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"Gear Up and Throttle Down" to Save Fuel

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Introduction

"Gear-up and throttle-down" (GUTD) is a fuel-saving practice that can be used for saving fuel when drawbar loads are lighter (<75 percent of rated power) and PTO (power takeoff) speed can be reduced.

For maximum operating efficiency, a tractor engine should be operated near its rated capacity. However, many field operations such as light tillage, planting, cultivating, spraying, and hay raking do not require full tractor power. This is particularly true when older implements that were sized for smaller tractors are used with today's high-horsepower tractors. Also, there are many operations that require fixed field speeds.

For these lighter operations, substantial fuel savings are possible by operating the tractor on a higher gear and lower engine speed maintaining the desired field speed. A good example of this GUTD procedure is shifting the manual transmission in a car or truck from second to third gear while reducing the throttle setting to maintain the desired travel speed.

General GUTD Operating Guidelines

1. Consider GUTD for light-load operations (<75 percent of full engine power).
2. Stay within the recommended engine speed range (rpm) as specified in the operator's manual.
3. Select a faster gear to maintain travel speed and productivity while reducing the engine rpm.
4. Avoid overloading the engine. Check the engine respomse to the throttle setting and drawbar load.

Work, Power, Energy, and Efficiency

Work is defined as moving a weight or a force over a distance and is commonly expressed in terms of foot-pounds (ft-lb_f). For example, the work required to lift a 55-pound object to a height of 10 feet is 550 ft-lb_f. In the case of a tractor, if the drawbar pull created by a disk plow is 3,300 pounds, the work done by the tractor to move the disk 10 feet will be 33,000 ft-lb_f.

Power is the amount of work done in a given period of time. If a 55-pound object is lifted to a height of 10 feet in one second, the power required to do this work would be 550 ft-lb_f/sec. Using the previous example, if it takes one minute to pull the disk 10 feet, the power required is 33,000 ft-lb_f/min. Generally, the power requirement is expressed in terms of horsepower (hp). One horsepower is equivalent to 550 ft-lb_f/sec or 33,000 ft-lb_f/min.

Tractor manufacturers generally specify the power output at the power takeoff or at the drawbar. PTO power is the most commonly used power specification for tractors. Manufacturers also specify the hydraulic and electrical power output. For each tractor model, the rated horsepower information provided is at rated engine speed. Typically, this power output is measured at the PTO and is referred to as "rated PTO power."

Energy is the capacity to do work. For tractors, gallons of fuel consumed are a measure of the amount of energy used.

Efficiency is defined as the ratio between the amount of work done and the amount of energy used. For tractors, horsepower-hour (hp-hr) is the standard measure of work done. One hp-hr is 1 horsepower expended over one hour, which is equivalent to 1,980,000 ft-lb_f of work.

Horsepower-hours per gallon (hp-hr/gal) of fuel is a common measure of tractor engine efficiency. Hp-hr/gal can be calculated from either PTO or drawbar power. The hp-hr/gal at the PTO is generally higher than at the drawbar because of transmission and traction inefficiency.

Specific volumetric fuel efficiency (hp-hr/gal) can be used to compare the fuel efficiency of different tractors. Higher values for hp-hr/gal indicate greater fuel efficiency in the same way that higher miles per gallon indicate a better fuel economy for highway vehicles. For diesel tractor engines, 13.5 hp-hr/gal would be average fuel efficiency for drawbar loads, while a very efficient tractor can achieve 18.5 hp-hr/gal for loads during PTO applications.

How Does GUTD Work?

Tractor engines operate within a power map (load versus engine speed), and the fuel consumption by the engine change with load and engine speed. Figure 1 is a common power map with the axes normalized to show how engines react to varying loads and engine speed. In this figure:

- The vertical axis is the "rated PTO power" (star indicates rated PTO power).The horizontal axis is the "rated engine speed."
- The solid line in the figure is the boundary of envelope, and it is known as the power curve.
- The portion of the curve where the engine speed is less than 100 percent of rated speed is known as "the torque response."
- The broken curves within the envelope are the lines of constant fuel efficiency (hp-hr/gal).

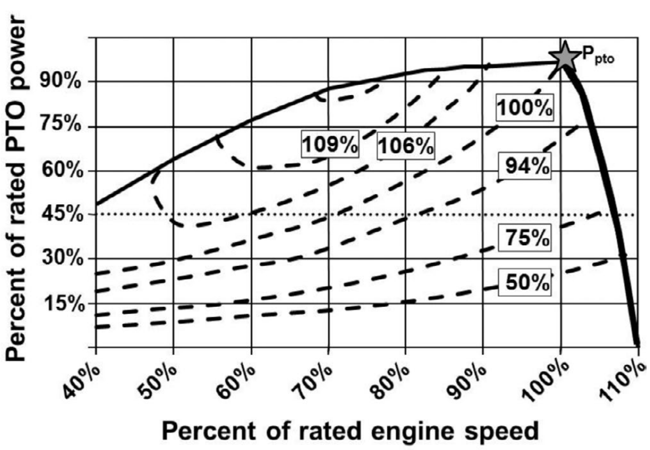

Figure 1. Engine power and speed map. Solid line indicates power curve. Dashed lines inside the envelope are constant fuel efficiency based on the rated PTO power measurement. Rated PTO power is indicated as P_{pto} (with a star), which is measured at rated engine speed.

Note that:

- If the tractor is operating at full throttle and full power, it is operating at the rated PTO power.
- If the engine speed is reduced from 100 percent rated speed (with the throttle), engine performance moves to the left on the power envelope curve, resulting in reduced available power.
- If the load is not reduced or if the throttle setting is not increased, there is a good likelihood that the engine will stall.
- Conversely, if the load is reduced (from rated PTO power), the engine will move along the governor response curve on the right side and the engine will speed up until the work rate matches the available power.

Within the envelope for reduced loads, the engine speed maybe decreased with the throttle. For a given load, say 45 percent of rated PTO power (broken horizontal line), you will note that the speed can be adjusted so that it will cross four different constant fuel-efficiency (hp-hr/gal) curves within the power envelope. Those intersecting farthest to the left and closest to the vertical axis will be most fuel-efficient.

For example, a tractor operating at 45 percent of rated PTO power (the horizontal dashed line) and operating at full throttle (at 107 percent engine speed on the governor response portion) the fuel efficiency is 75 percent. By gearing up (to keep the forward speed constant) and throttling back to 60 percent of rated engine speed, the tractor fuel efficiency improves to 106 percent. Thus, a net increase of 31 percent in fuel efficiency may be achieved with these operational adjustments. The operation has the same field capacity (acres per hour, ac/hr) but is saving fuel during the operation.

Thus GUTD allows one to operate the engine at higher fuel-efficient within the power envelope.

GUTD Limitations

There are a few limitations with the practice of GUTD. When operating at low engine speeds, some tractors hydraulic systems may react slower than they should. The PTO speed may also reduce correspondingly. When PTO speed is reduced, the PTO-driven device may be adversely affected reducing the productivity. Under certain operating conditions, reduced PTO speeds may reduce the life of PTO-driven unit and cause failure of drivelines.

Tractor Test Data

The fuel savings advantage from GUTD practice can be seen from the University of Nebraska Tractor Test results. Presented in tables 1 and 2 are results from two different tractors. The rest were conducted maintaining the following conditions:

- **Test 1:** Maximum available drawbar power. In a gear selected by the manufacturer, the pull and travel speed are measured and used to determine maximum available power. This test is performed at full throttle.
- **Test 2:** 75 percent of pull at maximum drawbar power. In the same gear as Test 1 and at full throttle, the tractor is operated at 75 percent of the pull measured in Test 1.
- **Test 3:** 75 percent of pull at reduced engine speed. The tractor is operated in a faster gear with a reduced throttle setting. Pull and travel speeds are maintained about the same as in Test 2.
- **Test 4:** 50 percent of pull at maximum drawbar power. In the same gear as Test 1 and at full throttle, the tractor is operated at half of the pull measured in Test 1.
- **Test 5:** 50 percent of pull at reduced engine speed. The tractor is operated in a faster gear with a reduced throttle setting. Pull and travel speeds are about the same as in Test 4.

Results of Test 3, for both tractors show 5 - 15 percent less fuel than in Test 2. Similarly, during Test 5, both tractors consumed 15 to 30 percent less fuel than in Test 4.

Test data from more than 700 diesel tractors tested during the last 20 years are summarized in tables 3 and 4. For additional details and for examples of test reports, readers may refer to *Using Tractor Test Data for Selecting Farm Tractors*, Virginia Cooperative Extension (VCE) publication 442-072.

A comparison of results from Test 4 and Test 5 demonstrates the advantage of using the GUTD practice. Note that the travel speed, drawbar pull, and drawbar horsepower were the same for these two tests. Only throttle and gear settings were changed between tests. In Test 5, the average engine speed was 27 percent less than in Test 4. This resulted in an 18 percent reduction in fuel consumption and a 23 percent increase in fuel efficiency over the full throttle setting of Test 4.

Normally, GUTD can be used when loads require less than 75 percent of a tractor's power. It is generally safe to reduce the engine speed rpm) by 20 to 30 percent of the rated engine speed. Check the operator's manual for specific recommendations for your tractor.

There is no justification for operating either turbocharged or naturally aspirated engines at full throttle when maximum drawbar horsepower is not required. Most tractor manufacturers suggest the GUTD practice for fuel savings. Further, this practice could decrease maintenance, downtime, and expenses generally incurred from over-speeding mechanical equipment.

Caution: Do Not Overload the Tractor

When using the GUTD practice, the most important thing to remember is NOT to overload or lug the engine. If the engine is overloaded, it may result in higher torque at a lower engine speed than it is designed for. Excessive black smoke is one indication of an overloaded situation.

To check whether the engine is overloaded, work the tractor for a short period at the desired speed and throttle setting, then rapidly open the throttle. If the engine readily picks up speed, it is not overloaded, and the throttle setting is acceptable. On the other hand, if the engine does not respond quickly, the gear may be shifted down or increase the engine speed. Follow the procedure again, to check the adequacy of the new settings.

Example: Tractor Selection and Sizing

Suppose a machinery system requires 165-drawbar horsepower. You have a choice between two tractors. The first tractor (a small, mechanical front-wheel drive) is rated at 165 drawbar horsepower (table 1), and the second tractor (a large four-wheel-drive) is rated at 314-drawbar horsepower (table 2). Should you use the small tractor at full throttle and full load, or the large tractor at full throttle and 50 percent load, or the large tractor at 50 percent load but using GUTD?

Table 5 shows that the small tractor has good fuel efficiency (15.5 hp-hr/gal). The savings is more thar 2 gal/hr compared to the full throttle operation of the large tractor. But note that a significant savings (1 gal/hr) in fuel consumption are possible with the small tractor (10.7 gal/hr) than the large tractor (9.7 gal/hr) using the GUTD procedure. In this comparison, using GUTD procedures, the larger tractor is more fuel-efficient than the smaller one. This example shows that a large tractor pulling a light load and operated with the GUTD procedure will use about the same or less amount of fuel as a tractor that is half the size operating at full load. An added gain is the increased annual usage of the large tractor, which helps spread the costs of owning a large tractor over more annual hours of use.

Remember, the fuel consumption may vary widely for individual tractor models. The University of Nebraska Tractor Test Reports are particularly useful for selection of tractors. Keep accurate records of the fuel usage of all tractors under a variety of operating and seasonal conditions. With accurate records, an equipment system manager will be able to select the most economical tractor for a specific operation. For details on estimating fuel consumption during field operations, review *Predicting Tractor Diesel Fuel Consumption*, VCE publication 442-073.

Constantly Variable Transmissions (CVT)

How often do you check to see if you are matching the right gear to the right engine speed as field conditions change or load on the engine changes? New "smart" transmissions make that adjustment hundreds of times per second. CVT or infinitely variable transmissions (IVT) are technologies that help improve fuel efficiency through electronic control of transmission and engine speed. The operator sets the operating speed and the controller determines the engine speed and transmission setting based on the load. These systems automatically perform GUTD to find the most efficient operating parameters.

Summary

From an economic perspective, avoid using smaller implements with large tractors. For most efficient operation, the implement should be operated using the best-matched tractor. If a larger tractor is used with small implements, use the principle of GUTD to maintain proper ground speed and reduce fuel consumption.

The fuel-saving practice of GUTD involves reducing engine speed to 70 to 80 percent of rated engine speed, and shifting to a faster gear to maintain the desired field speed and implement productivity. This practice is suitable for light drawbar loads (less than 75 percent of full power) and for when reduced PTO speed is not a problem. Remember, **DO NOT overload the engine**.

If you "gear-up and throttle-down" whenever possible, you will be on your way toward getting the most for your fuel dollars.

Additional Reading Materials

Predicting Tractor Diesel Fuel Consumption. Virginia Cooperative Extension (VCE) publication 442-073.

Five Strategies for Extending Machinery Life, VCE publication 442-451.

Using Tractor Test Data for Selecting Farm Tractors. VCE publication 442-072.

For tractor test information, contact:

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Table 1. The Drawbar performance Results from John Deere 8210 (NTTL Summary#308).

	Drawbar Performance									
	Fuel Consumption Characteristics									
						Fuel Consumption		Temp. °F (°C)		
	Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crankshaft speed rpm	Slip %	lb/hp-hr (kg/kW-h)	Hp-hr/gal (kW-h/l)	cooling med	Air dry bulb	Barom. inch Hg (kPa)
	Maximum Power 7th Gear									
Test - 1	165	14419	4.30	2199	5.22	0.456	15.50	195	65	28.95
	(123.18)	(64.14)	(6.91)			(0.277)	(3.05)	(91)	(18)	(98.04)
	75% of Pull at Maximum Power-7th Gear									
Test - 2	129.15	10802	4.48	2258	3.53	0.499	14.17	190	73	28.96
	(96.31)	(48.05)	(7.22)			(0.303)	(2.79)	(88)	(23)	(98.07)
	75% of Pull at Reduced Engine Speed-9th Gear									
Test - 3	129.18	10817	4.48	1773	3.80	0.430	16.43	191	72	28.96
	(96.33)	(48.11)	(7.21)			(0.262)	(3.24)	(88)	(22)	(98.07)
	50% of Pull at Maximum Power-7th Gear									
Test - 4	87.78	7211	4.56	2268	2.53	0.571	12.37	187	72	28.95
	(65.45)	(32.08)	(7.35)			(0.347)	(2.44)	(86)	(22)	(98.04)
	50% of Pull at Reduced Engine Speed-9th Gear									
Test - 5	87.62	7211	4.56	1779	2.47	0.480	14.74	187	71	28.95
	(65.34)	(32.08)	(7.33)			(0.292)	(2.90)	(86)	(22)	(98.04)

Table 2. The Drawbar performance Results from Case IH STX 375 (NTTL Summary#335).

	Drawbar Performance									
	Fuel Consumption Characteristics									
						Fuel Consumption		Temp. °F (°C)		
	Power Hp (kW)	Drawbar pull lbs (kN)	Speed mph (km/h)	Crankshaft speed rpm	Slip %	lb/hp-hr (kg/kW-h)	Hp-hr/gal (kW-h/l)	cooling med	Air dry bulb	Barom. inch Hg (kPa)
	Maximum Power 7th (B3) Gear									
Test - 1	313.95	23889	4.93	1997	2.89	0.428	16.41	187	63	29.08
	(234.12)	(106.26)	(7.93)			(0.260)	(3.23)	(86)	(17)	(98.48)
	75% of Pull at Maximum Power 7th (B3) Gear									
Test - 2	242.79	17857	5.10	2052	2.16	0.472	14.86	185	66	29.05
	(181.05)	(79.43)	(8.21)			(0.287)	(2.93)	(85)	(19)	(98.37)
	75% of Pull at Reduced Engine Speed 10th (C2) Gear									
Test - 3	243.17	17843	5.11	1555	2.16	0.371	18.93	179	66	29.05
	(181.33)	(79.37)	(8.22)			(0.225)	(2.73)	(82)	(19)	(98.37)
	50% of Pull at Maximum Power 7th (B3) Gear									
Test - 4	165.03	11901	5.20	2081	1.61	0.542	12.94	181	65	29.05
	(123.06)	(52.94)	(8.37)			(0.330)	(2.55)	(83)	(18)	(98.37)
	50% of Pull at Reduced Engine Speed 10th (C2) Gear									
Test - 5	165.54	11903	5.22	1574	1.52	0.411	17.08	179	64	29.05
	(123.44)	(52.94)	(8.39)			(0.250)	(3.36)	(82)	(18)	(98.37)

Table 3. Average performance of two-wheel-drive (2WD) and mechanical-front-wheel-drive (MFWD) diesel tractors.

	Range of PTO power (hp)				
	< 40	40-80	80-120	120-160	> 160
2WD					
PTO horsepower	28.1	59.3	98.4	137.2	172.4
Drawbar horsepower (concrete)	23.5	48.8	82.5	117.6	148.5
Test 1: Fuel consumption (gal/hr)	2.0	3.8	6.2	8.4	5.5
Test 1: Fuel efficiency (hp-hr/gal)	11.6	13.0	13.3	14.1	14.0
Test 4: Drawbar power (hp)	13.2	27.0	44.8	64.8	81.0
Test 4: Fuel consumption (gal/hr)	1.4	2.6	4.3	6.0	7.2
Test 5: Drawbar power (hp)	13.2	27.0	44.9	64.8	81.2
Test 5: Fuel consumption (gal/hr)	1.1	2.1	3.5	4.8	5.9
Reduction of engine speed (%)*	32.7	28.6	26.8	27.7	27.4
Decrease in fuel consumption (%)*	20.7	19.0	18.6	19.4	18.0
Increase in fuel efficiency (%)*	26.5	23.7	23.8	25.1	23.0
Number of tractors	23	66	66	31	19
MFWD-Engaged					
PTO horsepower	37.3	62.0	99.2	141.0	199.2
Drawbar horsepower (concrete)	30.4	51.9	83.8	119.7	169.6
Test 1: Fuel consumption (gal/hr)	2.5	3.9	6.2	8.7	11.9
Test 1: Fuel efficiency (hp-hr/gal)	12.4	13.2	13.6	13.8	14.3
Test 4: Drawbar power (hp)	16.6	28.0	44.6	63.8	91.1
Test 4: Fuel consumption (gal/hr)	1.8	2.8	4.3	5.9	8.0
Test 5: Drawbar power (hp)	16.5	28.0	44.7	63.8	91.2
Test 5: Fuel consumption (gal/hr)	1.5	2.3	3.6	4.9	6.6
Reduction of engine speed (%)*	27.4	22.3	19.6	20.5	21.6
Decrease in fuel consumption (%)*	17.2	16.0	16.4	16.7	16.4
Increase in fuel efficiency (%)*	20.6	19.6	20.4	20.4	20.1
Number of tractors	4	80	149	116	128
MFWD-Disengaged					
PTO horsepower	26.1	58.9	94.0	119.1	133.0
Drawbar horsepower (concrete)	21.1	49.1	79.3	100.2	110.9
Test 1: Fuel consumption (gal/hr)	1.8	3.7	5.9	7.3	8.2
Test 1: Fuel efficiency (hp-hr/gal)	11.5	13.3	13.6	13.7	13.5
Test 4: Drawbar power (hp)	11.9	27.2	43.2	54.3	59.9
Test 4: Fuel consumption (gal/hr)	1.3	2.5	4.1	5.2	5.7
Test 5: Drawbar power (hp)	12.0	27.2	43.2	54.5	59.8
Test 5: Fuel consumption (gal/hr)	1.0	2.0	3.3	4.2	4.6
Reduction of engine speed (%)*	32.3	29.9	26.7	23.5	22.7
Decrease in fuel consumption (%)*	17.9	18.1	20.1	18.4	19.6
Increase in fuel efficiency (%)*	22.1	22.7	25.5	23.3	24.3
Number of tractors	22	69	45	35	6

*Comparison of the results from Test 4 and Test 5.

Table 4. Average performance of four-wheel drive (4WD) and rubber-belted tracks diesel tractors.

	Range of PTO power (hp)					
Average	**80-120**	**120-160**	**160-200**	**200-240**	**240-280**	**> 280**
PTO horsepower	100.3	144.2	181.6	218.1	259.8	357.5
Drawbar horsepower (concrete)	72.4	121.7	157.8	192.5	231.3	320.9
Test 1: Fuel consumption (gal/hr)	6.9	9.2	11.3	13.0	15.4	20.8
Test 1: Fuel efficiency (hp-hr/gal)	10.7	13.2	14.1	14.8	15.0	15.4
Test 4: Drawbar power (hp)	41.7	67.6	85.8	104.0	125.8	173.0
Test 4: Fuel consumption (gal/hr)	5.2	6.7	8.0	8.9	10.7	14.2
Test 5: Drawbar power (hp)	41.6	67.6	85.7	103.9	125.9	173.1
Test 5: Fuel consumption (gal/hr)	4.0	4.8	6.2	7.3	8.6	11.9
Increase in fuel efficiency (%)*	31.3	38.4	28.9	21.1	24.4	19.9
Decrease in fuel consumption (%)*	22.8	27.6	21.6	17.0	19.0	16.1
Reduction of engine speed (%)*	29.4	43.4	31.4	27.3	30.3	26.7
Number of tractors	5	3	20	34	30	86

***Comparison of the results from Test 4 and Test 5.**

Table 5. Typical tractor size and operation comparison.

	Small[a] MFWD tractor	Large[b] 4WD tractor	Large[b] 4WD tractor
Throttle setting	Full	Full	Reduced
Percent load	100%	50%	50%
Drawbar Power (hp)	165.0	165.03	165.54
Fuel Consumption (gal/hr)	10.66	12.75	9.69
Fuel Efficiency (hp-hr/gal)	15.5	12.94	17.08

[a]John Deere 8210 (NTTL 1773-Summary 308); rated PTO power = 165 hp.
[b]Case IH STX 375 (NTTL 1783-Summary 335); rated PTO power = 314 hp.

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