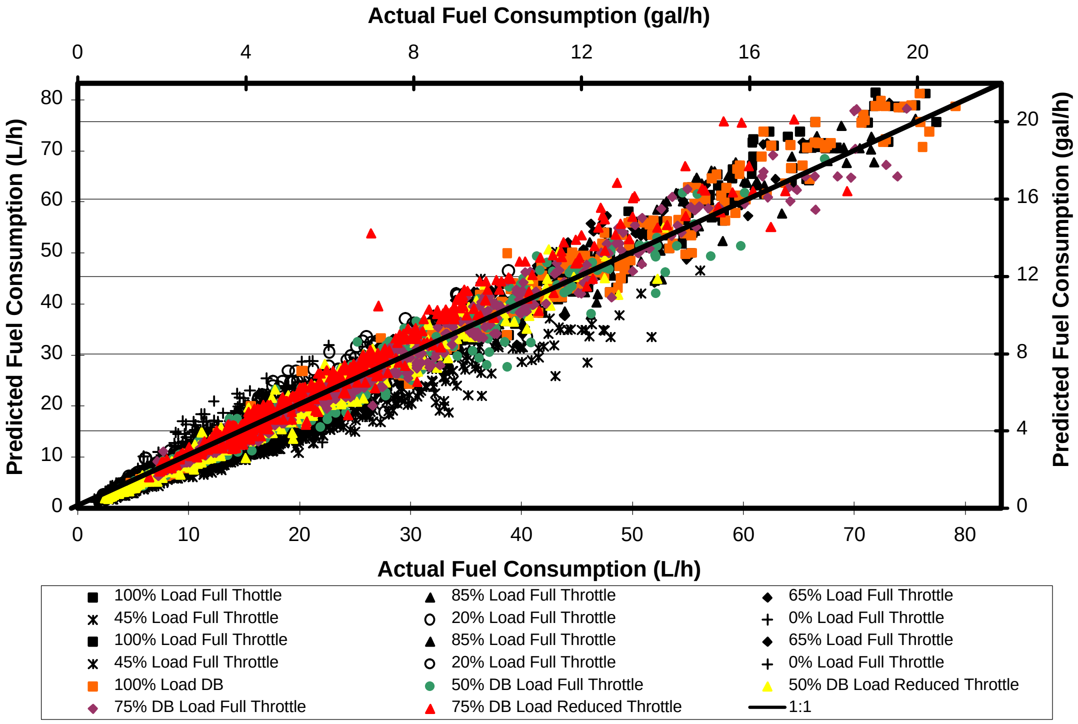

Figure 8. Comparison of actual and predicted fuel consumption for all the varying PTO and drawbar power tests. The fuel consumption was predicted with equations 19 and 20 (8140 comparisons, Pearson correlation coefficient = 0.989).

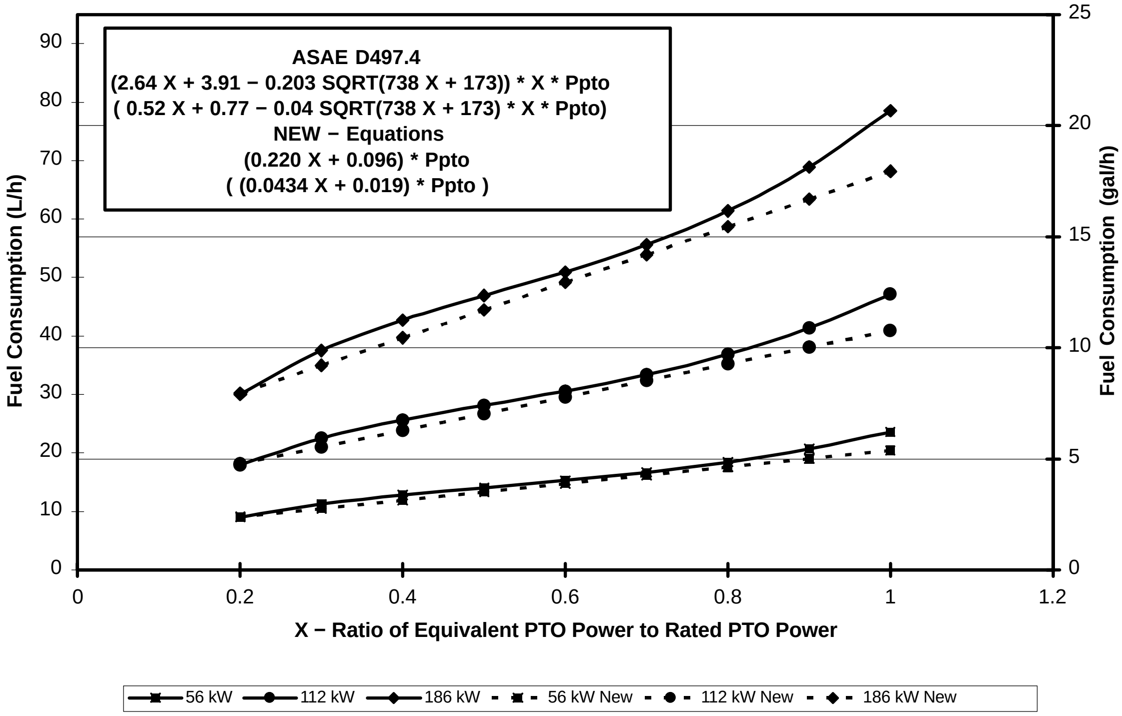

Figure 9. Fuel consumption as predicted by equations 12 and 13 (from ASAE D497.4) and by equations 16 and 17 at different equivalent and rated PTO power levels. The fuel consumption values predicted by equations 16 and 17 shown above reflect a 15% increase as suggested by the ASAE D497.4 (which is also incorporated into equations 12 and 13).

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