Energy management for crop production

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Energy management for crop production
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Introduction and overview
Almost all direct energy used during field operations is consumed by an engine during operation of tractors or self-propelled equipment such as combines, forage harvesters, or sprayers. Transmitting engine power as efficiently as possible for the task (pulling implements through soil, cutting plants, pumping, etc.) has significant effects on the amount of energy being used.

Before investigating specific ways to increase efficiency during these tasks, a first question to ask is if the field operation is necessary. Increased fuel efficiency may gain five, ten, twenty percent or more whereas omitting the operation and leaving the tractor parked saves 100 percent of fuel. Some type of seeding, harvest, and weed or pest control operation is nearly always necessary. However, the type and frequency of tillage operations to prepare or weed a seedbed are often variable. Row crops such as corn or soybeans may be produced with one or no tillage passes prior to planting. Establishment of perennial alfalfa and small grains traditionally used primary and secondary tillage operations. New no-till seeders with better seed bed preparation and seed placement have resulted in yields equal to stand established using conventional tillage. Factors in choosing tillage operations include comfort with a specific management style along with local soil, crop, and weather conditions. Successful reduced and no-till operations are often found in the same neighborhood as fields with more aggressive tillage schemes suggesting that options to reduce tillage frequently exist. For example, although surface cornstalks from the previous year can appear daunting, no-till soybean yields are frequently equal to those of full-width tillage systems in yield trials.

If tillage is required, consider using only a single-pass tillage system prior to planting. Strip-till systems till only a part of the field in the row zone for the subsequent crop to be planted. Ridge-till systems use row-crop cultivation for weed control to build ridges, then plant into the ridge the following year. Even when tilling the entire field area, consider why the tillage is being done and don't till any deeper than necessary. For example, chisel plow operation at a six or eight inch depth requires less drawbar pull and tractor energy than operation of a subsoiler or ripper at depths of a foot or more. Drawbar pull is directly related to tillage depth for many specific tillage implements. Aggressive primary tillage operations such as a moldboard plow or subsoiler often require around 1.5 gallon diesel fuel per acre or more, whereas chisel plowing may require about 1 gallon per acre depending on depth, soil conditions, and speed.

Other cultural or production schemes that generally increase efficiency also potentially reduce energy use for the amount of crop harvested. Narrow corn rows can help stimulate vegetative growth and increase potential harvested yield, particularly in northern areas of the Corn Belt. A leguminous cover crop can supply nitrogen to a subsequent crop, reducing the need for fertilizer nitrogen as well as field trips for transport and application.

Tractor use
Because so many field operations are tractor-powered, special attention must be given to optimizing how tractor engine power is generated and transmitted for work. For higher horsepower tractors, many operations are drawbar work that involves pulling tillage and seeding implements through the soil. Efficient transfer of engine power through the tractor's transmission, along with proper attention to ballasting and tire inflation, are important issues. Other tasks require transfer of engine power through the power-take-off (PTO) shaft (e.g. baling) or hydraulic or electrical systems (e.g., some spray pumps or planter seed metering drives). Taking time to assess how tractor engine power is being transferred and used for field operations allows focus on management strategies that can make a difference. Major areas affecting tractor fuel consumption include tractor selection, transmission, maintenance and ballasting/slip/tire inflation.
Tractor selection

Although matching available tractor power to the task at hand is desirable, moving a smaller tractor several miles to perform a limited task usually does not save fuel. Diesel tractors are generally efficient in fuel use for partial loads of 75 percent or even 50 percent if the throttle is reduced and a higher gear selected. For example, tractor test data on the Case IH Magnum 275 show fuel use efficiency is not reduced (from 100 percent loading) at 75 percent drawbar load and reduced only 14 percent at 50 percent drawbar load. The fuel efficiency of a smaller tractor properly sized to handle the reduced load is often not great enough to justify moving unless the new application is only 10 – 30 percent of tractor power and involves significant hours of use.

If a new or used tractor will be acquired, obtain and read Organization of Economic Cooperation and Development (OECD) tractor tests done at the Nebraska Tractor Test Laboratory for tractors being considered. Fuel use efficiency as measured in tests is listed as Hp-hr/gal under fuel consumption. Greater numbers indicate better fuel efficiency. Fuel efficiency values are listed for several levels of PTO and drawbar loading. Because tractor use is often at a partial load, using fuel efficiency from a 50 percent pull and reduced engine speed may serve as a good overall estimate. When comparing tractor models, compare fuel efficiency values with similar loading conditions. As with EPA automotive fuel efficiency estimates, fuel use will vary and depend on actual operation, but test values give an indication of relative efficiency between tractors.

Transmission

If the tractor is using only part of its power when pulling a lighter drawbar load, significant fuel savings are possible by shifting the transmission up to a higher gear and pulling the throttle back (reducing engine RPM). Pulling a sprayer or a smaller field cultivator, disk, or planter that is not well matched to the total tractor power available are common examples. Unless the implement requires PTO operation at a specific engine speed, shifting up and throttling back to reduce engine speed saves fuel. Avoid lugging the engine by only reducing speed to a point somewhat above where the engine starts to lug.

Some newer, higher-horsepower tractors manufactured in recent years offer infinitely or continuously variable transmissions using electronic control to automatically set the transmission at the most fuel efficient point for a given speed and drawbar load. Taking advantage of this new technology as a tractor is replaced saves fuel.

An example of actual fuel savings can be found from an (OECD) tractor test done on a Case IH Magnum 275 rated at 227 hp. Fuel use at 75 percent of maximum drawbar power was reduced 8 percent when the transmission was shifted from 9th to 11th gear and engine speed was reduced from 2091 to 1589 rpm. In similar conditions, fuel use was reduced by 21 percent when only 50 percent of drawbar power was used. Average fuel savings as indicated by tractor tests from 1979 to 2002 indicate fuel savings of 13 percent at 75 percent load and 21 percent at 50 percent load are possible by reducing engine speed and operating in a higher gear (Grisso et al., 2004).

Maintenance

Following a prescribed schedule for tractor maintenance is often a source of pride for agricultural tractor owners. Earlier studies with owner operators indicate that on average many operators are timely with maintenance and filter replacement. Still one study indicates that following scrupulous maintenance results in measurable savings.

In a University of Missouri study 99 tractors were brought in to be tested “as is” at six locations in the state. Tractor horsepower was measured on a PTO dynamometer. Primary and secondary air and fuel filters were then replaced on each tractor before re-testing tractor power. Average engine horsepower increased 3.5 percent after filter replacement. Factory tractor specialists indicated such increase was normal and expected.

In a check of maintenance records on the tractors, most operators were current on filter replacement. Although some were near the end of the service interval, others were near the beginning. Such results suggest that an average increase of 3.5 percent power can be easily obtained by being scrupulously vigilant on air and fuel filter replacement or setting the throttle/fuel supply back 3.5 percent to obtain the same engine power with less fuel.

Researchers at the time (1988-9) estimated fuel savings to be 105 gallons of diesel annually per tractor tested. Increases in average engine horsepower since then suggest that vigilant tractor maintenance may save more than this depending on annual hours of tractor use.
Ballasting/slip/tire inflation

Excessive wheel slippage during drawbar pull operations creates an obvious waste of labor, fuel, and tractor hours. Conversely, a tractor ballasted so heavily that there is little or no wheel slip sinks too far into the soil causing rolling resistance as the wheel tries to climb out of the track and extra energy use as tire sidewalls flex. Optimum wheel slip range for maximum tractive efficiency (equal to the ratio of drawbar power to power available at the drive axle) depends on surface conditions (Figure 1). Higher-horsepower tractors often have sensors allowing drive wheel slip to be monitored from the cab. Slip can be conveniently checked during fieldwork with significant drawbar loads. On tractors without slip measurement, slip can be approximated by measuring the distance a tractor covers during 10 wheel revolutions under drawbar load and comparing this with the distance traveled during 10 wheel revolutions without drawbar load. For example, if loaded wheel distance is 180 feet and unloaded wheel distance is 200 feet, the tractor under load is covering only 90 percent of the unloaded distance, or experiencing a 10 percent wheel slip. As a quick visual test, optimal wheel slip on soil usually occurs when wheel lug marks near the tire centerline are obliterated but lug marks at the outer edge are reasonably distinct.

![Figure 1. Tractive efficiency of transferring axle power to drawbar as affected by wheel slip for various surface conditions.](image)

If wheel slip is outside the optimal range of about 9–15 percent (depending on soil conditions) or if there are questions regarding whether the tractor is ballasted properly to use power available from the engine, the tractor operation manual or various references can be checked for advice on ballasting (e.g., Table 1). Specific amounts of total tractor weight per tractor horsepower are generally suggested depending on tractor style (two-wheel drive, front-wheel-assist, four-wheel drive) and operational speed. Tractors using faster field speeds (e.g., six to seven mi/h instead of four or five mi/h) have optimal fuel efficiency using slightly less weight as they don't need to pull quite as much load to accomplish an equivalent amount of fieldwork in a given time. Because power is efficiently transferred from engine to drawbar over a
range of slip, some variation in weight is allowed. Because most tractors spend a significant amount of time requiring only 70 – 90 percent of rated power available, weight values in Figure 1 are near the low side of the appropriate range. Carrying extra ballast for unused horsepower during operations with light drawbar loads (e.g., pull-behind sprayer, mower/conditioner, or baler) results in small amounts of slip. If the tractor is used for long periods of time for light drawbar loads but has been optimally ballasted for full drawbar horsepower, consider removing ballast to avoid burning fuel to carry dead weight.

Table 1. Gross tractor weight, lb/Hp

<table>
<thead>
<tr>
<th>Tractor type</th>
<th>Speed, mi/hr</th>
<th>&lt;4.5</th>
<th>5</th>
<th>&gt;5.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2WD &amp; MFD (lb/Hp)</td>
<td></td>
<td>130</td>
<td>120</td>
<td>110</td>
</tr>
<tr>
<td>4WD (lb/Hp)</td>
<td></td>
<td>110</td>
<td>100</td>
<td>90</td>
</tr>
</tbody>
</table>

Just as important as total tractor weight is splitting weight appropriately between front and rear axles. The correct percentage of total weight on each axle depends on tractor style (two-wheel drive, front-wheel-assist, four-wheel drive) and whether any rear implement weight is transferred to wheels on the rear axle (pull-type/mounted implement, significant tongue weight, etc., table 2).

Table 2. Front-to-rear axle weight ratio as percentage of total weight.

<table>
<thead>
<tr>
<th>Tractor type</th>
<th>Towed/drawbar</th>
<th>Semi-mounted</th>
<th>Fully-mounted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%Front/%Rear</td>
<td>%Front/%Rear</td>
<td>%Front/%Rear</td>
</tr>
<tr>
<td>2WD</td>
<td>25/75</td>
<td>30/70</td>
<td>35/65</td>
</tr>
<tr>
<td>MFD</td>
<td>35/65</td>
<td>35/65</td>
<td>40/60</td>
</tr>
<tr>
<td>4WD</td>
<td>55/45</td>
<td>55/45</td>
<td>60/40</td>
</tr>
</tbody>
</table>

Tires should be correctly inflated for the load they carry to maximize the ability for lugs to engage soil and develop pull. Contrary to ensuring automotive tires are well inflated to minimize fuel consumption, off-road tires operating on soft soil surfaces increase pull by exposing more of the lug surface at lower tire pressure. Over-inflated tires can create excessive slip as lug surfaces near the tire sidewall do not penetrate the soil surface. Knowing weight carried by the front and rear axles when making ballasting decisions allows the weight carried by each tire to be known. Correct pressure can be determined from tire load and inflation tables of the tire manufacturer or in the tractor operation manual. Maintaining correct rather than ‘low’ pressure is important as under inflation causes premature tire failure.

Other issues

Adding new technology such as auto-steering or auto-swath control for seed, pesticide, and fertilizer inputs can help to avoid wasting time and materials in the field. Auto-steering allows global positioning system (GPS) information to steer the tractor and avoid excessive overlap of swaths that wastes field time and energy. Auto-swath control allows sections across the implement swath to be turned off when previously treated areas would be overlapped. These technologies can be added to existing tractors and equipment but may be more cost effective to purchase as options as equipment is upgraded and replaced. Manufacturers are starting to embed this type of technology into new equipment, further decreasing prices. Cost for auto-steering can range from $5,000 to $50,000 depending on the accuracy desired.

A recent study at Auburn University indicated input savings from one percent to 12 percent for each pass across a field when using automatic section control. This study indicated that, on average, a 4.3 percent savings on seed cost could be observed for a farm while some operations could see as high as a 7 percent savings. Savings are dependent upon field shape and size with the highest benefits occurring in small, irregular shaped fields or fields containing conservation management structures such as grass waterways and terraces. Generally, automatic section control technology can pay for itself within two years.
Modern diesel engines require less idling time to cool the engine. Recommendations for specific equipment can usually be found in the operation manual or through the dealer. Don’t let newer engines idle for periods of many minutes and waste fuel. Check with state regulatory officials regarding proper fuel storage. Vacuum/pressure relief valves protect fuel from water condensation. Reflective white or aluminum paint on the fuel supply barrel and supplemental shading from trees or buildings reduce fuel losses occurring due to evaporation.

If an engine block heater is used to assist starting during cold weather, use a timer to avoid heating for many hours before start-up. A typical engine block heater can warm the engine up in about two hours. A low cost timer used to control swimming pool pumps can be used for most 120 volt heaters and pay for itself in about two months or less depending on the heater size and the amount of time currently being used.

Diesel fuel mixtures are different for summer and winter. Don’t purchase fuel ahead in late summer if it can’t be used up before cold weather sets in. Use a fuel conditioner or fuel-line antifreeze in equipment that isn’t used much during the winter.

Other individual equipment operations

Because a tractor powers most tillage, seeding, and many application operations and also because total energy available from the engine rapidly dissipates if there are significant losses in transmission, drives, and at the tire/soil interface, primary attention for energy saving should be done with the tractor. Look for ways to combine field operations into a single pass such as tilling and applying fertilizer with a strip-till implement or using one-pass tillage.

Many individual points regarding saving energy with tillage, seeding, application, and other types of field equipment involve good management and maintenance practices to ensure a good field job is accomplished and avoid the need for another field pass. If objectives of the desired amount of seed, fertilizer, or pesticide being applied or soil tilled to a certain condition are not met, fuel and perhaps additional crop inputs are needed for a second pass.

On tillage equipment, worn bearings, scrapers, or cutting edges affect soil manipulation and potentially draft (drawbar pull). Good planter operation involves a pre-field check of seed and fertilizer metering components along with in-field checks of seed placement, proper operation of soil-engaging components, and periodic lubrication.

For further information and references

Field operations - general


Hanna, M., J. Harmon, and J. Flammang. 2010. Limiting field operations. Iowa State University Extension publication PM 2089D. Available at: http://www.extension.iastate.edu/Publications/PM2089D.pdf

Tractor - general


Tractor ballasting/slip/tire inflation


Tractor transmission


Sawyer, J. E., M. Hanna, and D. Petersen. 2011. Shift up and throttle back to save tractor fuel. Iowa State University Extension publication PM 2089M. Available at: http://www.extension.iastate.edu/Publications/PM2089M.pdf
Tractor selection
Download Nebraska Tractor Test Laboratory reports at: http://tractortestlab.unl.edu/index.htm

Other tractor issues

No-till seeding