The selection, operation, and management of farm tractors and their implements is essential to cost-effective farming practices. Therefore, knowledge of tractor equipment, power requirements, optimum loading, and other factors can improve the effectiveness and efficiency of your farming operations. This publication is designed to help you understand, select, and best utilize your equipment in a way that will save you time, fuel, and money. Information is provided on the types of tractor power delivery, ways to improve tractor performance, implement power requirements, and field performance enhancements. This publication also includes step-by-step instructions for estimating power loads for various implements so that you can achieve optimum loading and use of your equipment.
Power Delivery

Power that is supplied from an agricultural tractor to farm implements may be available in several forms. It is important to understand the various forms of tractor power listed below in order to select and utilize appropriate equipment for your farm.

■ **Engine Power.** Power output from the engine that is available at the engine flywheel.

■ **PTO Power.** Power output that is available at the tractor power take-off (PTO) shaft to drive implement components and systems. This is the term most commonly used to rate agricultural tractor power. Typical PTO applications are rotary tillers, rotary cutters, and sprayers.

■ **Drawbar Power.** Power that is available at the drawbar to move implements and equipment. Typical implements are disc harrows, chisel plows, and planters.

■ **Fluid Power.** Power that is available in the tractor hydraulic system to power implement components and systems. Typical applications are loaders, backhoes, and cylinders.

■ **Electrical Power.** Power that is available from the tractor electrical system to drive components and systems. Typical applications are fans, air conditioners, and lights.

You must be careful to ensure that the power demands of these various applications do not exceed the engine’s capacity. Remember, the power supplied by the tractor engine is shared among all of the following applications:

■ the power provided at the PTO,

■ plus drawbar applications,

■ plus the hydraulic system,

■ plus the electrical system.

Typically, tractors should be loaded to no more than 80 percent of their rated power. For example, a tractor rated at 100 PTO horsepower (hp) should be loaded to a maximum of 80 hp. This allows for a power reserve to make changes and adjustments in the field and provides a margin for error.

**Tractor Features and Selection**

**Drive Configuration Options**

Tractors are available in several drive configurations. The first type of drive is the conventional two-wheel drive with single or multiple tires. Traction is usually provided by the rear axle, but some special-purpose machines are available with front-axle drive. The second type of drive is the front-wheel assist. These tractors are essentially two-wheel-drive units that have had a powered front axle added to the design. The front axle does not have the same tire size or weight as the rear axle so it does not pull as much as the rear axle. The third type of drive, four-wheel drive, has equal sized tires and equal pulling power on both the front and rear axles. The fourth type of drive, designed for maximum pulling power, is the track drive with steel or rubber tracks.

Two-wheel drives are the most versatile and under some conditions, with proper selection of tires and ballast, may perform as well as the front-wheel assist or even a four-wheel drive. There are several reasons for adding power to the front axle (choosing front-wheel assist or four-wheel drive): the use of front-mounted implements, poor traction conditions (where wheel slippage would be excessive, such as on sand, mud, or loose soil surfaces), operation on steep or sloping terrain, and the availability of more engine power than can be used on a single axle.

**Tire Options**

There are several options to consider when selecting tires. Standard bias-ply tires come in a variety of tread designs and tire sizes. Equipment performance can be enhanced by selecting and mounting dual tires or even triple tires. Multiple tiring offers a means of improving flotation, reducing soil compaction, or improving traction in some soils. For example, adding unballasted duals achieves about the same advantage as ballasting singles. (For a discussion on ballasting, see the next section.) The unballasted duals also reduce soil compaction. Adding ballast to duals offers maximum traction. Using triples will further reduce soil compaction and may offer better traction as well. However, multiple tiring has disadvantages in terms of additional cost and reduced machine maneuverability. Multiple tiring also places greater stress on the axles and axle housings. To prevent overloading the axle, be sure that the weight does not concentrate on the outboard tires.

Radial tires offer improved traction, better flotation, and longer life. Radial tires have been shown to have 6 to 18 percent better traction at 15 percent wheel slippage. Properly ballasted radials may eliminate the need for duals in some conditions. Bear in mind that radials provide the best advantage on firm soils and tend to lose some of their advantage on softer soils.

**Ballasting**

Whether equipped with radial or bias-ply tires, tractors perform better if properly ballasted. Ballasting a tractor means providing enough weight to develop the desired drawbar pull or power. Key determining factors in ballasting are ground speed and wheel slippage limits.

As the operating speed of a tractor increases, the ballast required to develop full power decreases (see Table 1). Getting full power with decreased ballast is more fuel efficient. You may have to decrease implement size (so that the tractor can pull at a higher speed), but the increase in speed will compensate for the decrease in width. Most tractor manufacturers now recommend sizing implements so that the tractor can operate in the 4-to-6-mile-per-hour range. However, excessive speed should be avoided to ensure safety.
Table 1. Ballasting Two-Wheel-Drive Tractors: Total Static Weight on Drive Wheels on Tilled Soil at 12 Percent Wheel Slip, 80 Percent Load

<table>
<thead>
<tr>
<th>No-load Ground</th>
<th>Total Rear Axle Weight (lb/rated PTO hp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (mph)</td>
<td>Mounted Implement</td>
</tr>
<tr>
<td>2</td>
<td>204</td>
</tr>
<tr>
<td>4</td>
<td>102</td>
</tr>
<tr>
<td>6</td>
<td>68</td>
</tr>
<tr>
<td>8</td>
<td>51</td>
</tr>
</tbody>
</table>

Note: For firm soil reduce weight up to 30 percent. For soft soil increase weight up to 30 percent.

Excessive ballast reduces wheel slippage, but the excess weight increases fuel consumption and soil compaction. On the other hand, too little ballast wastes fuel because of excessive slippage. Also, the distribution of weight plays an important role.

- For two-wheel-drive tractors, 70 to 75 percent of the total tractor static weight, including ballast, should be on the rear axle, as shown in Figure 1.
- Front-wheel-assist drives, when engaged, should have 60 percent of the total tractor static weight on the rear axle, including ballast, as illustrated in Figure 2.
- Four-wheel drives should have 60 percent of total tractor static weight, including ballast, on the front axle, as shown in Figure 3.

Proper ballasting for two-wheel-drive tractors that are fully loaded (at 80 percent of their rated PTO horsepower) is provided in Table 1. Remember that under no circumstances should the tire or tractor manufacturer's maximum weight recommendation be exceeded. Also, never leave the front of a tractor so light that it tends to tip or turn over.

The ultimate determining factor for ballast is field performance. Start with the recommendations above and then adjust as necessary to achieve proper wheel slippage and performance.

Using Drawbar Power: Wheel Slippage and Tractive Efficiency

Wheel slippage is the reduction in travel distance due to tires slipping in the soil. Wheel slippage can be controlled by adjusting the draft of an implement, which is done by adjusting the width or depth of the implement. Some slippage is desirable to develop pull and to protect the drive train components (see Table 2), while excessive slippage wastes power and fuel. Therefore, optimizing wheel slippage is the key to efficient operation in the field.

You need to be able to determine wheel slippage and know what adjustments to make to control slippage. There are three methods of monitoring wheel slippage. The first method is the measured course approach. Measure a convenient test course in the field (100 to 200 feet), and operate the tractor across the course first with the implement raised (no load)
Table 2: Optimum Wheel Slippage Ranges

<table>
<thead>
<tr>
<th>Surface Condition</th>
<th>Wheel Slippage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>4 – 8</td>
</tr>
<tr>
<td>Firm soil</td>
<td>6 – 10</td>
</tr>
<tr>
<td>Tilled soil</td>
<td>11 – 13</td>
</tr>
<tr>
<td>Soft soils and sands</td>
<td>14 – 16</td>
</tr>
</tbody>
</table>

and second with the implement in the soil (under load). Count the number of revolutions the drive wheel makes for each run. Actual wheel slippage can then be determined from the following equation:

\[
\text{Slippage} = \frac{(\text{DWR}_L - \text{DWR}_{NL}) \times 100\%}{\text{DWR}_L}
\]

Where:
- Slippage = Wheel slippage in percent
- \( \text{DWR}_L \) = Drive wheel revolutions under load
- \( \text{DWR}_{NL} \) = Drive wheel revolutions, no load

Example: A 100-foot course was laid out in a field with a tilled soil surface. Thirteen drive wheel revolutions were required to cover the course under no load and 15 drive wheel revolutions were required under load. Substituting these values in equation 1, we find:

\[
\text{Wheel Slip} = \frac{(15 - 13) \times 100\%}{15}
\]

Wheel Slip = 13.3%

The second approach to determining wheel slippage is the visual method. With the tractor and implement operating under load, look at the tire track left by the tractor drive wheel, as shown in Figure 4. If a perfectly formed track is visible, wheel slippage is probably too low. If the track appears “chewed up,” slippage is excessive. Proper slippage is indicated by a track that appears well formed but slightly broken.

The third approach requires wheel slip monitors and controls provided by some manufacturers as part of the tractor’s instrumentation. Add-on units are also available for most tractors. These systems consist of radar or ultrasonic devices to measure tire speed and a sensor on the axle to measure tire revolutions. Tire size is programmed into the unit and wheel slippage is displayed by the monitor. You can achieve desired slippage by reading the monitor and adjusting the implement as necessary. Some tractor manufacturers are also incorporating control systems that will monitor and control the desired wheel slippage automatically.

**Table 3: Tractive Efficiency Table, Two-Wheel Drive, Single Tires**

<table>
<thead>
<tr>
<th>Wheel Slippage (%)</th>
<th>Hard Soil</th>
<th>Firm Soil</th>
<th>Tilled Soil</th>
<th>Soft or Sandy Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.80</td>
<td>0.67</td>
<td>0.46</td>
<td>0.20</td>
</tr>
<tr>
<td>10</td>
<td>0.80</td>
<td>0.74</td>
<td>0.63</td>
<td>0.50</td>
</tr>
<tr>
<td>15</td>
<td>0.77</td>
<td>0.73</td>
<td>0.66</td>
<td>0.58</td>
</tr>
<tr>
<td>20</td>
<td>0.76</td>
<td>0.70</td>
<td>0.65</td>
<td>0.58</td>
</tr>
</tbody>
</table>

For front-wheel-assist tractors, increase tractive efficiency by 5% in hard or firm soil, 10% in soft or sandy soil.

For four-wheel-drive tractors, increase tractive efficiency by 10% in hard or firm soil, 20% in soft or sandy soil.

Figure 4. Estimating wheel slippage from tire tracks.
Table 4. Fuel Factor (gal/hr)/hp

<table>
<thead>
<tr>
<th>Tractor Load Ratio (%)</th>
<th>Diesel Engine</th>
<th>Gasoline Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.158</td>
<td>0.256</td>
</tr>
<tr>
<td>30</td>
<td>0.132</td>
<td>0.204</td>
</tr>
<tr>
<td>40</td>
<td>0.112</td>
<td>0.168</td>
</tr>
<tr>
<td>50</td>
<td>0.099</td>
<td>0.143</td>
</tr>
<tr>
<td>60</td>
<td>0.089</td>
<td>0.126</td>
</tr>
<tr>
<td>70</td>
<td>0.084</td>
<td>0.114</td>
</tr>
<tr>
<td>80</td>
<td>0.081</td>
<td>0.107</td>
</tr>
</tbody>
</table>

Drive axle to the implement. Thus, TE can be understood as the conversion of power from the axle to power that pulls the implements. For example, we may measure 100 hp at the axle but only 66 hp at the drawbar. Tractive efficiency would be 66/100 or 0.66. Typical tractive efficiencies are given in Table 3. The example of 0.66 tractive efficiency could be found on a tilled soil at 15 percent wheel slip. Refer to Table 3 to find the correct TE to use when you are calculating drawbar power later in this publication (see equation 7).

**Fuel Consumption and Fuel Efficiency**

Keeping a record of fuel consumption is useful in determining where costly energy may be wasted. Fuel consumption can also be measured by installing fuel flow meters in the tractor fuel system. Several models currently have these devices. For tractors that do not have fuel flow meters, fuel consumption (FC) can be estimated fairly accurately. First, you need to know the tractor’s rated PTO power. This information can be found in the manufacturer’s specifications. Second, you need to know the “total implement power” required by the job. This information may be in the implement manufacturer’s specifications or may be estimated from the data given later in the section titled “Implement Power Requirements.” Third, determine the tractor load ratio as follows:

\[
\text{Tractor Load Ratio (\%)} = \frac{\text{Total Implement Power (hp)}}{\text{Rated Tractor Power (hp)}} \times 100\%
\]

Next, use Table 4 to determine the proper fuel factor for the job.

Fuel consumption can then be determined as follows:

\[
\text{Fuel Consumption (gal/hr)} = \frac{\text{Fuel Factor} \times \text{Total Implement Power}}{100}\%
\]

Another term used by tractor manufacturers is fuel efficiency. Fuel efficiency ratings are useful because they allow you the opportunity to compare equipment on the basis of the work performed for a given amount of fuel used. Fuel efficiency is expressed as horsepower-hours per gallon (hp-hr/gal). Fuel efficiency can be determined as follows:

\[
\text{Fuel Efficiency (hp-hr/gal)} = \frac{\text{Total Implement Power, hp}}{\text{Fuel Consumption (gal/hr)}}
\]

**Example:** Assume that an implement requiring a total of 72 hp is pulled by a tractor rated at 90 hp. First, we calculate the tractor load ratio using equation 2:

\[
\text{Tractor Load Ratio} = \frac{72 \text{ hp} \times 100\%}{90 \text{ hp}} = 80\%
\]

From Table 4 we determine that the fuel factor for a diesel engine with a tractor load ratio of 80 percent is 0.081. We can then use equations 3 and 4 to calculate the fuel consumption rate and fuel efficiency.

\[
\text{Fuel Consumption} = 0.081 \times 72 = 5.83 \text{ gal/hr}
\]

\[
\text{Fuel Efficiency} = \frac{72 \text{ hp}}{5.83 \text{ gal/hr}} = 12.34 \text{ hp-hr/gal}
\]

In cases where tractors are not heavily loaded, additional fuel savings can be earned through “gear up—throttle back” operation—that is, using a higher gear ratio and reducing engine speed. If your tractor is properly loaded for a given gear selection and throttle setting, the engine speed indicated on the tachometer should drop 5 to 8 percent from the no-load speed when the load is applied.
As discussed earlier, tractors provide power from the engine to implements and components in the form of PTO, drawbar, fluid, and electrical power. Likewise, implements consume power from these same sources. To obtain maximum efficiency from your equipment, it is helpful to be able to estimate the power required to operate various implements.

The power needed to drive a given piece of equipment is measured in horsepower. Horsepower estimates for implements can be obtained from several sources. However, bear in mind that these values are estimates and may vary with changes in soil and crop conditions.

**PTO Power**

PTO power is the most direct application of engine power to a piece of equipment. It is also the easiest to measure and the easiest to compare. To determine PTO power, you need to know how much torque, in pound-feet (lb-ft), is needed to turn the drive shaft and at what speed in revolutions per minute (rpm) it will turn.

\[
PTO\ Power\ (hp) = \frac{Torque\ (lb-ft) \times Rotation \ Speed\ (rpm)}{5,252}
\]

**Example:** Assume that a baler requires 525 lb-ft of torque to turn under load. Drive shaft speed is 540 rpm. Using equation 5, we can calculate the PTO power required to operate the baler:

\[
PTO\ Power = \frac{525\ lb-ft \times 540\ rpm}{5,252} = 54\ hp
\]

**Drawbar Power and PTO Equivalent Power**

Drawbar power is used for a wide range of implements. However, accurate determination of drawbar power can be difficult. Drawbar power is based on (1) the draft of the implement, that is — the force in pounds (lb) necessary to pull or push it through the field; and (2) the true ground speed in miles per hour (mph) that the tractor and implement will travel.

Drawbar power must be determined for each implement. It can be calculated by multiplying the draft in pounds by the speed in miles per hour:

\[
Drawbar\ Power\ (hp) = \frac{Draft\ (lb) \times Speed\ (mph)}{375}
\]

Draft estimates for several implements are given in Table 5. The following example shows how to estimate drawbar power.

**Example:** You have a 9-foot-wide chisel plow operating at 4 miles per hour. The soil has average tillage conditions, the surface is firm, and wheel slippage is 10 percent. From Table 5, we find that the average draft is 460 lb/ft. Using equation 6, we first calculate the drawbar power required to pull the plow:

\[
Drawbar\ Power = \frac{460\ lb/ft \times 9\ ft \times 4\ mph}{375} = 44.2\ hp
\]
From Table 3 we find that the tractive efficiency for 10 percent slip and firm soil is 0.74. Substituting this value and the drawbar power in equation 7, we can calculate the PTO equivalent power:

\[
\text{PTO Equivalent Power} = \frac{44.2 \text{ hp}}{0.96 \times 0.74}
\]

\[
\text{PTO Equivalent Power} = 62.2 \text{ hp}
\]

**Fluid Power**

Fluid power systems are increasingly popular on agricultural machines. In some cases these systems are used for control purposes and in others to deliver power. Fluid power (the tractor hydraulic system) has the capability of delivering high power levels to an implement. Fluid power can be determined from the flow rate (in gallons per minute, or gpm) and pressure (in pounds per square inch, or psi) as follows:

\[
\text{Fluid Power (hp)} = \frac{\text{Flow Rate (gpm)} \times \text{Pressure (psi)}}{1,714}
\]

**Example:** A tractor hydraulic system delivers 15 gallons per minute at a pressure of 2,400 psi. From equation 8 we can calculate the fluid power available:

\[
\text{Fluid Power} = \frac{15 \text{ gpm} \times 2,400 \text{ psi}}{1,714} = 21 \text{ hp}
\]

**Electrical Power**

Electrical power used for implements can be determined from the voltage (volts) in the system and the current flow (amps).

\[
\text{Electrical Power (hp)} = \frac{\text{Volts} \times \text{Amps}}{746}
\]

**Example:** Using the equations given previously, an implement has been determined to require 25 PTO hp [equation 5], 30 PTO equivalent hp [equation 7], 10 fluid hp [equation 8], and 1 hp from the electrical system [equation 9]. Using these values in equation 10, we find:

\[
\text{Total Implement Power} = 25 + 30 + 10 + 1 = 66 \text{ hp}
\]

Remember, total implement power should not exceed 80 percent of the tractor’s rated PTO power. Therefore:

\[
\text{Rated Tractor PTO Power} = \frac{\text{Total Implement Power}}{0.80}
\]

For the example above where total implement power is 66 hp, the rated tractor PTO power should be:

\[
\text{Rated Tractor PTO Power} = \frac{66 \text{ hp}}{0.80}
\]

\[
\text{Rated Tractor PTO Power} = 82.5 \text{ hp}
\]

The operator should choose a tractor rated at approximately 82.5 hp.

**Total Implement Power**

Total implement power is the sum of all of the power requirements for the operation of an implement. Some implements may use only one form of power, such as direct PTO power or PTO equivalent power from the drawbar. Many implements, however, use two or more forms of power. Thus, to use a tractor of proper size, all forms of power must be considered.

\[
\text{Total Implement Power} = \text{PTO Power} + \text{PTC Equivalent Power} + \text{Fluid Power} + \text{Electrical Power}
\]
Using the appropriate equipment for your fields and employing simple methods of improving operating efficiency can save you time, money, and fuel. This section (1) demonstrates how to estimate the capacity of your equipment and then compare it to the requirements of your field, and (2) provides information on field management and machine adjustments that will increase the productivity and efficiency of your farming operations.

**Field Efficiency and Field Speed**

Field efficiency is the ratio a machine’s actual productivity to its theoretical maximum productivity. Field efficiency allows for turnaround time, adjustments, refilling and unloading, overlapping between passes for some implements, and other time-consuming operations. You will need to use field efficiency estimates from Table 6 when calculating effective field capacity in equation 12.

Field speed is the true ground speed of a given field operation. Speed is one of the most significant factors in determining power requirements and also one of the most manageable. Table 6 presents typical speed and field efficiency values for several selected implements.

**Effective Field Capacity and Required Field Capacity**

Effective field capacity is the actual productivity of a field machine considering field efficiency and field speed (just described in the previous section) in addition to the effective working width of an implement. Be sure to determine the effective working width of the implement accurately. Effective field capacity (\(C_e\)) is vitally important in ensuring that the equipment is sized properly to get the job done on a timely basis. It is calculated as follows:

\[
C_e \text{ (acres/hour)} = \frac{S \times W \times FE}{8.25}
\]

Where:
- \(S = \) Speed in miles per hour
- \(W = \) Working width in feet
- \(FE = \) Field efficiency, as a decimal fraction

Be sure to convert field efficiency to a decimal value for this equation.

**Required field capacity** (\(C_r\)) provides you with the implement size necessary to complete a given job within a certain time period. To estimate \(C_r\), you should know the total number of days available for the work to be done. Then you need to know the probability of a suitable day, meaning the probability that a given day within that time frame will be suitable for work. The estimates of the probability of a suitable day can be obtained from local estimates, weather service, or Extension Service publications.

\[
C_r \text{ (acres/hour)} = \frac{A}{D \times H \times P}
\]

Where:
- \(A = \) Area to be worked, in acres
- \(D = \) Total number of days
- \(H = \) Hours of work per day
- \(P = \) Probability of a suitable day, as a decimal fraction

**Example:** A 10-foot-wide disk harrow is to be used on 150 acres of land. The land is to be covered during the first two weeks (10 working days excluding weekends) of October. Probability of a suitable day is assumed to be 0.60. Working time per day will be 10 hours.

**Solution:** From Table 6, we find that the disk harrow typically operates at 4.0 mph and 80 percent (0.80) field efficiency. Using these figures in equation 12,
we are able to calculate the effective field capacity ($C_e$):

$$C_e = \frac{4.0 \text{ mph} \times 10 \text{ ft} \times 0.80}{8.25}$$

$$C_e = 3.87 \text{ acres/hour}$$

By substituting the appropriate figures into equation 13 (150 acres, 10 working hours, probability of a suitable day = 0.60, and 10 working hours per day) we find:

$$C_n = \frac{150 \text{ acres}}{10 \text{ days} \times 10 \text{ hr/day} \times 0.61}$$

$$C_n = 2.46 \text{ acre/hour}$$

The effective capacity of the equipment (3.87 acres/hour) exceeds the required capacity (2.46 acres/hour). Therefore the equipment is more than adequate for the job.

**Field Management and Machine Adjustments**

Field management involves studying the layout of a field to improve field efficiency. Changes that maximize the implement's operation cycle will improve field efficiency — that is, they will allow the machine to be more productive. Such improvements include reducing turnarounds, odd shapes, short rows, and unproductive time.

Machine adjustments can also enhance field efficiency. Simple modifications to the implements can reduce draft requirements and energy consumption. All soil-working implements respond to changes in depth, but many implements can be influenced by other factors as well. For example, a chisel plow is normally set with a 1-foot spacing between shanks. In many cases, increasing the spacing by 1 inch per shank will not change the quality of tillage, but additional effective working width can be gained that will increase the field capacity. Moldboard plow adjustments, such as landing and width of cut, have a direct effect on draft of the plow. Likewise, sharpness and condition of the share has a direct effect on draft requirements. Disk harrow draft can be reduced by decreasing gang angle. Mixing action can be restored by increasing field speed. Operating at lower draft and higher speeds will use the same power, but the job can usually be finished in less time and often with less fuel consumption.

To cut your fuel costs even further, try conducting multiple operations during each pass through your field. For example, some operations can be conducted simultaneously, such as seedbed preparation and planting. Contact your tractor dealer for information on accessories that allow you to use front-mounted implements for these types of applications.

Many pieces of equipment are supported by pneumatic tires. Maintaining proper inflation pressure ensures that the tires will roll freely. Also, for chemical application or planting equipment, proper inflation of the tires that drive the metering mechanism helps ensure proper calibration.

Know your field conditions and cropping systems. Excessive plowing depth and extra operations waste fuel, time, and money. Consider conservation tillage practices. Besides reducing soil erosion, they may reduce overall energy requirements.

There are many other machine and field management adjustments that you can make to improve the efficiency of your farming operations. See North Carolina Cooperative Extension Service publications AG-460, *Calibration of Chemical Applicators*, and AG-459, *Agricultural Machinery Maintenance*. For additional information on these topics, contact your county Extension Service agent.

**References**


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