

Predicting Tractor Diesel Fuel Consumption

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General relationships capable of predicting tractor diesel fuel consumption are very useful for budget and management purposes but may not have the ability to compare fuel consumption for several potential engine configurations, such as turbocharging and air densification components. The objective of this factsheet is to examine several methods that use field measurements and Nebraska Tractor Test Laboratory results to estimate fuel consumption. Using these equations, farmers can estimate and compare the fuel savings for different operating and loading conditions.

Introduction

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. ...” Thus, fuel consumption plays a significant role in the selection and management of tractors and equipment. Currently, most budget models use a simplified method for estimating diesel fuel consumption. Better estimates representing actual field operations are needed to compare machinery management strategies.

The worth of a tractor is measured by the amount of work that can be accomplished and the cost associated with completing the task. Drawbar power is defined by pull (or draft) and travel speed. An ideal tractor would convert all fuel energy into useful work at the drawbar. However, due to power losses, not all fuel energy is converted into useful work.

Efficient operation of farm tractors includes (1) maximizing the fuel efficiency of the engine and the mechanical efficiency of the drivetrain, (2) maximizing tractive

advantage of the traction devices, and (3) selecting an optimum travel speed for a given tractor-implement system. This factsheet focuses on methods to estimate and improve fuel efficiency of a diesel power unit.

The Nebraska Tractor Test Laboratory (NTTL) has a long history of testing tractors and disseminating power and fuel consumption data. The NTTL is the official testing station for agricultural tractors in the United States. Tractors manufactured in the United States and other countries are tested, and NTTL publishes the test results. During standardized tests, the power is calculated and the corresponding fuel consumption is measured. The power at the power takeoff (PTO) is calculated from the torque and speed at the PTO. Drawbar power is calculated from the drawbar pull and the forward speed of the tractor. For more details and for a sample test report, see *Using Tractor Test Data for Selecting Farm Tractors*, Virginia Cooperative Extension publication 442-072.

Terminology

Tractor manufacturers specify power output at several tractor locations, such as power takeoff, drawbar, hydraulic outlets, and electrical outlets. For each tractor model, the rated power output is measured at the rated engine speed. Typically, this power is measured at the PTO, and in this factsheet, it is referred to as “rated PTO power.” For most modern tractors, the rated power will not be the maximum available power. Most modern engines often produce more power because they can be operated at speeds other than rated speeds.

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”

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(SVFC), which is given in units of gallons per horsepower-hour (gal/hp-h). Specific volumetric fuel consumption is generally not affected by engine size, and it is used to compare the energy efficiencies of tractors with different size engines and under different operating conditions. SVFC for diesel engines typically ranges from 0.0476 to 0.1110 gal/hp-h.

For ease of computation, the reciprocal of SVFC is often used and is referred to here as “specific volumetric fuel efficiency” (SVFE) with units of horsepower-hours per gallon (hp-h/gal), with corresponding ranges from 12 to 21 hp-h/gal.

The NTTL reports the SVFE for several drawbar load tests, rated PTO speed, and varying PTO power tests. Figure 1 shows sample data from an NTTL report. The SVFE for this test is shown under the columns labeled with units of hp-h/gal (kW-h/L). For example, at rated engine speed, the tractor shown in figure 1 developed 115.96 PTO horsepower with an SVFE of 17 hp-h/gal.

The data measured in NTTL Report 1725 (shown in figure 1) is used to demonstrate the computation for equation (4). For the drawbar performance at “75% of Pull at Maximum Power,” the engine speed was 2,190 rpm, and the SVFE was 12.80 hp-h/gal. The corresponding test with a reduced throttle setting had an engine speed of 1,665 rpm and an SVFE of 14.63 hp-h/gal. The SVFC was calculated as 0.0781 gal/hp-h for full throttle and 0.0684 gal/hp-h for the reduced throttle test. The decrease in SVFC was 12.4 percent, while the engine speed was reduced by 24 percent. Similarly, the “50% of Pull at Maximum Power” tests resulted in a 24 percent reduction in engine speed and a 15.8 percent decrease in SVFC.

Tractor Fuel Efficiency Improvements

Newer tractors are generally more efficient than models produced 20 years ago. Improvements in fuel efficiency during the last 20 years prove this point. Figure 2 shows the average and maximum specific fuel consumption of tractors tested from 1980 to 2000. Models tested in 2000 averaged 16.5 hp-h/gal, compared to an average of 14.5 hp-h/gal for models tested in 1980. The fuel savings of 10 to 15 percent became possible because of improved engine/transmission design and improved ability to match tractors and implements for given field conditions. Today’s tractors have more electronic controls for more efficient delivery of power to the PTO, drawbar (for pulling), and hydraulic lifts and controls.

The reduction in fuel efficiency seen during years 1991, 1998, and 2004 (figure 2) is attributed to the new emission requirements that went into effect for off-road vehicles. Even though Environmental Protection Agency (EPA) regulations initially challenged engine designers, fuel efficiency has improved significantly since then. All tractors are not equal in fuel consumption. The maximum value line in figure 2 represents the fuel efficiency for the most fuel-efficient tractor for that year. The fuel consumption data is an important consideration during the selection and purchase of a tractor.

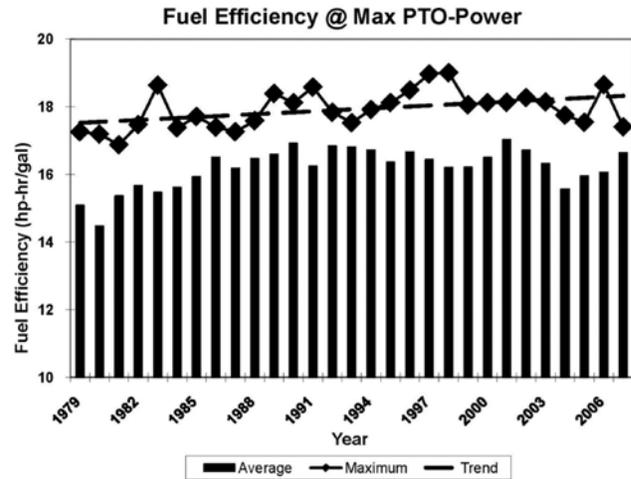


Figure 2. The average and maximum fuel efficiency (hp-hr/gal) for almost 30 years. This chart shows results averaged from annual NTTL reports (typically 10-30 tractors per year).

Fuel Consumption Estimates

ASABE Standards (2006, 2009) are widely used for estimating fuel consumption for budget preparations. The most widely used relationship for estimating fuel consumption in gallons per hour (gal/h) is

$$Q_{AVG} = a' \cdot P_{PTO} \quad (1)$$

where

Q_{AVG} = average diesel consumption (gal/h),

P_{PTO} = rated PTO power (hp),

$a' = 0.044$ gal/hp-h.

Bowers (2001, e-mail correspondence) stated that equation (1) was developed based on PTO power test results from the Nebraska Tractor Test reports during the mid-1970s. The fuel consumption (gal/h) over the varying PTO power tests (approximately 100 percent, 85 percent, 65 percent, 45 percent, 20 percent, and 0 percent of rated PTO power) were averaged, then the average was divided by the rated PTO power. For this

Power Take-Off Performance					
Power HP (kW)	Crank-shaft speed rpm	Gal/br (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 75°F (24°C)
102.08 (76.12)	2170	6.33 (23.95)	0.435 (0.265)	16.13 (3.18)	
77.46 (57.76)	2202	5.26 (19.91)	0.476 (0.290)	14.73 (2.90)	Relative humidity 47%
52.03 (38.81)	2233	4.28 (16.18)	0.576 (0.351)	12.17 (2.40)	
26.27 (19.59)	2257	3.12 (11.81)	0.834 (0.507)	8.42 (1.66)	Barometer 28.86" Hg (97.73 kPa)
1.03 (0.77)	2267	2.05 (7.77)	13.915 (8.464)	0.50 (0.01)	

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 l/s (kN)	Speed mph (km/h)	Crank-shaft speed rpm	Slip %	Fuel Consumption		Temp. °F (°C)		Barom. inch Hg (kPa)
					lb/hp.hr (kg/kW.h)	Hp.hr/gal (kW.h/l)	cooling med	Air dry bulb	
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 (26)	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 Nebraska Tractor Test Laboratory (NTTL) report. The sections show: *top*, the PTO performance tests; *center*, the varying power tests; and *bottom*, the drawbar performance test results. This is taken from the report of Nebraska OECD Tractor Test 1725 – Summary 225 for John Deere 7610 PowerShift.

reason, the annual fuel consumption estimates using this method give fuel consumption based on the assumption that the tractor is operated under the same load pattern for equal time. Due to this assumption, this method underestimates fuel consumption.

Field Measurement of Fuel Consumption

Farmers may consider numerous ways to estimate and reduce fuel consumption. The first step is to determine how much fuel is being used for a particular field operation and compare it to average usage. This measurement can be completed by filling the fuel tank of the tractor before and after a field operation, noting the number of acres covered. The number of gallons used, divided by the number of acres covered, gives the fuel consumption in gallons per acre (gal/ac). The resulting estimate of fuel consumption can be compared to the values listed in table 1¹. If measured fuel consumption is higher than the estimated average, the following tips should be considered to reduce fuel consumption:

- Eliminate one or more tillage/field operations.
- Substitute one type of tillage operation for another (e.g., chisel for plow).
- Combine tillage and other operations into one pass over the field.
- Optimize tractor performance (proper amount and distribution of ballast, tire inflation, etc.).
- Use “gear-up, throttle-down” (GUTD) practices.
- Properly match tractor and implement sizes.
- Optimize field efficiency with controlled traffic and navigation aids.
- Ensure sufficient machine maintenance.

Better Fuel Consumption Estimates

Two methods (general and specific) have been developed for estimating fuel consumption from Nebraska Tractor Test results. Both methods are based on tractor test results using the relationships between engine load and engine speed (rpm). The “general” method is based on the average results from more than 500 tractors. The “specific” method used the mathematical relationship found in the general model but is derived from the test results of a specific tractor.

¹Table 1 reports fuel consumption values for many field operations summarized from various states. Although data is not included from every state and is dated, the values may be useful as guidelines to determine whether fuel usage for a particular operation is reasonable.

Fuel consumption is estimated from reduced engine load and from full-throttle data (along the governor response power curve). ASABE Standards’ (2009) general fuel consumption equations for compression ignition engines were developed as follows:

$$Q_F = (0.0434X + 0.019) \cdot P_{PTO} \quad (2)$$

where

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

X = fraction of equivalent PTO power available (decimal).

$$X = P / P_{RATED}$$

where

P = equivalent PTO power required by current operation (hp),

P_{PTO} = rated PTO power available (hp).

$$Q_R = Q_F \cdot [1 - (N - 1) \cdot (0.45X - 0.877)] \quad (3)$$

where

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

N = ratio of reduced- and full-throttle engine speeds at operating load (decimal).

$$N = RPM_{PT} / RPM_{FT}$$

where

RPM_{PT} = engine speed at partial throttle at reduced engine speed (rpm),

RPM_{FT} = full-throttle engine speed (rpm).

These general equations are useful for predicting fuel consumption for diesel engines during full and partial loads and under conditions when engine speeds are reduced from full throttle.

Fuel Consumption Estimates for Specific Tractor Models

The second method for estimating fuel consumption was developed from the general model (equations (2) and (3)) and was used to derive the coefficients for specific tractor models. The method uses the NTTL test results, and the defining locations of the fuel consumption parameters are shown in figure 3. The equation for a specific tractor is defined as:

Table 1. Diesel fuel consumption for field operations.

Operation	Farm energy audit ^a			Average from other states ^b
	Range (gal/ac)			
	Average	High	Low	
Primary tillage				
Moldboard plow	1.81	3.50	0.90	1.87
Chisel disk	1.36	3.50	0.80	1.09
Offset disk	1.11	1.20	0.90	0.97
Subsoiler	1.54	2.30	1.10	1.56
Secondary tillage				
Disk	0.93	3.30	0.30	0.65
Field cultivator	0.78	1.80	0.30	0.68
Spring tooth harrow (drag)	0.73	1.80	0.20	0.48
Fertilizer and chemical application				
Pesticide spraying	0.33	2.90	0.10	0.13
Chemical incorporation	0.80	1.10	0.50	–
Spreading fertilizer	0.30	0.50	0.10	0.19
Knife in fertilizer	0.58	1.30	0.20	1.05
Planting				
Row crop planter	0.51	1.00	0.20	0.54
Grain drill	0.56	2.31	0.10	0.33
Potato planter	0.95	1.90	0.90	0.95
Broadcast seeder	0.28	1.12	0.10	0.15
No-till planter	0.68	–	–	0.43
Cultivation				
Cultivator	0.39	1.90	0.10	0.42
Rotary hoe	0.23	0.70	0.10	0.21
Forage harvesting				
Mower/conditioner	0.72	1.80	0.30	0.66
Rake	0.46	1.26	0.20	0.24
Baler	0.65	2.90	0.10	0.69
Large round baler	0.80	–	–	–
Forage harvester or green chop	1.57	2.00	0.20	1.87
Corn silage harvester	3.14	6.70	1.70	2.69
Grain and row crop harvest				
Small grain or bean combine	1.23	1.80	0.70	1.01
Corn combine	1.51	2.20	0.70	1.37
Corn picker	1.84	3.00	1.20	1.10
Pull and window	0.52	1.10	0.30	0.34
Beet harvester	1.37	1.90	0.90	1.91
Topping beets	0.83	1.20	0.40	1.47
Potato harvester	2.69	–	–	1.73
PTO operated (gal/hr)				
Forage blower	2.19	6.20	0.90	–
Irrigation	3.41	4.40	1.10	–
Grinding	3.84	6.90	2.20	–

^aHelsel, Z., and T. Oguntunde. 1985. Fuel requirements for field operations with energy saving tips. In *Farm Energy Use: Standards, Worksheets, Conservation*, ed. C. Myers. East Lansing: Michigan State University.

^bIowa, Pennsylvania, Nebraska, Missouri, New York, Oklahoma, North Dakota, and Ontario, Canada

$$Q = (aX + b) \cdot [1 - (N - 1) \cdot (cX - d)] \cdot P_{PTO} \quad (4)$$

where

a , b , c , and d coefficients are defined in appendix A,

Q = diesel fuel consumption (gal/h),

X = ratio of equivalent PTO power to rated PTO power (decimal),

N = ratio of reduced- and full-throttle engine speeds at operating load (decimal),

P_{PTO} = rated PTO power (hp).

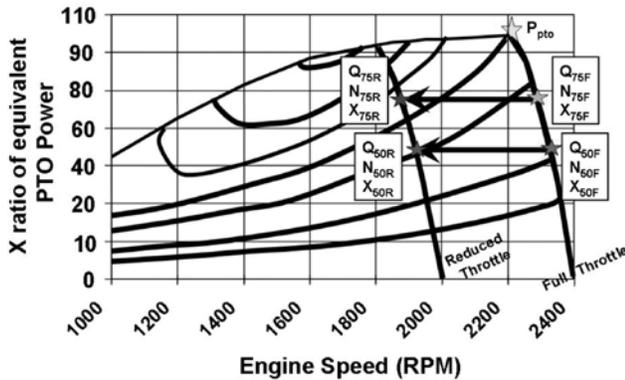


Figure 3. Engine map with the tractor test information and notations described.

Coefficients (a , b , c , and d) were computed for specific tractors tested from 1986 through 2008. More than 770 tractors with complete drawbar tests (both 50 percent and 75 percent pull tests) were considered. Calculating the coefficients for each individual tractor showed significant improvement in accuracy. These coefficients may be computed for a specific tractor (of your choice) as shown in appendix A or by downloading and using an Excel spreadsheet that is available at: <http://filebox.vt.edu/users/rgrisso/Tractor.htm>. For tractors already available, the coefficients have been calculated and can be downloaded at the same URL.

Fuel Consumption Comparison

Estimated fuel consumption for the John Deere 7610 (JD7610) is compared against measured fuel consumption during the Nebraska tractor test in table 2. The agreement between estimated fuel consumption – using equation (4) – and measured fuel consumption was good. On the other hand, estimates using the general model were found to be slightly higher. Estimates from the traditional method were consistently lower than the actual fuel consumption for full-load tests. The best estimates were from the specific tractor model; the second-best estimates were from the general method. Both showed the impact of GUTD practices.

Specific Model Application

The NTTL report can be a very useful resource when deriving the coefficients for equation (4). As shown in the example in appendix A, the coefficients can be derived directly from the NTTL reports. To use the specific model to predict fuel consumption for a given field operation, ensure that the current engine and the engine reported in the NTTL report are adjusted in the same manner. The high-idle (full-throttle, no-load) engine speed shown in the “Varying Power and Fuel Consumption” section of the NTTL report must be compared with the current engine setting. For example, the high-idle engine speed shown in the NTTL report example (figure 1) is 2,267 rpm. The user’s high-idle engine speed (RPM_{HI}) can be determined by observing the engine speed at full throttle and no load. If the high-idle engine speed is significantly different from the NTTL reported speed, errors using this approach can be significant.

To determine the engine speed during field operation (RPM_{FES}), the operator must record the engine speed

Table 2. Measured and predicted fuel consumption.*

	Fuel consumption (gal/h)			Actual test data
	Traditional estimate (eq (1))	General prediction (eq (2)-(3))	Specific prediction (eq (4))	
PTO power test, rated	5.102	7.236	6.882	6.821
Drawbar test, maximum pull, rated	5.102	7.236	6.882	6.714
Drawbar test, 75% pull, full throttle	5.102	6.162	5.916	5.916
Drawbar test, 75% pull, reduced throttle	5.102	5.397	5.183	5.185
Drawbar test, 50% pull, full throttle	5.102	4.895	4.776	4.776
Drawbar test, 50% pull, reduced throttle	5.102	4.149	4.027	4.031

*Fuel consumption measured and predicted by the “traditional,” “general,” and “specific” models for Nebraska OECD Tractor Test 1725 – Summary 225 (shown in figure 1).

with the throttle fully open and under typical field load. This engine speed is used to estimate the ratio of rated power being used. The rated engine speed (RPM_{RATED}) is typically found on the tractor's tachometer, operator's manual, or NTTL report.

Using the relationship below, the estimated ratio of rated power that is being used during field operation is computed:

$$X = (RPM_{HI} - RPM_{FES}) / (RPM_{HI} - RPM_{RATED}) \quad (5)$$

where

RPM_{HI} = high-idle engine speed (rpm),

RPM_{RATED} = rated engine speed for the tractor being considered (rpm),

RPM_{FES} = field engine speed during field operations at full throttle (rpm).

This relationship assumes that the governor response (engine droop on the right side of figure 3) is linear. If this is not the case, use speed ranges found in the "Varying Power and Fuel Consumption" section of the NTTL report to estimate the ratio of rated power.

For example, suppose that a JD7610 model tractor is being used for primary tillage and the field engine speed is 2,150 rpm. From the test report (figure 1) and field testing, the high-idle speed is 2,267 rpm and the rated engine speed is 2,100 rpm. The equivalent power, calculated from equation (5), being used for this operation is 0.7, and using the specific coefficients from the example in appendix A, the fuel-use equation becomes

$$Q = (0.039X + 0.0203) \cdot [1 - (N - 1) \cdot (0.5247X - 0.9345)] \cdot 115.96 \text{ hp}$$

At full throttle ($N = 1$), the estimated fuel consumption for primary tillage with the JD7610 is

$$Q = (0.039 \cdot 0.7 + 0.0203) \cdot 115.96 = 5.52 \text{ gal/h}$$

To estimate the savings from employing the gear-up and throttle-down practice (Grisso and Pitman), the operator can look at several engine reduction possibilities and match with the most appropriate. If the tractor engine speed is reduced by 10 percent and 20 percent ($N = 0.9$ and 0.8 , respectively), the decrease of fuel consumption is estimated as:

$$D_{10} = 1 - \{(0.9 - 1) \cdot [(0.5247 \cdot 0.7) - 0.9345]\}$$

$D_{10} = 0.943$, or a 5.7 percent fuel savings for reducing the throttle by 10 percent.

Likewise,

$D_{20} = 0.887$, or an 11 percent fuel savings for reducing the throttle by 20 percent.

In terms of fuel consumption rate,

$$Q_{10} = 5.52 \cdot 0.943 = 5.21 \text{ gal/h, or a savings of 0.31 gal/h,}$$

$$Q_{20} = 5.52 \cdot 0.887 = 4.90 \text{ gal/h, or a savings of 0.60 gal/h.}$$

The easiest way to reduce the engine speed is from the no-load condition (at high idle). A 10 percent and 20 percent engine-speed reduction would require moving the throttle from high idle (2,267 rpm) to 2,040 rpm and 1,813 rpm, respectively.

Estimating Fuel Consumption From Field Operations

The impact of individual operations of cropping systems for a 350-acre grain/pasture cropping system is examined and compared. The farm is separated into 125 acres for haying operations and 225 acres for traditional corn production using a 100 hp tractor. Table 3 provides the operations that the tractor performs for the grain/pasture operations. Note that the tractor is used for slightly more than 240 hours annually. The estimated fuel consumption using the "traditional" method would be 4.4 gal/h, irrespective of the type of operation; the total fuel use on the 350 acres would be 1,064 gallons.

When the "general" model (equations (2) and (3)) is applied for each operation and the load factor is taken into consideration for different field operations that do not require full power, the fuel consumption is estimated at a total of 904 gallons. It is interesting to note that the gallons per acre estimates can be compared with table 1, and the planting operation appears to consume more fuel than other uses (0.64 versus 0.51 gal/ac). This approach gives producers potential areas to adjust and manage their systems, as well as to optimize their machinery systems based on operating averages.

When the GUTD practice is used in these operations, with only a 20 percent reduction in speed (some operations can probably be dropped further based on the load level), it is estimated that a fuel savings of 87 gallons is possible. This translates into a fuel savings of 10 percent for this tractor annually.

Table 3. Fuel consumption estimates for field operations using a 100-hp tractor.

	Acres per hour	X [†]	Acres	Full (gal/h)	Reduced (gal/h)	Gallons per acre	Total gal	Save	Labor hours
225-acre, minimum tillage corn for grain									
15-ft no-till drill (cover crop)	7.6	0.75	225	5.2	4.6	0.68	154	17.8	29.6
30-ft sprayer (2-X)	15.0	0.35	550	3.4	2.9	0.23	125	18.3	36.7
15-ft, 6-row planter	7.0	0.60	225	4.5	4.0	0.64	145	16.1	32.1
125-acre pasture (haying: two cuttings)									
12-ft mower/conditioner*	6.0	0.50	250	4.1	4.1	0.68	171	0.0	41.7
12-ft tedder	7.1	0.20	250	2.8	2.3	0.39	99	17.6	35.2
12-ft side-delivery rake	7.1	0.20	250	2.8	2.3	0.39	99	17.6	35.2
Round baler*	8.0	0.40	250	3.6	3.6	0.45	113	0.0	31.3
Total							904	87.4	241.8

*Denotes that because PTO driven, the engine cannot be reduced in speed.

[†]Fraction of equivalent PTO power available.

Conclusion

Three methods for estimating tractor fuel consumption are presented. Comparing estimated and measured fuel consumption shows that the fuel consumption estimated using the “specific” model agrees best with the measured fuel consumption. This model has the capability to predict fuel consumption when the tractor is fully or partially loaded and when the engine speeds are reduced from full throttle.

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Additional Reading Materials

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Appendix A. Coefficient determination for equation (4) for specific tractor.

$$a = (Q_{75F} - Q_{50F})/[P_{PTO} (X_{75F} - X_{50F})] \quad (6)$$

$$b = (Q_{75F}/P_{PTO}) - aX_{75F} \quad (7)$$

$$c = (f/h - e/g)/(X_{75F} - X_{50F}) \quad (8)$$

$$d = cX_{50F} + f/h \quad (9)$$

$$e = 1 - [(X_{75F} \cdot Q_{75R})/(X_{75R} \cdot Q_{75F})] \quad (10)$$

$$f = 1 - [(X_{50F} \cdot Q_{50R})/(X_{50R} \cdot Q_{50F})] \quad (11)$$

$$g = (RPM_{75F} - RPM_{75R})/RPM_{75F} \quad (12)$$

$$h = (RPM_{50F} - RPM_{50R})/RPM_{50F} \quad (13)$$

where

Q = diesel fuel consumption (gal/h),

X = ratio of equivalent PTO power to rated PTO power (decimal),

N = ratio of reduced- and full-throttle engine speeds at operating load (decimal),

RPM = engine speed for partial loads from full and reduced throttle (rpm),

P_{PTO} = rated PTO power (hp).

The specific subscript refers to the condition of the test, where the tractor tests were conducted at full throttle (F) and reduced throttle (R) during the 50 percent and 75 percent drawbar load tests. For example, Q_{75F} is the fuel consumption at 75 percent drawbar load and full throttle. The method used the fuel consumption data, power levels, and engine speed from four partial-load drawbar load tests and the PTO and drawbar power at rated engine speed. The equivalent power ratios (at the four test points) were computed from maximum drawbar power at rated engine speed and the current power level.

As an example, below are the coefficients developed using equations (6) through (13) for the tractor test Summary 225 (shown in figure 1):

$$P_{PTO} = 115.96 \text{ hp}$$

$$P_{MaxDB} = 96.26 \text{ hp}$$

$$RPM_{50F} = 2,221 \text{ rpm}$$

$$Q_{50F} = 51.48 \text{ hp}/(10.78 \text{ hp-h/gal}) = 4.78 \text{ gal/h}$$

$$X_{50F} = 51.48 \text{ hp}/96.26 \text{ hp} = 0.535$$

$$RPM_{75F} = 2,190 \text{ rpm}$$

$$Q_{75F} = 75.72 \text{ hp}/(12.8 \text{ hp-h/gal}) = 5.92 \text{ gal/h}$$

$$X_{75F} = 75.72 \text{ hp}/96.26 \text{ hp} = 0.787$$

$$RPM_{50R} = 1,685 \text{ rpm}$$

$$Q_{50R} = 51.60 \text{ hp}/(12.80 \text{ hp-h/gal}) = 4.03 \text{ gal/h}$$

$$X_{50R} = 51.60 \text{ hp}/96.26 \text{ hp} = 0.536$$

$$RPM_{75R} = 1,665 \text{ rpm}$$

$$Q_{75R} = 75.86 \text{ hp}/(14.63 \text{ hp-h/gal}) = 5.19 \text{ gal/h}$$

$$X_{75R} = 75.86 \text{ hp}/96.26 \text{ hp} = 0.788$$

$$a = \frac{5.92 \text{ gal/h} - 4.78 \text{ gal/h}}{115.96 \text{ hp} (0.787 - 0.535)} = 0.039 \text{ gal/hp-h}$$

$$b = \frac{5.92 \text{ gal/h}}{115.96 \text{ hp}} - (0.039 \cdot 0.787) = 0.0203 \text{ gal/hp-h}$$

$$e = 1 - \frac{0.787 \cdot 5.19 \text{ gal/h}}{0.788 - 0.92 \text{ gal/h}} = 0.1251$$

$$f = 1 - \frac{0.535 \cdot 4.03 \text{ gal/h}}{0.536 \cdot 4.78 \text{ gal/h}} = 0.1578$$

$$g = (2,190 - 1,665 \text{ rpm}) / 2,190 \text{ rpm} = 0.2397$$

$$h = (2,221 - 1,685 \text{ rpm}) / 2,221 \text{ rpm} = 0.2413$$

$$c = \frac{(0.1578 / 0.2413) - (0.1251 / 0.2397)}{(0.787 - 0.535)} = 0.5247$$

$$d = (0.5247 \cdot 0.5350) + (0.1578 / 0.2413) = 0.9345$$

Substituting the coefficients a , b , c , and d in equation (4), the final prediction equation for JD7610 becomes:

$$Q = (0.0390X + 0.0203) \cdot [1 - (N - 1) \cdot (0.5247X - 0.9345)] \cdot 115.96 \text{ hp}$$

This equation can be used to predict the fuel consumption when a JD7610 is used for different field operations with varying loads and engine speeds. For ease of calculations, an Excel spreadsheet (figure A-1) with this example has been posted at: <http://filebox.vt.edu/users/rgrisso/Tractor.htm>; users can insert their own data from the Nebraska Tractor Test Laboratory report.

1	Input	#	PowerShift.		INPUT		
2	Rate Power		$P_{pto} =$	115.96	115.96 hp		
3	Max Drawbar Power		$P_{MaxDB} =$	96.26	96.26 hp		
4	Engine Speed @ 50% Load, Full Throttle		$RPM_{50F} =$	2221	2221 rpm		
5	Power @ 50% Load, Full Throttle		$P_{50F} =$	51.48	51.48 hp		
6	SFC @ 50% Load, Full Throttle		$SFC_{50F} =$	10.78	10.78 hp-hr/gal		
7	Fuel Use @ 50% Load, Full Throttle		$Q_{50F} = P_{50F} / SFC_{50F} = 51.48 \text{ hp} / 10.78 \text{ hp-h/gal}$	4.78	4.78 gal/hr		
8	Equivalent Power @ 50% Load, Full Throttle		$X_{50F} = P_{50F} / P_{MaxDB} = 51.48 \text{ hp} / 96.26 \text{ hp}$	0.535	0.535		
9	Engine Speed @ 75% Load, Full Throttle		$RPM_{75F} =$	2190	2190 rpm		
10	Power @ 75% Load, Full Throttle		$P_{75F} =$	75.72	75.72 hp		
11	SFC @ 75% Load, Full Throttle		$SFC_{75F} =$	12.8	12.8 hp-hr/gal		
12	Fuel Use @ 75% Load, Full Throttle		$Q_{75F} = P_{75F} / SFC_{75F} = 75.72 \text{ hp} / 12.8 \text{ hp-h/gal}$	5.92	5.916 gal/hr		
13	Equivalent Power @ 75% Load, Full Throttle		$X_{75F} = P_{75F} / P_{MaxDB} = 75.72 \text{ hp} / 96.26 \text{ hp}$	0.787	0.787		
14	Engine Speed @ 50% Load, Reduced Throttle		$RPM_{50R} =$	1685	1685 rpm		
15	Power @ 75% Load, Full Throttle		$P_{50R} =$	51.6	51.6 hp		
16	SFC @ 75% Load, Full Throttle		$SFC_{50R} =$	12.8	12.8 hp-hr/gal		
17	Fuel Use @ 50% Load, Reduced Throttle		$Q_{50R} = P_{50R} / SFC_{50R} = 51.60 \text{ hp} / 12.80 \text{ hp-h/gal}$	4.03	4.031 gal/hr		
18	Equivalent Power @ 50% Load, Reduced Throttle		$X_{50R} = P_{50R} / P_{MaxDB} = 51.60 \text{ hp} / 96.26 \text{ hp}$	0.536	0.536		
19	Engine Speed @ 75% Load, Reduced Throttle		$RPM_{75R} =$	1665	1665 rpm		
20	Power @ 75% Load, Full Throttle		$P_{75R} =$	75.86	75.86 hp		
21	SFC @ 75% Load, Full Throttle		$SFC_{75R} =$	14.63	14.63 hp-hr/gal		

Figure A-1. Spreadsheet for calculating the coefficients a , b , c , and d for equation (4).