Matching tractors and implements

I W. Grevis-James
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By I. Grevis-James*

Tractor and implement matching involves balancing implement load characteristics with tractor output characteristics to obtain the best output from the combination. When tractors were first introduced, matching them with implements was simple; most tractors were designated by the number of horses they replaced or the size of implement they pulled. Today matching tractors and implements is far from simple owing to the changes in types of equipment, the rapid changes in the size of equipment and the range of alternatives.

Until quite recently little engineering has been applied to the problem of matching. Experience has been the only guide in the selection and operation of tractor and implement combinations.

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Today however, there is an awareness that good matching can improve efficiency of operation and thus minimise operating costs. Consequently machinery companies and other organisations have started to help farmers to improve their matching.

Example

The following example will indicate the type of problem and how correct matching can increase work output.

Farmer Smith has a 7.6m scarifier (two 3.8m units) which he pulls with a model Y tractor at 7.2 km/hour at a depth of 75 mm in heavy soil.

Smith decides to purchase a larger two-wheel-drive tractor that will allow him to cover his ground faster. The scarifiers he has are in good condition so he decides to keep these and purchase a third unit if necessary.

The pto power of the present tractor is 78 kilowatts and as Smith would like to cut his working time by one-third he reasons that he needs a tractor of 117 kW. After much discussion with various tractor salesmen he decided upon a Model Z with a quoted pto power of 120 kW.

Initially Smith hitches up his existing scarifiers and finds that the tractor pulls the load at an indicated speed of 9.5 km/hour in gear 9 giving a working rate of 6.9 ha/hour.

After a period of use of the new tractor, Smith decides that the operating speed is too high and he purchases an extra scarifier to take the overall width out to 11.4 m. The tractor now pulls the load at an indicated speed of 7.8 km/h in gear 7 and Smith is quite happy with this speed. However, 1400 hours later the tractor's rear tyres are worn out. Previously, he had always managed 2000 hours before replacement. The real working rate with the 11.4 m width is 7.2 ha/hour.

In fact neither of the two implement widths suited the new tractor at all well. The narrow implement gave a low working rate at a higher than desirable speed. The wide implement resulted in a higher working rate but at the expense of increased tyre wear and increased investment.
If Smith had purchased two 0.95 m wide wings to add to the original scarifiers, his working rate would have been 7.5 ha/an hour using gear 8. Tyre wear would be normal and the required investment small. With good matching, improved outputs are possible with little increase in cost.

In the selection of a tractor and implement combination, the farmer has a huge range of alternatives such as implement type and width, tractor type and power. Other variables are the depth and speed at which equipment can be operated. The selection must be compatible with the characteristics of the soil and a tractor and implement combination that works well in one area may not necessarily work well in another area.

A good understanding of both implement operating characteristics and tractor operating characteristics is essential for good matching and thus efficiency. In grain farming, the most important implements are tillage implements and discussion in this article is confined to tillage implements.

Implement types
The logical starting point in matching is the choice of an implement type. This choice will initially depend upon the job to be done, for example primary tillage, secondary tillage or light cultivating. The depth of tillage required will also influence the choice.

Consideration must be given to alternative types of machine for doing the same job. For example, in primary cultivation, disc ploughs, chisel ploughs and scarifiers could all be used. Provided the job done by each is acceptable, the one with the lightest pull should be chosen.

In some instances there may be differences in pull between makes of the same type of machine. Generally these differences will be hard to substantiate but they should at least be considered.

Depth of working is the major factor controlling the pull of tillage implements. For this reason, working depths should always be the minimum for the desired result.

Implement width
The width of an implement should not be decided upon without first considering the working rate, either area covered per hour or per day. Hourly working rates should be determined on the basis of the area to be covered and the time available. The variability of the Australian climate makes it difficult to predict the time available for a given operation. This in turn accounts, in part, for the different working rates that farmers choose.

Having settled on an hourly working rate, a range of implement width/speed combinations are available to choose from. The broad choice is between using narrow implements at high speed and broad implements at low speed. However, with all tillage implements, the higher the speed of operation the larger the pull. As a consequence, the higher the speed of operation, the higher the fuel consumption to cover a given area with a particular machine. This is the result of the larger amount of energy put into the soil at high speeds.

Figure 1 shows typical pull/speed curves for tillage implements.

Implement operating characteristics
The major operating characteristics of tillage implements are as follows:

1. Pull increases directly with width. Thus, doubling the width will double the pull.
2. Pull increases almost directly with depth. Thus a doubling of depth will almost double the pull.
3. Pull increases with speed in a similar way to that shown in Figure 1.

The net result of these characteristics is that it is relatively easy to predict the effect on pull of changes in implement width and depth but not so easy to predict the effect of speed. For disc implements an increase in speed of 1 km/h may increase pull by 50 per cent whereas for tined implements the increase is unlikely to exceed 10 per cent.

Other less important characteristics are:

1. Worn tillage tools (points) usually increase pull as compared with new tools.
2. In hilly terrain average pull will be higher than for the same implement on flat terrain.

In the paragraphs above, the implement characteristics have been stated in terms of pull only. The power required to operate an implement is calculated by multiplying pull by speed. Thus for the above characteristics, pull can be replaced by power if the implement speed is included, for example, power increases directly with width multiplied by speed.

The tractor
The characteristics of the tractor are largely determined by the engine, and the remainder of the tractor comprising transmission and traction system. Three different traction systems are available — two-wheel-drive, four-wheel-drive and tracks, and these three systems require different approaches when matching tractor to implement.

The tractor engine
The power/speed output characteristics of a typical governed diesel tractor engine are shown in Figure 2 for the maximum setting of the governor (throttle). The vertical dotted line through rated speed separates the areas where the engine is part loaded (governed range) and fully loaded (full fuel range). In the governed range the engine operates at speeds between high idle speed and rated speed. Over this speed range, the engine produces a power output varying between zero and maximum power. The engine is controlled by the governor in this range and the function of the governor is to keep engine speed almost constant despite large fluctuations in engine load.

At speeds less than rated speed, output power decreases and the governor no longer controls the engine. In the full fuel range (or overload range as it is often called) small changes in load produce a
large change in speed. Most engine manufacturers advise against prolonged operation of the engine in the full fuel range.
For good utilisation of the power available and to keep a little "up the sleeve" an average engine loading of 80 per cent of maximum power should be aimed at. This level of load will also ensure good fuel economy. To achieve this level of loading the engine needs to be loaded down from high idle speed to close to rated speed.

**The traction system**
The traction system, whether it be a wheel or track, converts the rotational power output of the axle into a linear output. The efficiency of the conversion depends upon the type of traction system, the soil surface and the level of wheel slip. The efficiency of the conversion process is called "tractive efficiency".

Tractive efficiency equals output power (drawbar power) divided by input power (power put into the axle or sprocket)

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\text{Tractive efficiency} = \frac{\text{drawbar power}}{\text{axle power}}
\]

Axle power is the engine power less the losses arising between the engine and axle.

Wheel slip is defined as the distance travelled in one wheel revolution under no load (\(S^o\)) minus the distance travelled under load (\(S^1\)) all divided by the distance travelled under no load (\(S^o\))

\[
\text{Wheel slip (\%)} = \frac{S^o - S^1}{S^o} \times 100
\]

Figure 3 shows, for a rubber tyre, how tractive efficiency varies with wheel slip, and this illustrates several important points. Firstly, maximum tractive efficiency is around 75 per cent. The remaining 25 per cent is power that is wasted in the conversion process. Secondly, tractive efficiency is at a maximum in the wheel slip range between 8 per cent and 12 per cent. Thirdly, at very low and very high levels of wheel slip, tractive efficiency is very low. There is thus no point in aiming for very low wheel slip.

The effect of different soil surfaces on tractive efficiency is shown in Figure 4. In general the poorer the surface, the lower the tractive efficiency and the higher the wheel slip level for optimum efficiency.

The soil conditions quoted in Figure 4 are as follows:
- Firm soil. A high strength soil in which there is little tyre sinkage. Most pastures in a dry condition would be considered as firm soil.
- Tilled soil. A medium strength or loose soil condition, for example a soil that has been chisel ploughed or scarified.
- Soft or sandy soil. Any soil of low strength, very sandy or where tyre sinkage is high.

Also shown in Figure 4 is a comparative curve for a tracked machine operating in a firm soil. The tractive efficiency is far higher than a wheel tractor, and the wheel slip much lower at best tractive efficiency. The curves for a four-wheel drive tractor are generally similar to a two-wheel-drive but moved slightly up and to the left, that is, the optimum tractive efficiency is slightly higher and optimum wheel slip slightly less.

In both Figures 3 and 4, the dotted line divides the curves into those areas where the wheel slip is above or below optimum. Where wheel slip is above optimum the tractor is too light and where it is below optimum the tractor is too heavy.

In the context of correct matching, the tractive efficiency to be aimed at is the optimum. For two-wheel-drive tractors, the optimum wheel slip on firm soil is 9 per cent, and 12 per cent on cultivated soil. For four-wheel-drive tractors, 8 per cent slip is optimal for firm soil, and 10 per cent for cultivated soil. Reliable figures are not available for crawlers, but for most situations, slip should be 5 per cent or less.

**Procedure for matching tractor and implement**
A tractor and implement will be correctly matched when the...
combination is working so that:
- The implement is working at the desired depth and at a satisfactory speed.
- The engine is loaded to 80 per cent of maximum power.
- Wheel slip is in the range that will give close to optimum tractive efficiency for the particular soil surface.

To achieve these conditions in the field, it is essential to know engine loading and wheel slip.

Unfortunately the modern tractor is not equipped with engine load and wheel slip monitors so it is necessary to establish these conditions by other means.

**Engine load**

For setting engine load the following procedure will give approximately the correct result. At full setting most governors operate over a range of 100 to 300 rpm between high idle speed and rated speed. At high idle speed, engine load is zero, at rated speed engine load is the maximum. At a speed 80 per cent below high idle (just above rated speed) engine load will be about 80 per cent of full load. Thus by keeping the engine loaded to this speed on the tachometer the engine load will be properly set.

The above procedure assumes that the tachometer is accurate but this may not always be so. Tachometer accuracy is checked by running the engine at high idle and noting any discrepancy between the specified (from owners manual) high idle speed and the speed indicated on the tachometer. Any inaccuracy must be allowed for in setting the engine load.

**Wheel slip**

Wheel slip must be established by measurement as it cannot be satisfactorily judged by eye. Although the job requires two people it can be done very quickly after some practice, using the following procedure.

First make a reference mark on the side of the rear tractor tyre. Walk alongside the tractor while it is

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**Fig. 4. — Tractive performance on different soils**

<table>
<thead>
<tr>
<th>Wheel slip (%)</th>
<th>Tractor too heavy</th>
<th>Weight correct</th>
<th>Tractor too light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine load too light</td>
<td>Use higher gear and/or increase width</td>
<td>Use next higher gear</td>
<td>Add ballast and use higher gear</td>
</tr>
<tr>
<td>Engine speed less than correct speed</td>
<td>Increase width and use lower gear</td>
<td>Correct matching</td>
<td>Reduce width and use higher gear</td>
</tr>
<tr>
<td>Engine load higher than desirable</td>
<td>Reduce ballast and/or use lower gear and increase width</td>
<td>Use next lower gear</td>
<td>Use lower gear and/or reduce width</td>
</tr>
</tbody>
</table>

**Note**

- Raising the drawbar height will have the same effect as adding ballast, and vice versa.
- Use of weight transfer hitch or mounted implements has the same effect as adding ballast
- Add ballast up to the recommended maximum only

**Fig. 5. — Tractor/implement matching chart**
working and mark the spot where the reference mark comes down to the ground.
Continuing alongside, count twenty wheel revolutions and again mark the spot where the reference mark comes down.
With the tractor unloaded, drive the tractor between the two marks, marking the tyre as it passes the first mark. Count the number of revolutions of the wheel required to travel the distance between the two marks on the ground, estimating the last revolution as closely as possible. The wheel slip can then be determined:

<table>
<thead>
<tr>
<th>Revolutions</th>
<th>Slip Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>No slip</td>
</tr>
<tr>
<td>19</td>
<td>5% slip</td>
</tr>
<tr>
<td>18</td>
<td>10% slip</td>
</tr>
<tr>
<td>17</td>
<td>15% slip</td>
</tr>
<tr>
<td>16</td>
<td>20% slip</td>
</tr>
<tr>
<td>15</td>
<td>25% slip</td>
</tr>
</tbody>
</table>

It is important to do the measurements under the actual working conditions with representative depth, speed, soil type and soil condition.

Figure 5 can be used to establish the changes in operation necessary to arrive at the best possible matching of tractor and implement. The chart shows the possible operating combinations and gives the steps necessary to achieve correct matching.
In practice several adjustments may be needed to match implements, and slip measurements are required after each change. Unfortunately at present there are no short cuts to this fairly laborious routine. In the future instruments will be available to make this job much easier. Some means of rapidly making small changes to the width of an implement could also help in fine tuning the system.
Changing the width of the implement is often not easy, but in many instances it can be done by adding or removing tines. Most tractors have fixed gear ratios and as a consequence there are only a small number of travel speeds available at correct engine speed.
In hilly country, engine power and traction are required to propel the tractor and implement uphill. This extra load must be accounted for when matching the tractor and implement. This means that matching should be made on the gradient upon which the tractor is operating. This is clearly not feasible on country with a variety of grades and a compromise will have to be reached. You should however, at all times, aim to keep slip within 2 or 3 per cent of the optimum.
In light working such as sowing, it may not be feasible to achieve correct matching using maximum governor setting. In these situations a reduced governor (throttle) setting can be used. If wheel slip is also low then the removal of ballast will bring it up to the correct level, saving fuel and reducing compaction.

Reliability of seeding machines

Because of a lack of information on reliability of farm machinery, the Kondinin and Districts Farm Improvement Group organised a survey of seeding machines. The report of this survey is essential reading for farmers buying seeding machinery, and it offers valuable suggestions for existing machinery. For example, the results could help a farmer avoid a costly breakdown at a critical time by alerting him to common weaknesses in a combine. The full report of this survey is available for $17 posted from the Kondinin and Districts Farm Improvement Group, c/o Post Office, Kondinin, Western Australia, 6367.
The survey was based on a wide range of farming conditions, covering farms from Geraldton to Lake Grace. The first part was a mail questionnaire and replies were received from 70 farms with a total of 83 machines.
The second part of the survey involved visits to farms selected at random. Mr Vern Anderson of Jennacubbine was employed assisted by funds from the Commonwealth Extension Services Grant, and 187 farms with 250 machines were covered.

Farmers surveyed had the opportunity to comment on aspects of their machinery not covered in the interview questions, and modifications made have been listed in the report. These modifications could not be properly evaluated, but are likely to be useful suggestions for other farmers.
As well as being of immediate use to farmers, in the long term the report should help manufacturers improve their machinery. Copies have been circulated to manufacturers in the hope of improving communication in the industry.