QUESTION: Can the performance of a tractor be improved?

ANSWER: Yes, a tractor’s performance can be improved by means of the choice of the correct gear and implement size, double tyres, ballasting and four-wheel drive. To understand this, let’s first look at the factors that play a role in the performance of a tractor.

QUESTION: What is the rolling resistance and how can it be explained?

ANSWER: Rolling resistance is the tractive effort or power necessary to roll a wheel over a surface. Therefore, the rolling resistance of a tractor is the sum of the rolling resistance of all the wheels. Before a tractor can pull anything, it first has to overcome its own rolling resistance. A part of the tractor’s drive is lost merely to overcome this rolling resistance.

As a result of the weight resting on the wheel, pressure is applied on the soil. If the pressure on the soil becomes too great, the soil gives way. If draft power is now applied on the wheel to let the wheel roll over the soil, the wheel has to be pulled uphill. See Figure 1.

![Fig. 1: Rolling resistance](image1)

The wheel therefor runs uphill all the time but never gets out on top, because the soil sinks in under the wheel each time. The deeper the soil sinks in, the deeper the wheel treads. The uphill then becomes steeper and the rolling resistance becomes greater.

QUESTION: What are the factors that influence rolling resistance?

ANSWER: Soil hardness, soil pressure and weight. The measure to which the tractor wheel treads into and compacts the soil depends on the firmness of the soil, and the pressure applied on the soil. A great mass on a wheel will therefor cause the wheel to tread in deep into soft soil, which causes a great rolling resistance. See Figure 2. Hard soil can withstand high soil pressure without the soil sinking in deep and the rolling resistance remains low.

![Fig. 2: Wheel weight, soil pressure and depression](image2)

The more the weight, the greater the rolling resistance. If the soil is so hard that it does not sink in even with heavy ballasting, the rolling resistance will remain low, e.g. on concrete. See Figure 3.

![Fig. 3: Rolling resistance and soil density](image3)
QUESTION: What is the influence of tyre pressure?

ANSWER: By reducing the tyre pressure, the tyre contact surface on the soil is increased because the tyre then yields more. If the tyre contact surface increases, the soil pressure reduces and it leads to a slighter measure of tread and less resistance. See Figure 4.

![Figure 4: Rolling resistance and tyre pressure](image)

In hard soils, which are not treaded in by highly inflated tyres, no reduction in rolling resistance will be experienced with a lower tyre pressure but rather an increase, resulting from tyre distortion.

The lifespan of a tyre depends largely on tyre pressure. With a too-low tyre pressure, tyres will fold and form cracks. The recommended tyre pressure must be maintained as far as possible. Also guard against the tyres distorting or folding too much with high wheel ballasting and traction.

On the other hand, the tyres must not be inflated too high because the soil pressure is thereby unnecessarily increased and the rolling resistance increases, specifically in soft soil.

QUESTION: What is the influence of tyre width and double tyres?

ANSWER: With the same diameter, a broader tyre has a larger contact surface, which leads to lower soil pressure and therefore lower rolling resistance.

With the use of double tyres, the contact surface is doubled and the soil pressure reduced by half. See Figure 5.

Since the weight that each tyre carries is halved, the tyre pressure can even be reduced by 40% without the tyres distorting and folding too much, which damages the tyres. If only the inner wheels are filled with water, the weight increase as a result of the double wheels will be slight.

![Figure 5: Rolling resistance, tyre width and double tyres](image)

In hard soils, which are not treaded in by highly inflated tyres, no reduction in rolling resistance will be experienced with a lower tyre pressure but rather an increase, resulting from tyre distortion.

The lifespan of a tyre depends largely on tyre pressure. With a too-low tyre pressure, tyres will fold and form cracks. The recommended tyre pressure must be maintained as far as possible. Also guard against the tyres distorting or folding too much with high wheel ballasting and traction.

![Figure 6: Wheel diameter and rolling resistance](image)

QUESTION: What is the influence of tyre diameter?

ANSWER: Firstly, the tyre with a larger diameter has a larger contact surface than a smaller tyre with the same width. With the same ballast on both tyres, the soil pressure and the treading into the soil by the larger tyre will be less. This will therefore lead to less rolling resistance.

A second factor in favour of a tyre with a larger diameter is that the “uphill” it has to climb is less steep with the same tread-in depth of the soil. See Figure 6.
The less-steep uphill against which the tyre has to climb leads to a further reduction in rolling resistance.

It is clear therefore that a greater wheel diameter contributes more to a reduced rolling resistance than a wider tyre. There is however a practical limit in the rear wheel diameter of tractors, as the torque on the rear axle and drive system becomes greater as the wheel diameter increases, which leads to higher design costs.

**QUESTION:** What is the influence of four-wheel drive?

**ANSWER:** The soil pressure caused by the wheels may become too high, especially with very large tractors, so that preference is given to 4 WD with larger wheels (sometimes double wheels) on both axles. A large tractor with eight tyres will result in a lighter soil pressure than a tractor with 1/3 of its total weight, fitted with single tyres of the same size.

In loose soil, a further factor in favour of the 4WD is that the front wheels compact the soil ahead of the rear wheels, so that the rolling resistance of the rear wheels are reduced.

**QUESTION:** How is traction developed on a soil surface?

**ANSWER:** Because the treads of the tyre “clutches” the soil, the grip capacity of a tyre depends on the friction power that the soil can resist. The friction power of the soil depends on:

1. The ability of the soil particles to adhere to each other
2. The weight of the wheel that compresses the soil particles together. See Figure 7.

![Fig. 7: Traction and weight](image)

**QUESTION:** What happens when a wheel slips

**ANSWER:** When the traction which a wheel applies becomes greater than the grip that the soil particles have on each other, they begin to slip over each other. The wheel therefore covers a smaller distance per revolution than in the case where the soil particles did not begin to slip over each other. We then say the soil has begun to tear.

**QUESTION:** Why does slip increase with an increase in traction?

**ANSWER:** When the soil particles slip over each other, they are rearranged and hook onto each other to give maximum resistance against slip. With low traction, a slight increase of rearranging is sufficient and the slip is therefore low. The higher the traction becomes, the greater is the rearranging and therefore slip that has to take place to overcome the traction. We see that slip must occur before sufficient adherence can be obtained in order to give traction.

An example is a person pushing a vehicle over loose sand. In order to push, his feet must first slip slightly to get his heels dug into the sand. See Figure 8.

![“Foot grip”](image)

**Fig. 8: Slip and grip**

**QUESTION:** What is the influence of weight on wheel slip?

**ANSWER:** With additional ballasting on a wheel, the soil particles are pressed tighter together, which prevents them from slipping over each other easily. The result is that an increase in weight will reduce the wheel slip. This does, however, result in a deeper tread which increases rolling resistance, as with a tyre of smaller diameter. In soft soils, these effects can in fact cancel each other (Also see Fig. 10).

**QUESTION:** Does it matter if a tyre slips even 50%?

**ANSWER:** If 50% wheel slip occurs it means that 50% of the forward speed is lost. It also means that 50% of the tractor’s productivity is lost.

**QUESTION:** How is wheel slip measured?

**ANSWER:** A simple method of measuring wheel slip, is as follows: See Figure 9.

Make a clear mark on the rear tyre of the tractor. Measure the distance that the wheel will cover with about five revolutions on hard soil without the implement in the soil. Then do the normal tilling on the field and measure the distance covered again with the same wheel revolutions. The wheel slip is calculated by dividing the difference in these distances by the distance covered on hard soil. It is usually shown as a percentage. If the distance covered on hard soil is 25 metres and in the field 20 metres, then the calculated wheel slip is $\frac{25}{25} \times 100 = 20\%$. 

QUESTION: What are the practical implications of rolling resistance and wheel slip?

ANSWER:

1. **Traction:**
   The greater the traction, the greater the wheel slip becomes. With nil traction no slip will take place theoretically.

   Maximum traction does occur at high slip, i.e. from 50 to 60% (see Table 1) but the power loss is then very great.

   ![Diagram of wheel slip](image)

   Wheel slip = \(\frac{25 - 20}{25} \times 100\% = 20\%\)

   **Fig. 9: Measuring wheel slip**

   **Table 1: Traction and wheel slip**

<table>
<thead>
<tr>
<th>Traction (kN)</th>
<th>Wheel slip (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>6,5</td>
<td>50</td>
</tr>
</tbody>
</table>
2. **Soil type/soil hardness**

The “grip” ability of a wheel is reduced in soft soil, firstly because the soil particles slip over each other more easily and secondly because the rolling resistance in soft soil is greater than on hard soil, which causes a further reduction in nett traction. The following table shows “grip” ability and rolling resistance in various soil types. See Table 2.

**Table 2: Traction and soil type**

<table>
<thead>
<tr>
<th>Soil type</th>
<th>“Grip” power (kN)</th>
<th>Rolling resistance (kN)</th>
<th>Drawbar pull (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loam</td>
<td>5,5</td>
<td>0,6</td>
<td>4,9</td>
</tr>
<tr>
<td>Sandy loam (wet)</td>
<td>4,0</td>
<td>1,0</td>
<td>3,0</td>
</tr>
<tr>
<td>Clay loam (wet)</td>
<td>3,0</td>
<td>1,5</td>
<td>1,5</td>
</tr>
<tr>
<td>Silt (wet)</td>
<td>1,0</td>
<td>1,0</td>
<td>-</td>
</tr>
</tbody>
</table>

3. **Weight:**

For a tyre to provide traction, there must be sufficient weight on the wheel to press the soil particles together tightly enough against each other. As previously explained, an increase in weight on the wheel will increase its rolling resistance, especially in soft soil where the wheel treads in deeper. Whatever is gained by reduced wheel slip, is lost as a result of additional rolling resistance. The following graphs show the influence of weight on wheel slip and rolling resistance. See Figure 10.

---

*Fig. 10: Weight and power losses*
Wheel slip can be reduced on hard and soft soil, by additional ballasting, but in soft soil the rolling resistance becomes so great as a result of the high ballasting that the wheel slip can begin to increase again with increase in weight.

4. Tyre width, double tyres

As explained before, broader and larger tyres can reduce the rolling resistance in soft soils, but it has little effect on hard soil. Table 3 shows the influence of weight on single and double tyres (13x38) on hard soil at a tractor traction of 6.5 kN.

Table 3: Slip versus axle weight, hard soil

<table>
<thead>
<tr>
<th>Total weight (kN) On the rear axle</th>
<th>Slip % Single tyre</th>
<th>Slip % Double tyre</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>40%</td>
<td>35%</td>
</tr>
<tr>
<td>10</td>
<td>15%</td>
<td>13%</td>
</tr>
<tr>
<td>13</td>
<td>10%</td>
<td>8%</td>
</tr>
<tr>
<td>20</td>
<td>8%</td>
<td>6%</td>
</tr>
</tbody>
</table>

The reduction in slip with the aid of double wheels on hard soil is slight. It is clear that a slight increase in weight has a greater influence on reduction of slip than double wheels.

Table 4 shows the influence of weight on single and double tyres in soft ploughed sandy soil at a traction of 4.5 kN.

Table 4: Slip versus axle weight, soft soil

<table>
<thead>
<tr>
<th>Total weight (kN) On the rear axle</th>
<th>Slip % Single tyre</th>
<th>Slip % Double tyre</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7</td>
<td>50%</td>
<td>25%</td>
</tr>
<tr>
<td>8</td>
<td>27%</td>
<td>12%</td>
</tr>
<tr>
<td>10</td>
<td>22%</td>
<td>11%</td>
</tr>
<tr>
<td>13</td>
<td>23%</td>
<td>10%</td>
</tr>
<tr>
<td>20</td>
<td>24%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Since the rolling resistance is reduced with double wheels, double wheels are more effective to reduce wheel slip in soft soil than single wheels with additional weight.

5. Four wheel drive:

When a tractor applies traction on the implement, weight transfer occurs from the implement and from the front of the tractor to the rear axle, as seen in Fig. 11.
It is however not possible in practice to work with a tractor with its front wheels aloft. In this case, additional weight must be placed on the 2WD tractor’s nose for steering control and safety.

If traction conditions are poor, e.g. in mud or soft soil, the 2WD tractor begins to slip and entrench before sufficient traction is developed to obtain adequate weight transfer. The result is that the only about 2/3 of the total tractor weight rests on the drive wheels.

The other 1/3 of the weight on the front wheels causes high rolling resistance as a result of the small narrow front wheels. In the first place, the traction provided by the rear wheels is low as a result of the poor weight displacement and secondly, the front wheels consume some of the developed traction to overcome rolling resistance. (See Figure 14).

In the case of a 4WD tractor all the weight of the tractor is always on drive wheels. There is also not a non-driven wheel that consumes some of the traction just to overcome rolling resistance. (See Fig.15).

In normal hard soil conditions it is doubtful whether the high cost of a 4WD is justifiable, except in the case of very large tractors more powerful than 150 kW where the traction becomes too much for only double rear tyres. More drive wheels are therefor necessary to handle the high weight and traction.

**QUESTION: What is the effect of double wheels on tyre lifespan?**

**ANSWER:** Double wheels are even used on hard soil, especially with large tractors, with the purpose of increasing the tyre lifespan.

The weight and traction is then spread over more tyres and ensure that the tyres are not over-loaded.

**QUESTION: What is the effect of additional weight and double wheels on a tractor’s gearbox and final drive?**

**ANSWER:**

1. **Influence of weight on gear lifespan**

   Wheel slip is an important safety factor for a tractor’s gearbox and final drive.

   A tractor’s gearbox and final drive is designed to handle stresses in normal agricultural and weight conditions, caused by high traction powers. If wheel slip is limited by additional ballasting, especially on hard soil, the design specifications of the gear components can be exceeded. This shortens the lifespan of the drive train considerably.

2. **Gear lifespan as a result of double wheels**

   Double wheels without additional ballasting holds less risk for a tractor’s gearbox and final drive than single wheels with additional ballasting.

   On soils with a medium firmness, 30% additional ballasting on single tyres will provide the same slip reduction as double tyres. On hard soils, the single tyres with a 30% ballasting can provide 30% more traction than double tyres without ballasting. This can possibly damage the drive system. On firm soil, double wheels will not provide much higher traction than additionally ballasted single wheels.

**QUESTION: Why does a tractor slip less with a mounted plough than with a semi-mounted plough?**

**ANSWER:** Because of the larger weight transfer by a mounted plough, considerably more weight is transferred to the rear wheels of a tractor than with a semi-mounted or drawn plough. It then appears as if a mounted plough pulls lighter.
To adapt a tractor for a drawn or semi-mounted plough, some of the nose-weights can be removed and additional weights can be placed on the rear wheels.

**Question:** How efficient is it to plough with a single wheel in the furrow and double wheels outside the furrow?

**Answer:** In soft soil conditions, the double wheel outside the furrow can help to reduce the rolling resistance and wheel slip. The soil in the furrow is usually firm, so that the soil is able to withstand high soil pressure without sinking. The rolling resistance and slip of the single wheel in the furrow therefore remains low.

**Question:** When must a farmer ballast his tractor, use double wheels or obtain 4 WD tractors?

**ANSWER:**

**Ballasting:**
Greater traction can be obtained on hard and soft soil by placing additional ballast on the tractor’s drive wheels. However, when a tractor’s wheels already tread in 100 to 150mm or deep in soft soil, extra ballasting will be of little benefit, since the wheels will then tread in even deeper and the rolling resistance will be increased.

As previously explained, too high ballasting can be detrimental to the tractor’s gear components. It is much better to rather select a smaller implement than additional ballasting on the tractor’s drive wheels.

Additional ballasting on the front of the tractor must be just sufficient to prevent the tractor’s front wheels from lifting. Too much ballasting on the front of a 2 WD tractor is of no benefit, but rather a disadvantage, since it increases the rolling resistance of the front wheels.

**Double wheels:**
Double wheels are of little benefit on hard soil, compared to single wheels with the same weight, except that the lifespan of the tyre can be increased. In soft soil, and when a single wheel treads in deeper than 100 to 150mm, double wheels will increase the traction ability of a tractor a great deal.

Double wheels without additional ballasting has fewer disadvantages for a tractor’s gear components than single wheels with additional ballasting.

**Four-wheel drive:**
On hard soil, 4 WD will have slight benefits compared to 2WD. In poor traction conditions such as loose sand and mud, a 4WD will succeed significantly better than a 2WD tractor. In hilly terrain, steering a 4WD will be much steadier against slopes than a 2WD tractor, since the front wheels of a 4WD tractor are able to “pull” the tractor around a corner.

Because of the high purchase price of a 4WD tractor, a farmer must ensure that the tractor will be able to compensate against a larger 2WD tractor at the same purchase price.

Some farmers maintain that it is beneficial for them to purchase a 4WD tractor to perform critical operations during very wet years.

**Question:** What must the farmer do to obtain maximum performance from his tractor?

**ANSWER:**

1. **Correct gear selection**
Because of modern design tendencies in tractor manufacturing, the weight/power ratio is getting smaller, with the result that a tractor is no longer able to utilize its engine power to the full at a low speed of 5 km/h with a large plough, since the wheel slip loss becomes too great. If the tractor is ballasted additionally, gearbox and final drive problems will be experienced.

A high gear must therefore be selected, so that the engine power becomes the limiting factor. See Figure 16. If a tractor has the ability to achieve high wheel slip in a specific gear without the engine speed decreasing, a higher gear must be selected. Wheel slip must therefore never be a limiting factor, since the wheel slip means direct loss.

![Wheel slip](image)

**Too low gear and a too large implement**

![Engine power](image)

**High gear**

**Fig. 16: Limiting factors**

2. **Selection of the correct implement**
The size of the implement determines the traction requirement and the wheel slip. A too large implement will cause a high wheel slip loss, while a smaller implement is cheaper and handles easier.
The correct implement size will result in a wheel slip of approximately 10 to 15% on hard soil and approximately 15 to 20% in soft soil and will load the engine to its full in one of the tractor’s available gears.

QUESTION: What is the influence of high speed?

ANSWER: Not all implements can be used beneficially at high speed. An example is that not all planters can plant effectively at high speed. The traction requirement of a low-speed plough can even double if the speed is increased. What the tractor gains in reduced wheel slip with a smaller plough at a higher speed, the plough can waste as a result of greater draft requirement. The curves of figure 17 show typical traction requirements of different plough bottoms. Note that the increase in traction with increase in speed depends on the horizontal angle $\theta$ that the share and the mouldboard form with the direction of movement.

QUESTION: How do I know whether my gear / implement combination is correct?

ANSWER: The following simple test can give an indication whether the tractor is maintaining an optimum work rate:

While the tractor is in motion, the implement may be set slightly deeper than usual. Take note how the tractor reacts to this:

1. If the wheel slip does not increase noticeably and the engine speed remains constant, change to a higher gear and/or select a larger implement.

2. If the wheel slip increases noticeably, but the engine speed remains constant, change to a higher gear and select a smaller implement and if necessary ballast the tractor’s rear wheels to limit wheel slip.*

3. If the wheel slip does not increase noticeably, but the engine speed reduces, the combination is correct for maximum performance.

After each change, following results 1 and 2, the test must be repeated until result 3 is obtained.

*Where a lower gear and additional ballasting is used, the farmer must realize that the gearbox and final drive might be overloaded.

\[\text{A – Low-speed plough} \quad \theta = 48^\circ\]

\[\text{B – High-speed plough} \quad \theta = 25^\circ\]

![Fig. 17: Speed and plough resistance](image)

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