The objective of practical machinery use is to match and schedule the machinery operations in such a way that the maximum amount of work can be achieved within the appropriate time frame so that the overall performance will return the biggest profit to the farm business.

PRACTICAL PLANNING

PART II

4. MATCHING TRACTORS AND IMPLEMENTS

CHAPTER OBJECTIVES:

- ***To introduce the reader to the process of matching an implement with a suitable tractor;***
- ***To describe the equation and formulas that is used to determine the size of the implement and the tractor;***
- ***To show by example the use of the formulas to match the tractor and implement;***
- ***To discuss the factors influencing the efficiency of a tractor and implement combination.***

Tractor and implement matching concerns the proper balancing of the load characteristics of an implement with the output characteristics of a tractor to achieve the most effective working and economical result. While this result is usually looked at in terms of achieving the fastest working rate, it should also be looked at in terms of economical usage per hectare worked. Proper tractor and implement matching therefore should result in the maximum amount of work achieved within a given time frame at the most economical rate.

Farmers should take more care when matching tractors and implements if they want to achieve the maximum rate of useful work from the tractor-implement combination for as many operating conditions as possible. Providing that there is no severe restriction on the travel speed of a working machine, a reasonable degree of matching is possible for a range of conditions. It is however necessary to understand the key factors influencing the best match. This includes factors like soil conditions, management practices, as well as tractor or implement types, makes, and models. These factors will play a major part in the final match of the tractor with an implement.

4.1. THE PROCESS

Matching tractors and implements is a practice used by farmers whenever they engage in applying equipment. It is an attempt to balance the characteristics of the load application unit (the implement) with the power unit (the tractor). It may also be used to determine machinery unit size in relation to property size, management practices, and other considerations. It is normally a process that involves three steps, as illustrated in Figure 4.1.

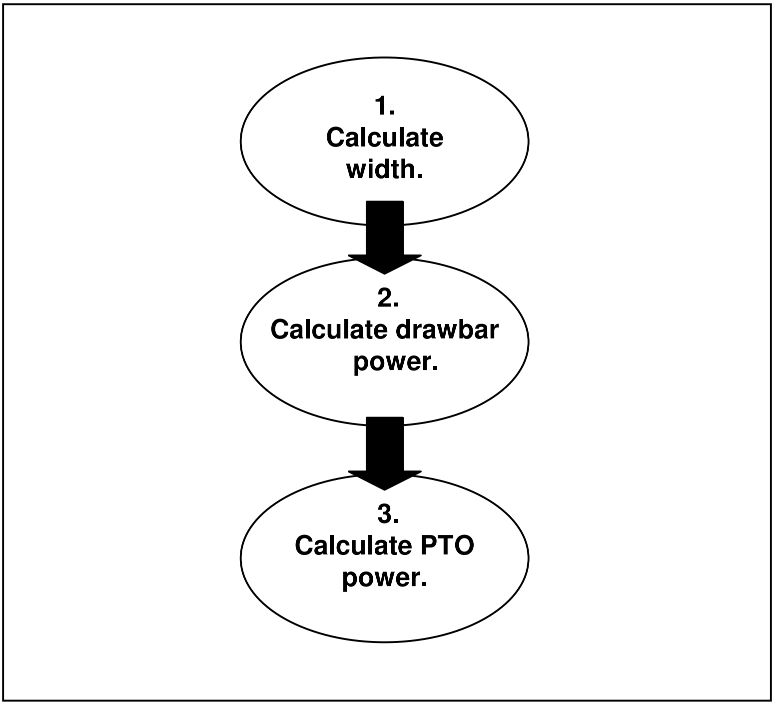

FIGURE 4.1: PROCESS OF MATCHING TRACTORS AND IMPLEMENTS

The matching process is something that farmers often do sub-consciously. Mostly this approach, whilst producing acceptable results in many circumstances, leaves room for improvement. Obtaining the best output is of paramount importance and any improvements that can be made will substantially influence the profit of the farm business as a whole.

The following points must be considered carefully during the decision making process:

- Future cropping areas;
- Comfortable, feasible and desirable speeds for the job;
- The time available to do the job;
- Crop losses that can occur if the ground isn't covered rapidly enough;
- The drying out or else the wetting of the field that can make traction difficult, resulting in time losses;
- The availability of labor;
- The shape and gradient of the field that can influence field efficiency.

Correct matching of machinery should then result in:

- Increased efficiency of operations;
- Less operating costs;
- Optimal use of capital.

The matching process normally begins by determining the most important operation in the context of farm operations. For many farmers, this operation will probably be sowing, for which absolute importance is put on the timeliness of the activity.

4.2. THE BALANCING EQUATION

When determining an appropriate match between tractor and implement, various factors must be considered so that values can be attached to four of the following five components:

- Area to be covered in acres or hectares (*ha*);
- Working speed in miles or kilometers per hour (*km/h*);
- Working hours (*hrs*);
- Estimated field efficiency (*%)*;
- Working width of the implement (*m*).

Area to be covered

The area covered must be considered together with the other farming operations. Different crops or even varieties within a crop may allow the farmer to spread his critical operations and reduce the area to be covered at a time.

Working speed

The implement must be pulled at the proper speed to get optimum performance. High-speed operations may cause poor seed placement or soil damage. Low speed operation may cause transmission damage or poor weed kill and soil disturbance.

Working hours

Available working hours depend on timeliness, labor, transportation, maintenance, and refueling. Time must also be allowed to fill seed and fertilizer and to re-fuel.

Field efficiency

The field efficiency allows for losses in both time and area covered due to overlapping, filling operations, turning and cutting out corners, making adjustments and changing operators.

Implement width

This is the actual *cutting* width of the machine. If a value for four of the above figures is available, the fifth one can be calculated. Adjusting one or more of the selected components may be necessary to find an acceptable implement size, bearing in mind the following points:

- Critical time available regarding;
  - crop yields,
  - available soil moisture,
  - available labor.
- The shape or terrain of fields;
- Future cropping areas;
- Desirable working speeds;
- Weed problems;
- Cropping practice (conventional, reduced or no-till).

4.3. THE FORMULAS

Any unknown component can be determined by using the following formulas:

$$\text{Area(ha)} \times 1000 = \text{Speed(km/h)} \times \text{Time(hrs)} \times \text{Width(m)} \times \text{Field Efficiency(\%)} \quad [4.1]$$

$$\text{Field Efficiency(\%)} = \frac{\text{Area(ha)} \times 1000}{\text{Speed(km/h)} \times \text{Time(hrs)} \times \text{Width(m)}} \quad [4.2]$$

$$\text{Width(m)} = \frac{\text{Area(ha)} \times 1000}{\text{Speed(km/h)} \times \text{Time(hrs)} \times \text{Field Efficiency(\%)}} \quad [4.3]$$

Note:

- After calculating the theoretical width, the closest available commercial implement needs to be selected;

- If the calculated field efficiency figures are abnormally high or low, recheck the figures.

Table 4.1 indicates the typical field efficiencies for a range of machines. A more comprehensive list is included as Appendix I.

TABLE 4.1: FIELD EFFICIENCIES FOR A RANGE OF IMPLEMENTS

Implement	Efficiency
Tillage Implements	75 - 80%
Seeders	70%
Boom sprayers	65%
Fertilizer applicators	65%
Grain harvesters	60 - 70%
Mowers	70%
Balers	75 - 80%

Implements not using a lot of reloading are more efficient than those requiring reloading. Balers and tillage implements are therefore more efficient than sprayers and fertilizer applicators.

4.4. TRACTOR DRAWBAR POWER

The power required to pull a tillage implement is a function of the travel speed and the pull or draft of the implement. This is the power the tractor must be able to provide at the drawbar. The engine power will be higher than this, as will be explained later.

The draft for a particular type of implement varies a lot depending on soil type, soil condition, depth, and speed. Tables 4.2 and 4.3 give an indication to the draft that could be expected for different implements on a range of soils or conditions. The draft is given in terms of kilograms force per meter width of implement (*kgf/m*). Strictly speaking, draft should be quoted in kilo-Newtons per meter (*kN/m*), using the standard metric unit of force, however it is easier to use kilograms or pounds force.

$$1\ kN = 102\ kgf = 225\ pounds\ force \qquad [4.4]$$

TABLE 4.2: APPROXIMATE DRAFT OF TILLAGE IMPLEMENTS

IMPLEMENTS	Primary or Secondary tillage	Depth	Speed	Draft per unit width (*kgf /m*)		
				Conditions		
		mm	*km/h*	Heavy	Medium	Light
One way disc plough	P	100	7	700	550	450
Offset disc	P	80	7	800	650	500
	S	80	8	500	400	300
Scarifier	P	80	8	550	450	350
	S	100	10	450	350	250
Cultivator	S	90	8	300	200	100
Chisel plough	P	100	7	700	550	400
	S	70	8	450	250	150
Combine seeder	S	40	8	300	250	150
No-till / direct drill seeding (narrow points)	n/a	75	8	*See Table 4.3 for effect of tine spacing.*		

** Smith and Palmer 1987*

TABLE 4.3: APPROXIMATE DRAFT OF NARROW POINT DIRECT DRILL TINES IN *KGF/TINE*

Light draft (stubble etc)	Heavy draft (pasture etc)
90	150
To calculate draft per meter width for a particular machine: $$Draft(kgf/m) = \frac{Draft\ per\ tine(kgf) \times 1000}{Row\ spacing(mm)}$$ **[4.5]**	

Once the draft and working speed are known, the required drawbar power can be calculated by using the following formula:

$$Drawbar\ Power(kW) = \frac{Draft(kgf/m) \times Implement\ width(m) \times Speed(km/h)}{367}$$

[4.6]

Notes:

- Draft is represented in Table 4.2.
- Factors for converting meters per second (m/s^{-1}), the standard unit of velocity, to kilometers per hour (*km/h*) and kilo-Newtons (*kN*) to kilograms force (*kgf*) are combined in the constant 367.

It can be derived that traveling faster means getting the job done quicker. What is actually true is that the drawbar power required, and therefore engine power, will go up very quickly as speed increases, especially since draft increases with speed.

4.5. SELECTING TRACTOR SIZE

When buying a tractor, the quoted PTO power is more important than the engine power. To calculate the required tractor PTO power from a known drawbar power, the power losses associated with wheel slip and rolling resistance must be taken into account. Additionally, for long term reliability the tractor should not be worked for long periods at maximum power. For this reason, divide the drawbar power required by a conversion factor from Table 4.4.

TABLE 4.4: POWER CONVERSION FACTORS: DRAWBAR TO PTO

SURFACE	Two wheel drive	Front wheel assist	Four wheel Drive
Firm surface	0.72	0.77	0.78
Tilled surface	0.67	0.73	0.75
Soft surface	0.55	0.65	0.70

Overloading can cause early failure of components so tractor loading must also be considered. The tractor should not continuously work at over 80% of maximum power. It is also wise to have some power in reserve to cope with additional demands like hard spots. Thus, matching the tractor with reserve power gives better reliability.

The following formula can be used to calculate PTO power requirements for only 80% of maximum engine power:

$$\text{PTO Power (kW)} = \frac{\text{Drawbar power(kW)}}{\text{Conversion factor} \times 0.8} \qquad [4.7]$$

Note:

- The selected tractor must be matched to the most critical time sensitive operation, requiring the highest power. The power selected will then suit all the planned operations.

- If the operation needing the highest power can be completed over a longer time using slightly smaller equipment, than a smaller tractor can be used. This will reduce the capital outlay.

Tractors must not be overloaded. It is recommended that they should be worked at about 80% of maximum power. More reserve power may also be needed for working on undulating country if the tractor is to maintain working speed when going uphill. In agriculture, conditions can vary widely, especially implement pull. Therefore, comparing the above calculations that was based on broad assumptions against practical experience is essential.

4.6. TRACTOR MATCHING

The formulas and principles discussed above can be demonstrated by an example. Select a two-wheel-drive tractor and combine seeder to conventionally sow a 120 ha crop of wheat into medium cultivated soil. Optimum moisture conditions will last only 5 days and the operator are being used for 10 hours per day.

- Area = 120 ha
- Speed of sowing = 8 km/h
- Time, 5 days x 10 hrs = 50 hrs
- Field efficiency = 70%

STEP I Calculate the width

Calculate the width of the implement to complete the activity within 5 days according to formula [4.3]:

$$\text{Width(m)} = \frac{\text{Area(ha)} \times 1000}{\text{Speed(km/h)} \times \text{Time(hrs)} \times \text{Field Efficiency(\%)}}$$

$$= \frac{120 \times 1000}{8 \times 50 \times 70}$$

$$= 4.3 \text{ m}$$

From a manufacturer's catalogue, select a 24 run 4.27 m sowing width combine seeder.

STEP II Calculate the drawbar power

From Table 4.2, the draft for a combine seeder is 250 *kgf/m* width in medium soil. The drawbar power requirement, according to formula [4.6] is:

$$\text{Drawbar Power(kW)} = \frac{\text{Draft(kgf/m)} \times \text{Implement width(m)} \times \text{Speed(km/h)}}{367}$$

$$= \frac{250 \times 4.27 \times 8}{367}$$

$$= 23.3 \text{ kW}$$

The drawbar power required is 23.3 kW.

STEP III Calculate the PTO power

For a two-wheel-drive tractor on tilled soil at 80% power, the PTO power can be calculated with formula [4.7] and by using the conversion factors in Table 4.4:

$$\textit{PTO Power (kW)} = \frac{\textit{Drawbar power(kW)}}{\textit{Conversion factor} \times 0.8}$$

$$= \frac{23.3}{0.67 \times 0.8}$$

$$= 43.5 \text{ kW}$$

From a manufacturer' s catalogue, the tractor that closely fits the required specification is:

- Maximum available PTO power, 45 kW
- Engine power, 57 kW

4.7. IMPLEMENT MATCHING

The matching can also be done the other way round, if the tractor power is known. Select a scarifier to suit the 45 kW PTO tractor for uses as a primary tillage implement.

STEP I Calculate the drawbar power

From Table 4.4, the power conversion factor is 0.72 for firm soil.

$$\textit{PTO Power (kW)} = \frac{\textit{Drawbar power(kW)}}{\textit{Conversion factor} \times 0.8}$$

Thus:

$$\textit{Drawbar Power(kW)} = \textit{PTO power(kW)} \times \textit{Conversion factor} \times 0.8$$

$$= 45 \times 0.72 \times .8$$

$$= 25.92 \text{ kW}$$

Therefore the tractor has 26 kW of power available to pull the scarifier.

STEP II Calculate the width

Use the following formula to calculate the scarifier width, using a draft of 450 kgf/m at 8 km/h from Table 4.2:

$$\textit{Drawbar Power(kW)} = \frac{\textit{Draft(kgf/m)} \times \textit{Implement width(m)} \times \textit{Speed(km/h)}}{367}$$

Thus:

$$\textit{Width(m)} = \frac{\textit{Drawbar power} \times 367}{\textit{Draft(kgf/m} \times \textit{Speed(km/h)}}$$

$$= \frac{26 \times 367}{450 \times 8}$$

$$= 2.65 \text{ m}$$

Therefore a 2.65 m wide scarifier can be pulled with 26 kW of drawbar power. From a manufacturer's guide, the best option is a 2.9 m 19 tine machine. To reduce the risk of overloading the tractor, removing two tines from the scarifier can be considered. If this means that the cultivation will take too long, the next size tractor may be needed, resulting in the size of combine seeder and scarifier being recalculated.

4.8. SELECTING A TRACTOR

It is not possible to match a tractor for every operation as described previously.

The tractor should be chosen to suit the job with the highest power consumption. It may be primary cultivation, or operating a forage harvester, or a similar task. The choice will vary depending on the needs of the individual farm. An undersized tractor will take too long on cultivation jobs and may not be capable of doing a particular job. An oversized tractor on the same job may not be used to its full capacity and will be more costly to operate. A bigger tractor does not improve output unless bigger implements can be used or the speed of operation is increased.

Small or big

If operators are available, the selection of tractor can be between two smaller ones that can do the job in the available time, instead of one bigger tractor. The normal experience is that two smaller tractors doing the same job will be more expensive than a bigger tractor. The two smaller ones will however give the farmer more options with other operations or in times of a breakdown. On pure cost calculations for a specific task, one big enough tractor will be more cost effective but within the total farm business, two smaller ones may be more practical and economical in the long run.

Power

Power is defined at the rate of doing work. Work is defined as completed when a force moves through a distance and is calculated by multiplying a force (drawbar pull) by a distance travelled.

When selecting a tractor, the farmer should know how to compare tractor power. Engine power mentioned in tractor brochures can be confusing. Engines tested in the factory, without ancillary items like an alternator, water pump, etc. connected to it will obviously produce more power as when the engine is used in a tractor. Therefore, losses between engine and PTO or drawbar vary with every tractor.

Incorrect ballasting will have a negative effect on drawbar power. The drawbar power of the same tractor being lightly, correctly and heavily ballasted will vary significantly. Furthermore, even drawbar power output of a correctly ballasted tractor that works in firm soil and then moves into soft soil, will also drop remarkably. Thus, the most important criteria for tractor selection should be the power available for pulling the implement.

4.9. FACTORS INFLUENCING EFFICIENCY

The main factors that influence the efficiency of the tractor and implement combination are increasing width, increasing depth and increasing speed:

- Pull will increase directly with width, so doubling the width of an implement will double the pull required from the tractor;

- Pull increases almost directly with depth of working, so doubling the depth will almost always double the pull required from the tractor. Working depth should therefore always be at the least necessary to do the job adequately; otherwise both time and fuel will be wasted.

- Pull increases with speed, in a way that differs for different types of implements. If speed is increased form 6 km/h to 12 km/h, pull will rise about 25 to 40% for tined implements, and about 120% for disc machines.

The choice can also be between a wide implement working slower and a narrow one working faster, bearing in mind:

- The wide implement traveling at a slower speed will have the advantage of a lower draft per meter of width, but will probably have a higher purchase cost, and may be less convenient to transport.

- Conversely, traveling at a higher speed with a narrow implement will increase the pull required per meter of width, using more fuel per hectare and needing more tractor power, but the purchase price will be lower. Difficult patches will be handled more easily and the loadings on tires, bearings, and gears will be lower.

- Some compromise between the two extremes is probably the way to go and by choosing a working speed somewhere in the middle of the range will provide the opportunity to work faster if conditions are better than expected, and slower if they are worse.

Efficiency is therefore a fine balance between width, depth, and speed of the tractor and implement combination.

4.10. CONCLUSION

The calculations and principles outlined in this chapter can be used to select and match tractors and tillage implements. In following these steps, the opportunities, limitations, and interaction between the machinery selected and the cropping program are made much clearer. It may mean that the above calculations have to be modified or the proposed cropping program adjusted to find a satisfactory solution that will fit the particular time and financial constraints of the individual farmer. Bear in mind that the figures quoted in the tables are general, representing a range of numbers, and that they may need to be modified to suit an individual situation.

The tractor must be adequate for the operation with the highest power requirement. It is therefore important to carefully reconsider the operations as significant savings in tractor power may be available by allowing more time for some operations or using a contractor in some cases.

When selecting implement and tractor size, the most important decision to be made is the minimum working rate needed to do the most urgent power requiring job in the available time. On most farms this will probably be the planting operation, providing the different weather patterns that can occur every season.

4.11. REFERENCES

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