The Mechanics of

Tractor - Implement Performance

Theory and Worked Examples

R.H. Macmillan

CHAPTER 7 and 8

TRACTOR - IMPLEMENT MATCHING AND OPERATION

GENERAL PROBLEMS

CONTENTS

Note: The Title Page, Preface, Table of Contents, Index, Appendices and details of the Farmland tractor can be found with Chapter 1.

CHAPTER 7

TRACTOR - IMPLEMENT MATCHING AND OPERATION

7.1 INTRODUCTION

Having considered the performance of the tractor on a firm surface (Chapter 3), on soft soil (Chapters 4 and 5) and the effect of the implement on the weight carried by the tractor wheels (Chapter 6), we finally need to consider the steps involved in matching, in performance terms, an implement and tractor. Here matching means choosing the size and / or setting up the tractor and implement so that they may perform their functions in the most efficient way. We will do this by considering what measures would be most appropriate to represent their performance efficiency and how these might be maximised.

Many other factors of an agronomic, economic and organisational nature may also need to be considered, particularly when choosing a type of implement; these are beyond the scope of this book. Readers are referred to existing text books for consideration of the functional performance of the various types of implement.

There may also be many gaps in the information required for matching an implement and tractor. Notwithstanding this lack, setting out the steps in a formal way may help to clarify the logic of making the choices and to determine what further data are required in any particular circumstances.

7.2 IMPLEMENT PERFORMANCE

7.2.1 Implement Draught

The study of the in-field performance of a tractor is related to the performance of the implement to which it is attached; the latter, which is a complex subject in its own right, is also beyond the scope of this book. However we can consider the input to implements in a general way (in terms of force, speed, power etc) and so consider the matching problem, at least in principle.

For the purposes of matching an implement that is being pulled, the important parameter to consider is the horizontal force to move the implement commonly known as the 'draught' force (from the word to 'draw' or to 'pull'). This force is equal and opposite to the forces that arise from the process that the implement is performing and will of course vary with the nature of that process (represented broadly by the implement type), the size of the implement and the travel speed.

If the total force of the implement on the tractor is not horizontal, the vertical component will alter the weight on the wheels, as discussed in Chapter 6, and so affect the traction process. However it will not significantly alter the draught and will only have a second order effect on the matching process.

The draught of an implement is expressed as a force, usually in kN. However draught may also be expressed in terms of parameters that take into account the size of the implement or the magnitude or intensity of the process or of the work that is being done.

These parameters, which are usually termed 'unit draught' or 'specific draught', include:
(i) draught per unit effective width of machine, kN/m
(ii) draught per unit of effective cross-sectional area disturbed (usually for tillage implements), kN/sq m (kPa)
(iii) draught per unit tool (usually for tillage implements), kN/ tool.

These measures are used as a basis for comparing implements of different size and type (ASAE 1998).

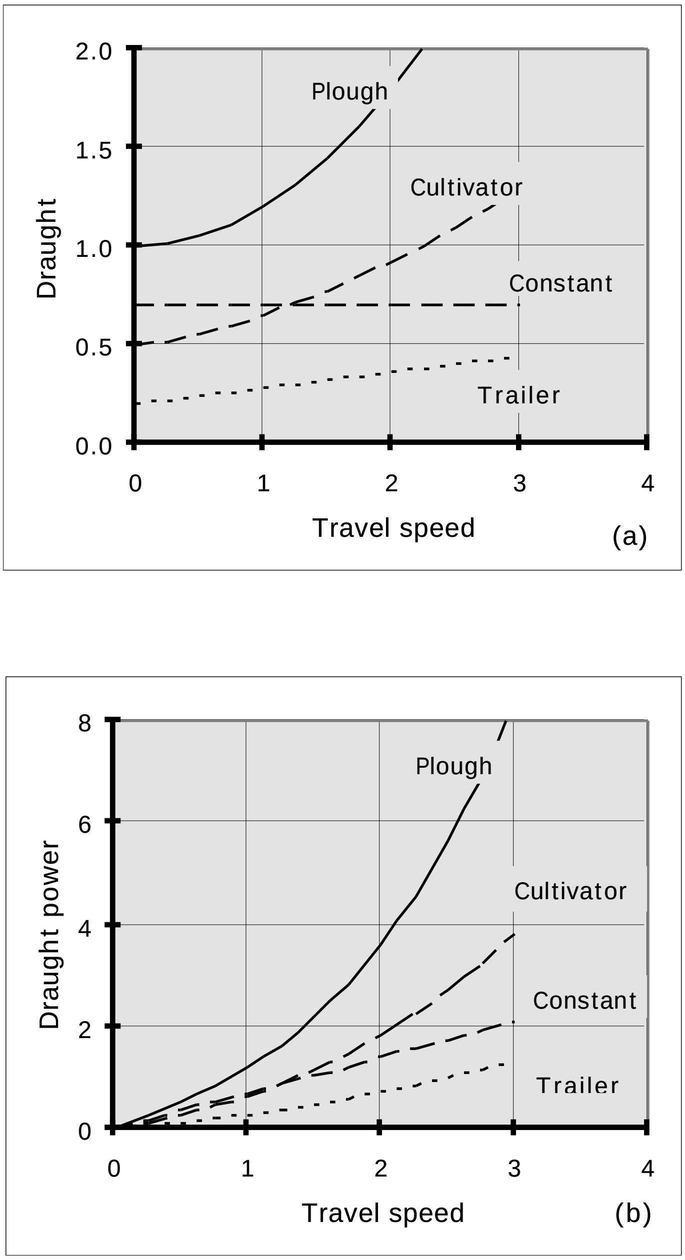

Figure 7.1: (a) Hypothetical draught - speed characteristics for implements, also constant draught
(b) Corresponding power - speed characteristics

7.2.2 Implement draught - speed characteristic

Because the tractor is a variable speed machine, the fundamental and important characteristic of any implement that will be attached to it, (working in given conditions (eg, crop / soil) and with a given adjustment (eg, depth)), is the relationship between its draught force and travel speed.

Some implements, such as those used for tillage, have a significant draught component at 'zero' speed; this represents the force to rupture the soil under 'quasi-static' (ie, effectively zero speed) conditions. At higher speeds the force will generally increase due to the fact that higher speeds involve greater acceleration of the soil and that soils are slightly stronger under dynamic conditions. Hence implements such as mouldboard ploughs that lift and move soil a greater distance and have large draught due to friction and adhesion show a greater increase in draught with speed than do implements, such as tined cultivators, which just lift or move the soil a short distance.

Heavy load carrying implements such as trailers will, due to their rolling resistance, also have a large drawbar pull at zero speed; this may increase slightly as speed increases to moderate levels. For other relatively light implements involved in some form of crop processing (mowing, harvesting, spreading) with power transmitted through the PTO, the draught will be small at zero speed and substantially constant. However the PTO power may increase significantly with speed.

These characteristics of agricultural implements contrast with those of barges being pulled through water where, ideally at least, the draught will be zero at zero speed and vary as the square of the speed (for low speeds).

Figure 7.1(a) shows the hypothetical draught - speed characteristics for various implements also for an implement with a constant draught.

7.2.3 Implement power

While draught is the <u>fundamental</u> measure of input to the implement (as drawbar pull is for the output of the tractor), so draught power is a <u>useful</u> measure of input to the implement (as drawbar power is for the output of the tractor).

Since drawbar power is the product of draught force and travel speed, any increase in speed of an implement will cause an increase in the drawbar power due to:

(i) the direct effect of the travel speed increase
(ii) the indirect effect due to the associated increase in draught (if any) with increase in travel speed

Thus if an implement has a draught - speed characteristic of the form,

$$D = D_o + d' \cdot V^{1.2} \qquad (7.1)$$

Draught power

$$Q = D \cdot V$$

$$= D_o \cdot V + d' \cdot V^{2.2} \qquad (7.2)$$

The corresponding power - speed characteristics for the implements are shown in Figure 7.1(b). The power - speed characteristic for an implement with a constant draught (for d' = 0 in Equation 7.1) is also shown.

7.2.4 PTO driven and towed implements

Many agricultural machines used for 'processing' crop or soil are driven through the PTO as well as being pulled by the drawbar. The effect on the tractor engine will be the sum of the two separate effects.

The increase in engine power required from the tractor with an increase in travel speed (for a constant PTO speed which is typical for a processing type operation) will be the sum of the:

(i) direct effect on drawbar power of the travel speed increase (as in (i) above) - (first term in Equation 7.2)
(ii) indirect effect of drawbar power due to the associated increase in draught with travel speed as in (ii) above - (second term in Equation 7.2); this is likely to be small for processing type implements
(iii) increase in the PTO power due to the increase in rate of crop / soil processing that arises from the increased travel speed.

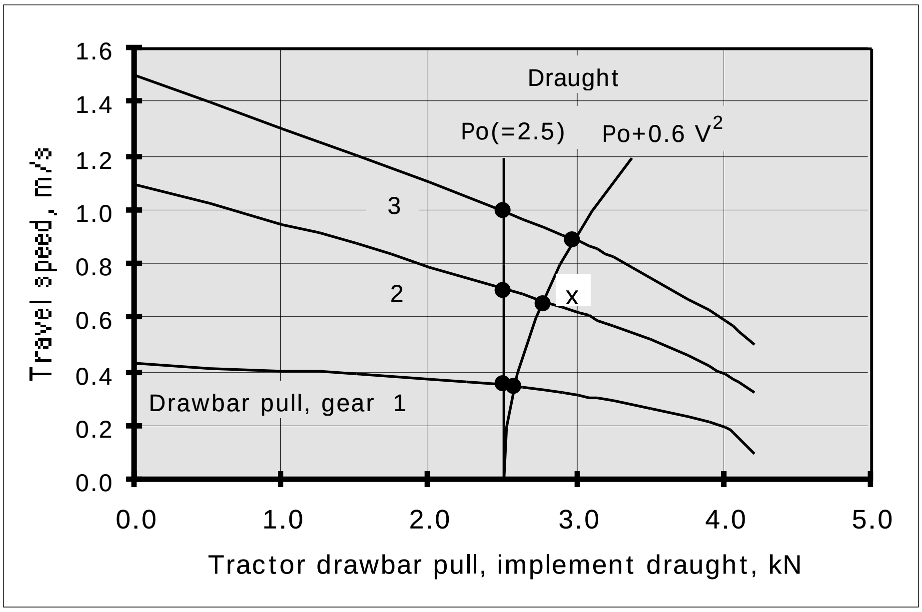

Figure 7.2 Operating points for a tractor in three gears with two implement characteristics

7.3 TRACTOR - IMPLEMENT PERFORMANCE

7.3.1 Operating conditions

When an implement is hitched to a tractor:

(i) the draught of the implement determines the drawbar pull required to be developed by the tractor and is equal but opposite to it
(ii) the travel speed of the tractor determines the travel speed of the implement and is equal to it

Consider a tractor with a travel speed - drawbar pull characteristic (in a particular gear) attached to and pulling an implement with a particular draught - travel speed characteristic.

Because (i) and (ii) above are true, the operating point of the combination will be where these two curves intersect.

Similarly consider a small tractor with three gears as shown in Figure 7.2 to which we can attach two alternative implements (with a particular width), one with a constant draught - speed characteristic and one where the draught is a function of travel speed, V. These may be expressed either on an absolute (kN) or on a unit basis (kN / m width).

Draught, $D = 2.5$

Draught, $D = 2.5 + 0.6\ V^2$

We can identify the operating conditions for the tractor in the various gears as the points where the draught - travel speed graph for the implement and travel speed - drawbar pull graphs for the tractor intersect as shown in Figure 7.2 at points similar to X. The graph shows the performance for maximum governor setting but it should be remembered that for each gear there is a range of engine governor settings giving a range of lower travel speeds.

We can also imagine the operating points for an implement of different widths having a proportional increase or decrease in draught.

Hence in matching an implement and tractor, there are a large number of possible operating conditions as represented by all the possible intersection points within the overall performance envelope. The question therefore arises as to which point or group of points would represent suitable operating conditions. As an example we might consider a wide implement with the tractor travelling slowly or a narrow implement with the tractor travelling quickly. Within reasonable limits either of these possibilities, or any others between them, would be suitable. However if we wish to consider the efficiency or other aspects of the processes we need to consider the criteria by which we might make a choice between these various alternatives.

7.3.2 Optimum performance criteria

At its simplest the matching process involves deciding what draught to apply on the tractor, ie, what drawbar pull it will be required to develop.

We could consider choosing an implement with a draught that would cause the tractor to reach:

(a) Maximum drawbar pull

This (or near it) may be an appropriate condition if we were, for example, attempting to pull a tree over where we could accept a very low travel speed and a very large wheel slip for a few seconds. It would not however be suitable for the long-term continuous operation of a tractor / implement system.

(b) Minimum drawbar specific fuel consumption

This would give the best fuel economy. It could be a suitable basis for selection because (at least on firm surfaces) it corresponds to a drawbar power slightly less than the maximum.

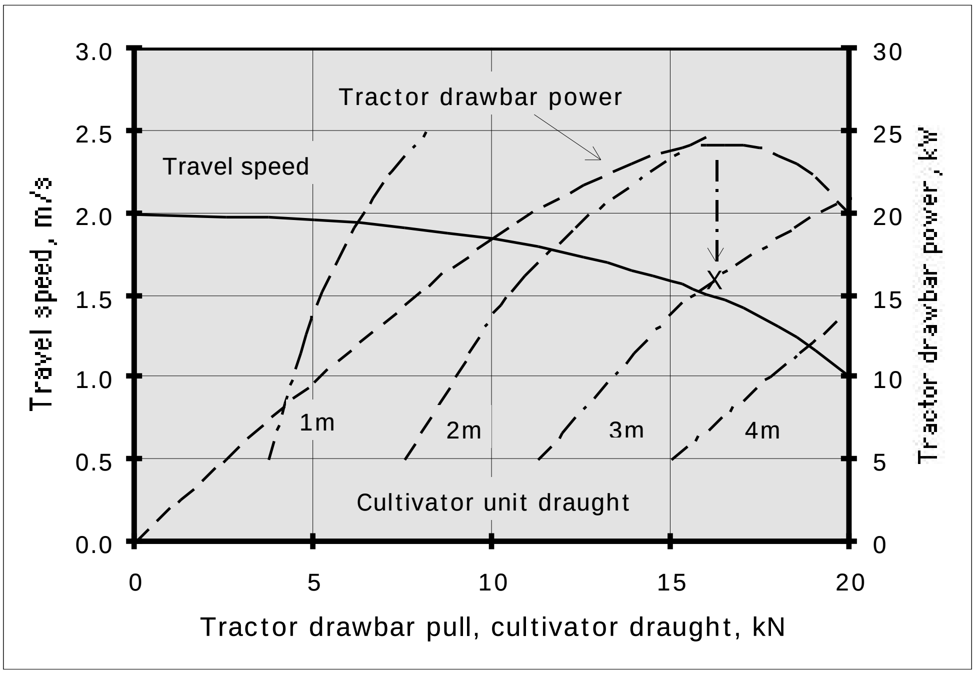

Figure 7.3: Tractor and implement performance for Problem 7.1

(c) Maximum drawbar power

This would also be a suitable basis for selection because maximum power (or a slightly lower value that would allow for natural variation in the draught) would correspond to operation with good fuel economy.

(d) Maximum tractive efficiency

This would also be a suitable basis but with this criteria, drawbar power may be somewhat less than the maximum in (c) above; see for example Figure 5.7 and 5.8.

The most common criterion for optimum matching is that of maximum drawbar power which gives a good fuel economy (criterion (c)) and also a good tractive efficiency (criterion (d)).

Problem 7.1

Figure 7.3 shows:

(i) the travel speed - drawbar pull graph tractor operating in a certain gear on a soil surface.
(ii) the unit draught (per metre of width) - travel speed graph for a plough cultivating the same soil.

Determine a suitable width for the implement, 1, 2 or 3 m, etc.

Answer:

(a) Tractor

A suitable width implement will be such that the tractor is working at maximum drawbar power. For points on the travel speed - drawbar pull graph, calculate the drawbar power and plot the resulting points against drawbar pull.

For example, with drawbar pull P = 5kN, travel speed V = 1.95 m/s

$$Q = P \cdot V = 5 \times 1.95 = 9.75 \text{ kW}$$

From this graph it is seen that the maximum drawbar power of 24.3 kW will be generated when the drawbar pull is 16.5 kN.

(b) Implement

The draught for the implement will be the width times the draught per metre of width; use this to plot the draught for various widths of implements (2, 3 and 4 m) as shown.

(c) Implement - tractor combination

The operating point for the implement - tractor combination, for maximum drawbar power will be the intersection point of the draught - speed graph (for the particular width of implement) and the drawbar pull graph for the tractor. The point on the graph for the width that intersects at or below 16.5 kN is 3 metres. The implement width is 3m, the drawbar pull is 15.7 kN and the drawbar power is 24 kW.

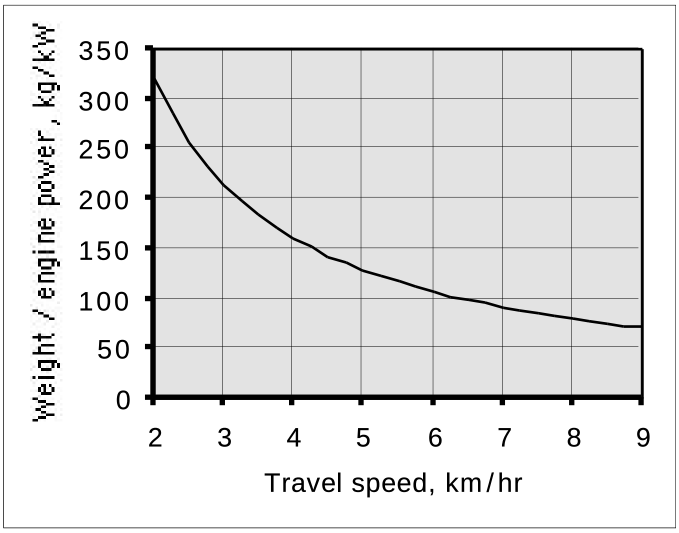

Figure 7.4: Weight - speed relationship for maximum drawbar power; plotted from Dwyer (1984)

7.3.3 Matching wheels and engine

Before considering the overall problem of matching implement and tractor it is helpful to consider the more limited design problem of choosing the maximum weight on the driving wheels to suit a given travel speed and engine power.

Neglecting the rolling resistance and the transmission efficiency, the drawbar power for a tractor (Equations 4.22) may be written:

$$Q_e \ \eta_t = Q_d$$

$$= V \ (Ac + W \tan\varphi) \ X$$

$$= V \ W \left(\frac{c}{\sigma} + \tan\varphi \right) \ X$$

$$= V \ W \ \psi \qquad (7.3)$$

This suggests that there should be an inverse relationship between the weight on the driving wheels and travel speed if the maximum tractive power is to be maintained.

Dwyer (1984) gives typical values for maximum tractive efficiency, η_t = 0.7 and corresponding tractive coefficient, $\psi = 0.4$ for a range of tyres and soil conditions.

Hence

$$Q_e \ 0.7 = V \ W \ 0.4$$

$$\frac{W}{Q_e} \ V = 1.75$$

For W in kg, V in km/hr and Q_e in kW we have

$$\frac{W}{Q_e} \ V = \frac{1.75 \quad 3.6 \quad 1000}{9.8} = 643 \qquad (7.4)$$

As plotted in Figure 7.4, this shows the inverse relationship between the weight on the driving wheels per kW of engine power and travel speed for maximum performance. This is an important conceptual relationship that illustrates the alternatives of light, 'high' speed tractor / implement systems compared to heavy, slow ones.

For a multi-purpose tractor (with a given engine power) one would choose the lowest (or highest) sensible working speed and calculate the appropriate weight. At higher (lower) speeds the tractor would be heavier (lighter) than required; some weight could be removed (added) if desired.

7.4 MATCHING TRACTOR AND IMPLEMENT

7.4.1 Variables available

The selection of a tractor / implement system involves a series of choices about the relevant factors. These may be listed as follows:

Purchase	Indirect	Combined	Operation
Maximum engine power	Implement type Implement depth Soil condition	Implement width Weight on wheels	Engine speed Gear ratio

Table 7.1 Parameters in selection, matching and operation of a tractor - implement system

(a) '<u>Purchase</u>'

This implies the factor is chosen at purchase. Maximum engine power is an upper bound value, the choice of which is a very important one since it determines the maximum capacity of all the equipment that will be used with the tractor. However the issues involved in the choice of an optimum value for it, such as the relative costs of capital and labour and the timeliness penalties or costs of the various operations for which it will be used, are beyond the scope of this book. The following discussion has therefore been limited to the matching of an implement to a tractor that has already been chosen.

(b) <u>Indirect</u>

This implies that these parameters are chosen, not in terms of performance but in consideration of other factors such as the functional objective (implement type), agronomic significance (tillage depth) and weather (soil or crop condition). Again these are also beyond the scope of this book and will not be considered further.

(c) <u>Combined</u>

This implies that these parameters are chosen both at purchase and before operation, ie, they may be altered, in principle at least, but in practice may not be.

(d) <u>Operation</u>

This implies that they are primarily chosen during operation, ie, they can be varied by the operator to suit the conditions that partly arise as a result of earlier choices and partly due to particular local physical circumstances such as land form, soil type, crop condition, etc.

7.4..2 Optimising performance

On the basis of the above decisions we are left with four factors that will determine the operating point on the drawbar pull - travel speed and travel speed - draught characteristics;

(i) engine speed, gear ratio and weight on wheels related to the tractor.
(ii) implement width related to the implement.

Following the discussion in Section 7.3.2 above, let us assume that the desirable matching criteria is to achieve maximum drawbar power. A somewhat lesser value may be chosen as discussed below; the logic of the argument would be the same.

Equation 2.14 gives

$$\text{Maximum drawbar power} = \text{Maximum engine power} \times \text{Maximum transmission efficiency} \times \text{Maximum tractive efficiency} \qquad (7.5)$$

From this it will be clear that maximum drawbar power will be achieved if the engine can be made to work at its maximum power and the transmission and the tractor wheels can both be made to work at their maximum efficiencies.

Considering each of these terms in turn:

(a) Maximum engine power

As discussed in Section 3.2.2, maximum engine power will be achieved at the maximum governor setting and with a load (torque) that brings the engine to the condition where the fuel pump is just delivering maximum fuel per stroke. As the load on the engine is increased from zero, the engine speed decreases slightly and the governor increases the fuel flow rate to the maximum; this is the condition of maximum engine power. Any further increase in torque will (because of the constant fuel flow) cause a significant decrease in engine speed and a corresponding reduction in engine power.

The condition of maximum engine power will not be directly evident to the operator. The only evidence will be the single speed value corresponding to maximum engine power.

(i) A higher speed than this will indicate that the engine, while running in the governed range is not delivering maximum power and is not fully loaded.
(ii) A lower speed will indicate that the engine is running in the full fuel range, is again not delivering maximum power and is therefore ‘over’ loaded.

If, for some reason, it is thought to be undesirable to run the engine at full power (eg, to ensure greater engine life), a lesser value of say 90% of maximum power and / or a governor setting less than the maximum setting may be chosen. Such a value would coincide with a general area of good fuel economy and would allow a margin for the load to increase temporarily without the engine running into the full-fuel range.

Strategies to increase (or decrease) the torque on the engine and so bring it to maximum power involves:
(i) using a higher (lower) gear, ie, decreasing (increasing) q in Equation 2.2
(ii) using a wider (narrower) implement, ie, increasing (decreasing) P in Equation 2.2

(b) Transmission efficiency

As noted in Section 2.4.1(b) above, the transmission efficiency is high and sensibly constant; the operator cannot increase it, so it does not enter into the matching process.

(c) Maximum tractive efficiency

Maximum tractive efficiency will be achieved, by the appropriate choice of implement width (in effect, drawbar pull or strictly draught) and the size and weight on the wheels. However again the condition of maximum tractive efficiency will not be directly evident to the operator, hence it is necessary to use a surrogate variable, ie, one, the value of which, at maximum tractive efficiency, is known; wheel-slip is the variable that may be used.

(i) too high a slip indicates that the tractor has too large a draught load or has insufficient weight on the driving wheels
(ii) too low a slip indicates that the tractor has too small a draught load or has excess weight on the driving wheels.

Thus the evidence of the wheels achieving maximum tractive efficiency will be optimum slip. However this varies with the soil condition. Typical values are shown in Table 7.3, adapted from Dwyer et al (1976).

Thus achieving maximum tractive efficiency is based on strategies to decrease (increase) the slip which involves:

(i) increasing (decreasing) the weight on the wheels
(ii) using a narrower (wider) implement.

Description of surface	Cone index kPa	Percentage of maximum weight on wheel			
		60 - 70	70 - 80	80 - 90	90 - 100
Dry grass	1500	10	10	10	10
Dry stubble	1000	10	10	11	11
Wet stubble	500	11	12	12	12
Dry loose soil	400	12	13	13	13
Wet loose soil	200	15	16	17	18

Table 7.2 Slip at maximum traction efficiency (Adapted from Dwyer et al, 1976; reproduced with permission of Silsoe Research Institute)

7.4.3 Setting up implement and tractor

It is clear from the above that the optimisation of the performance of a tractor - implement system involves a complex set of choices related to both the engine / transmission and the wheels.

Grevis-James (1978) has developed a grid shown in Table 7.3 that summarizes the changes that may be made to match the tractor and implement and set them up to achieve maximum drawbar power (or some proportion of it).

In this table two alternative strategies are offered.

(i) maintain the output work rate shown in normal font in the upper part of each cell

(ii) increase the output work rate shown in italic font in the lower part of each cell.

MAINTAIN OUTPUT ***INCREASE OUTPUT***	**WHEEL SLIP ->**	**LOWER THAN OPTIMUM**	**OPTIMUM**	**HIGHER THAN OPTIMUM**
ENGINE SPEED | V		**WHEELS PART LOADED**	**WHEELS FULLY LOADED**	**WHEELS 'OVER' LOADED**
HIGHER THAN RATED	**ENGINE PART LOADED**	Reduce weight, use higher gear & lower governor setting *Use higher gear & increase width*	Use higher gear & lower governor setting *Use higher gear*	Reduce width & use higher gear *Add weight & use higher gear*
RATED	**ENGINE FULLY LOADED**	Reduce weight *Increase width & use lower gear*	**OPTIMUM MATCHING**	Reduce width & use higher gear *Add weight*
LOWER THAN RATED	**ENGINE 'OVER' LOADED**	Use lower gear & increase width *Use lower gear & increase width*	Use lower gear *Use lower gear*	Reduce width *Add weight & use lower gear*

Notes:
1. Use of a weight transfer hitch or mounted implement has the same effect as adding weight.
2. “Wheels 'over' loaded" refers to the drawbar load not the weight being carried.
3. "Engine ‘over’ loaded" refers to engine running in full - fuel range (Section 3.2.2, (a) & (b)).
4.. 'Engine speed' refers to rated speed at maximum power, not governor setting.

Table 7.3: Tractor - implement matching chart (Modified from Grevis-James, 1978; reproduced with permission of Institution of Engineers, Australia)

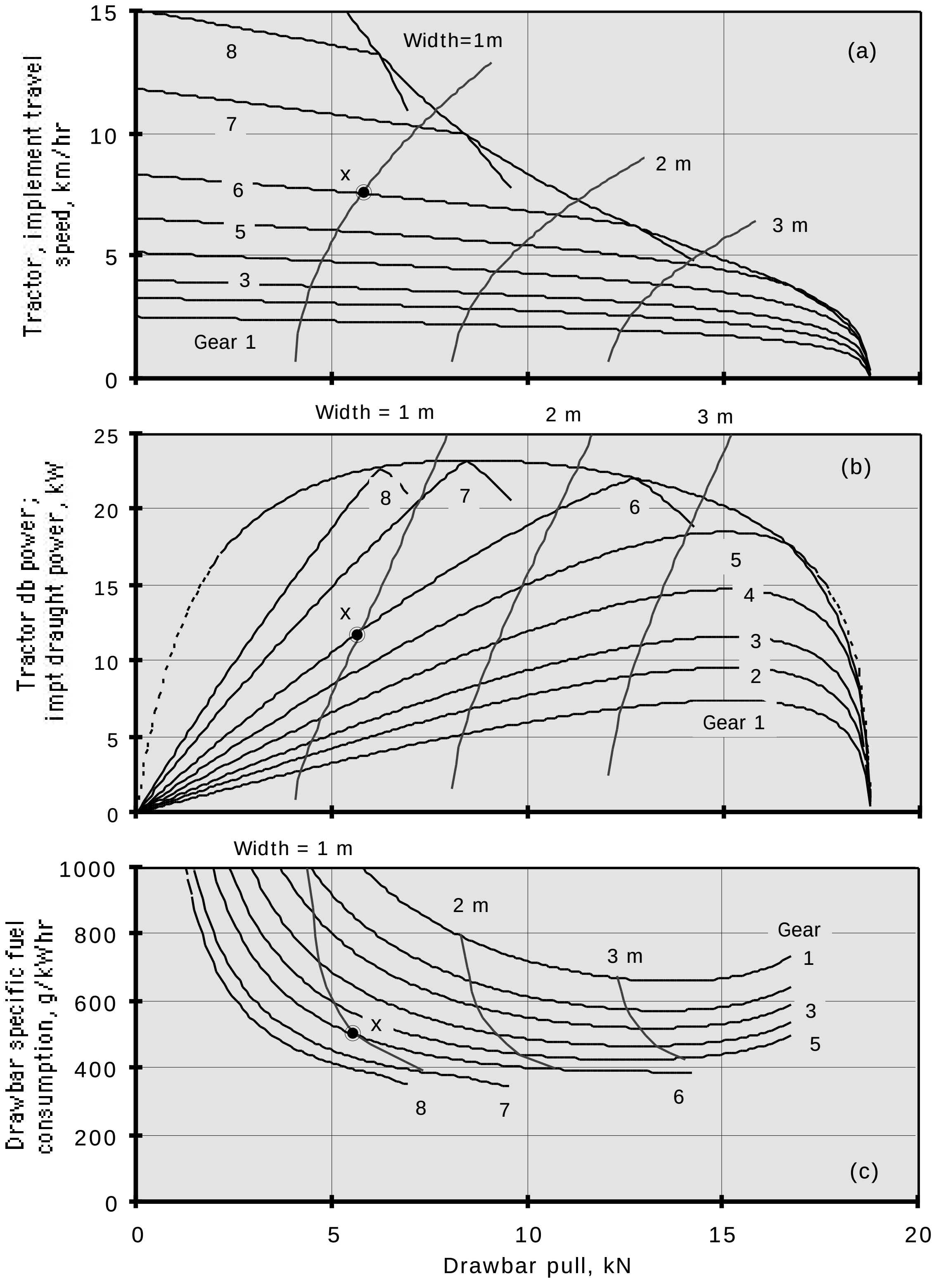

Figure 7.5: (a) Travel speed - drawbar pull and draught characteristic for tractor and implement
(b) Drawbar and draught power - drawbar pull and draught characteristic for tractor and implement
(c) Specific fuel consumption - drawbar pull and draught characteristic for tractor and implement

7.5 OPERATING THE TRACTOR

The above sets out the principles involved in achieving optimum matching of an implement and tractor. In practice the tractor may be used for many different types of work under differing draught and soil conditions. Hence it is unlikely that the tractor / implement will be set up in a way that is optimum for all the types of work for which it may be used.

Notwithstanding this compromise, we need to consider how to adjust the tractor during operation to achieve optimum fuel economy. In doing this the only factors that are available for choice by the operator are the gear ratio and engine speed, as determined by governor setting.

Consider the Farmland tractor and an associated one way plough. The model described in Chapter 5 was used to plot the tractor performance for maximum governor setting for the 6 working gears as shown in Figure 7.5(a).

Figure 7.5 (a) also shows the travel speed versus draught characteristics for three implement widths of 1, 2 and 3 metres (Palmer and Kruger (1982)). This is given by:

$$D = w \cdot d\,(20 + 0.15\,V^2) \qquad (7.6)$$

Figure 7.5 (b) shows the drawbar power versus drawbar pull for the 6 gears and draught power versus draught (force) also for same three implement widths; depth = 0.2 m.

The latter is given by:

$$Q = D \cdot V = w \cdot d\,(20 + 0.15\,V^2)\,V \qquad (7.7)$$

Figure 7.5 (c) shows the drawbar specific fuel consumption versus drawbar pull for the 6 gears. The specific fuel consumption graphs for the three implement widths were plotted by projecting down from the appropriate intersection points on the travel speed (or power curves) marked 'x'.

This set of graphs illustrates various aspects of the matching / operation.

(i) For a given tractor, various implement widths can be used. For heavy work such as ploughing it would be usual to operate in a low gear with an implement that would bring the tractor to near maximum power. This is illustrated by the 3m implement operated by the tractor in 5th gear as shown in Figure 7.5(b).

(ii) A narrower implement can be operated but, in order to get good fuel economy, it must be worked in the higher gears. This is illustrated by the 2m implement operating in 6th gear as shown in Figure 7.5 (a) and (b).

(iii) Changing up to a higher gear increases the drawbar power and reduces the drawbar specific fuel consumption along the lines shown in Figure 7.5 (c). Such a change increases the (torque) load on and power from the engine and allows the engine to run in more economical conditions as discussed in Sections 3.2.3, 7.4.2 and 7.4.3.

Changing to a lower gear always makes the fuel economy worse. Clearly the more gears there are available, the smaller will be that change.

(iv) Changing up a gear increases the speed which may cause control or vibration problems. It may therefore be necessary to reduce the speed by reducing the governor setting; this will mean that the implement characteristic will intersect the characteristic for the chosen gear somewhat below the lines shown at the maximum governor setting in Figure 7.5 (a) and (b).

(v) If a tractor could be made to work along the maximum power envelope it is clear that the tractor will work in a region of excellent fuel economy. This of course corresponds to the region of high tractive efficiency as shown in Figure 5.9 (c). The limits to this procedure occur:
- * at high speeds where rolling resistance power loss is high and ride comfort may be unacceptable
- * at high pulls where wheelslip is high.

> In summary, when using the tractor for drawbar work, the fuel economy can be improved by changing up a gear and reducing the governor setting, hence the engine speed, to avoid excessive travel speed. If it is necessary to change down a gear, the fuel economy will be worse; increasing the engine speed by increasing the governor setting will improve it to some extent.

If the PTO is being used and a fixed speed for it is required, it would only be possible to change gears; the fuel economy will change as above.

Notwithstanding all of these choices and adjustments, it is important to operate the tractor under safe conditions where control can be maintained and at speeds with which the work being done is satisfactory.

7.6 References

American Society of Agricultural Engineers (1998) *ASAE Standards* Agricultural Machinery Management Data; ASAE Data: D230.4.

Dwyer, M.J., Evernden, D.W. and McAllister, M.(1976), *Handbook of Agricultural Tyre Performance*; National Institute of Agricultural Engineering, Report No 18.

Dwyer, M.J. (1984) The tractive performance of wheeled vehicles *Journal of Terramechanics*, 21 (1), 19 - 34.

Grevis-James, I.R. (1978) Matching tractors and implements; *Conference on Agricultural Engineering,* Toowoomba, Institution of Engineers, Australia, Conference Publication No. 78/8, 142 - 145.

Palmer, A.L. and Kruger, I.R. (1982) Comparative drafts of six tillage implements; *Conference on Agricultural Engineering,* Adelaide, Institution of Engineers, Australia; Conference Publication No. 82/2, 163 - 167.

Parkhill, G.J., (1986) A computer simulation of tractor drawbar performance; *Conference on Agricultural Engineering* , Adelaide, Institution of Engineers, Australia, Conference Publication No. 86/9, 258-263.

CHAPTER 8

GENERAL PROBLEMS

Problem 8.1

A tractor has an engine having a maximum power of 62kW at 1950 rpm at maximum governor setting.

When tested in the field, the following data were obtained:

Drawbar pull	= 26.2 kN		
Distance traveled for 10 revolutions of driving wheels		- with no drawbar pull	= 55.8 m
		- with drawbar pull	= 46.2 m
Engine speed	= 1950 rpm		
Fuel consumed	= 126 g		
Time taken	= 25.8 s		
Transmission efficiency	= 92%		

Determine: Drawbar power, wheel slip, traction efficiency, fuel consumption and specific fuel consumption.

Answers: 46.9 kW;17.2%; 82%; 21L/hr; 374 g/kWhr

Problem 8.2

The following data applies to a tractor operating on a level frictional soil:

Diameter of driving wheels	= D
Overall gear ratio	= q
Maximum engine torque	= T
Angle of internal friction	= φ

Show that the minimum weight on the wheels to bring the engine to maximum torque is given by:

$$W = \frac{2qT}{D\tan\varphi}$$

Problem 8.3

Consider a rear wheel drive tractor operating on a level surface. If the coefficient of traction based on the weight on the rear wheels is ψ and the coefficient of rolling resistance for the front wheels in ρ show the drawbar pull that can be achieved is:

$$P = \frac{\psi W_r - \rho W_f}{1 - \frac{y'}{x}(y + r)}$$

Problem 8.4

Consider a tractor with rear wheel braking for which the maximum braking coefficient, λ is

$$\lambda = \frac{\text{maximum horizontal braking force}}{\text{vertical rear wheel reaction}}$$

By assuming that the dynamic inertia force ‘ma’ in braking is a static force acting through the centre of gravity of the tractor, show that the maximum retardation, a is given by:

$$a = g\,\frac{\lambda\, x_f}{x + \lambda(r + y)}$$

Problem 8.5

A small, rear wheel drive tractor was tested in three gears with normal weight on a bitumen road and on a firm soil surface also with extra weight also the road. The results are shown in Table 8.1.

Drawbar pull, kN	Soil, standard weight				Road, standard weight			
	Travel speed, m/s			Slip %	Travel speed, m/s			Slip %
Gear ->	3	2	1	%	3	2	1	%
0.0	1.51	1.05	0.42	0.0	1.63	1.07	0.45	0.0
1.0	1.32	0.95	0.40	3.5	1.54	1.03	0.42	1.7
2.0	1.13	0.83	0.36	9.9	1.44	0.99	0.40	3.6
3.0	0.90	0.68	0.29	18.4	1.35	0.95	0.38	5.9
4.0	0.57	0.44	0.12	-	1.26	0.90	0.35	9.0
5.0	-	-	-	-	1.09	0.83	0.29	14.1
6.0	-	-	-	-	0.60	0.48	-	25.0

Drawbar pull, kN	Road, extra weight				Fuel cons, L/hr: gear 3		
	Travel speed, m/s			Slip	Soil	Road	Road
Gear ->	3	2	1	%	Std wt.	Std. wt	Extra wt.
0.0	1.64	1.08	-	0.0	1.80	1.66	1.50
1.0	1.56	1.04	-	1.6	2.20	2.10	1.95
2.0	1.49	0.99	-	3.0	2.50	2.50	2.35
3.0	1.42	0.96	-	4.6	2.65	2.87	2.74
4.0	1.35	0.92	-	6.6	-	3.10	3.10
5.0	1.28	0.88	-	9.1	-	-	3.35
6.0	1.19	0.82	-	12.8			
7.0	0.95	0.70	-	19.8			

Table 8.1

(i) Plot:

(a) Travel speed and wheelslip versus drawbar pull
(b) Drawbar power versus drawbar pull
(c) Fuel consumption and specific fuel consumption versus drawbar power for gear 3
(d) Drawbar power versus wheelslip

(ii) Discuss the effect of gear, weight and surface on the performance of the tractor.

Problem 8.6

Some tractors are available with a three-point linkage on the front of the tractor. Compare such an arrangement with a rear-mounted linkage with respect to weight transfer and implement control.

Problem 8.7

Imagine that you have been requested to advise on the preliminary design of a harvesting machine to be powered by the Farmland tractor. The machine will be towed over very firm soil by the drawbar and the harvesting mechanism will be driven by the PTO.

The machine has the following performance characteristics:

Specific draught	= 8 kN/m of width
Specific PTO power	= 3.2 kW/m of width
Operating speed not more than	= 3 km/hr (approx.)

Assume the following for the tractor:

Traction efficiency	= 70 %
Transmission efficiency to wheels	= 90 %
Transmission efficiency to PTO	= 90 %
Wheel slip not more than	= 15 %

Using the graphs given in Chapter 3 and considering both power and draught requirements, estimate the maximum width of harvester that can be operated and the fuel consumption.

Answers: 2.25 m, 8 kg/hr

Problem 8.8

(a) Show that the slope, θ on which the Farmland tractor will just roll forwards is given by:

$$\tan\theta = \frac{x_r\,\rho_r + x_f\rho_f}{x + (r + y_3)(\rho_r + \rho_f)}$$

Hence determine the slope for the tractor on:

(a) concrete
(b) loose sand

(b) Repeat for the tractor rolling rearwards

Problem 8.9

By taking appropriate measurements of a small motor bike investigate its capacity to operate a small trailer. Give careful consideration to instability and safety issues.

Problem 8.10

Apply the principles developed for the two-wheeled tractor in Section 6.4.4 to the design of a trailer of the type shown in Figure 6.1(b) for use with such a tractor.

- x – x – x -